A Software Roadmap for the Fab Lab Network

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Abstract

For continuous effective collaboration, information exchange and daily operation within a multinational, distributed organization, both internal and external processes require efficient hard- and software support systems. The findings of this report are based on interviews and observations during a fab lab network workshop, aimed to determine the requirements for the software capabilities. The analysis of requirements gave an overview of what kind of software is feasible to use; i.e. where custom software can be used and the requirements which can be covered using already existing software, or off-the-shelf products.

One of the main findings addresses the need for developing a common platform for knowledge exchange in the fab lab network in order to take advantage of all the contributors’ competence. Other findings include a recommendation for a plan for how to implement a feasible roadmap for software usage throughout the fab lab network.

Vägkarta för mjukvara i fab lab-nettverket

Sammendrag

Løpende effektivt samarbeid, utveksling av informasjon og daglig drift i en multinasjonal distribuert organisasjon krever velfungerende løsninger for så vel programvare som maskinvare. Dette gjelder både for interne prosesser i organisasjonen og eksterne prosesser mot andre aktører. Funnene i denne rapporten er basert på intervjuer og observasjoner under en workshop i nettverket av distribuerte fab labs. Målet med undersøkelsen var å finne krav til programvaresystemer for organisasjonen. Analysen av kravene har gitt en oversikt over hvilke typer programvare det er formålstjenelig å benytte, det vil si på hvilke områder skreddersydd programvare bør utvikles og for hvilke krav allerede eksisterende programvare kan benyttes.

Et av hovedfunnene er at det er behov for å utvikle en felles plattform for kunnskapsutveksling mellom de ulike fab labs for å kutte utnytte kompetanse fra alle bidragsyterne i nettverket. Andre funn inkluderer et forslag til en plan for et veikart for programvare og hvordan dette kan implementeres i hele nettverket av fab labs.

(Front-page illustration: From da Vinci to modern CAD tools)
This is a report conducted at the Royal Institute of Technology in Stockholm (KTH). The basis of the interest for writing this report is to understand how a distributed international organization shares knowledge and information independent of cultural and geographical borders. The fab lab initiative is a suitable organization to study because it is an expanding network based on sharing technological knowledge. From existing as ideas at MIT the concept has spread around the globe and allows people from different background to share knowledge and interconnect.

I would like to extend my sincerest thanks to my supervisor Dr Alex Jonsson at KTH and people in the fab lab network who have given me access to valuable knowledge for this report. My wish is that this work can contribute to further collaboration in the network.

Hans Erik Grøthaug

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1 Introduction

This chapter describes the incentive, the problem to be solved, the method and usefulness of performing this work.

1.1 Incentive

“The ability for the organization to sustain itself depends on how information, the lifeblood of the organizational system, is managed” (Hensgen, 2005, p.128).

Aggregation and distribution of knowledge is one of the challenges every organization will experience, especially organizations with the key activity of sharing information and knowledge (Alavi & Leidner, 1999 Volume 1). The spread of information is technically easier than ever, and information technology and the internet have a significant impact in the nature of the information flows. Global, distributed organizations will deal with subdivisions of the organization in different parts of the world, from big cities to rural, less populated areas as well as areas totally without, or with very limited means of technical infrastructure. The cost of software and technology itself could well be a limiting factor in the spread of technology. Many times the cost of managing and supporting software exceeds the purchase cost many times around. The return of investment (ROI) could be used as a cost metric for choosing between alternative solutions in the life cycle of the software (Rico, 2004).

One of the trade-offs that has to be done is using open-source, bespoke or commercial available software. Even if cost is an issue for every organization, non-commercial organizations have challenges with the cost of technology as there are no underlying earnings in order to cover these expenses.

One organization that faces these problems is the fab lab network. Fab labs are a global network of local labs, enabling inventions by providing access for individuals to tools for digital fabrication [Figure 6 The Fab Charter]. This network is an example of a multinational non-profit organization based on a concept much like an open-source community. The fab labs intent is to share information and make knowledge and education available for all the people that want to take part in the development of the community, regardless of social background or geography. A study of the fab lab network is a unique way to see how information is managed in such an organization. The roadmap describing which software tools should be available to support the spread of knowledge, information and education in this organization will be useful for other organizations with similar needs.
1.2 Objective and aim

The purpose of this work is to develop suggestions for a roadmap to meet the future software needs in the fab labs:

1. How could the software support the work processes internally, between the fab labs and to the outside world?
2. In which areas is it feasibly to develop custom made software instead of using existing open source or free available solutions?

The methods for conducting this work are described in Chapter 3, Method.

1.3 The fab lab concept

“The importance of a community is not in the crusade, but in how you unify people to march forward together, side by side” (Bacon, 2009, p.3).

Professor Neil Gershenfeld is the director of the Center of Bits and Atoms (CBA) at Massachusetts Institute of Technology (MIT) and the founder of the fab lab idea. The initiative to start fab labs was a result of a co-operation between MIT Media Lab and CBA in 2002 (Gershenfeld, 2005). A fab lab as such is a small, physical workshop equipped with machines to perform rapid prototyping and personal production, also known as personal fabrication. The Fab Charter [Figure 6 The Fab Charter] gives an overview of the idea behind a fab lab: “You can use the fab lab to make almost anything (that doesn’t hurt anyone).”

Gershenfeld has spread the idea worldwide but wants an organization to support the idea outside the CBA boundary. Fab Foundation is an umbrella organization for between thirty and forty fab labs all over the world. Lateral alignment has been introduced to describe the collaboration between fab labs: “The extent to which interdependent stakeholders orient and connect with one another to advance their separate and shared interests” (Cutcher-Gershenfeld, 2007, p.5). The role for the Fab Foundation in the network is not clear. Some principles for the fab lab network have been discussed:

- It shall be no single, overarching hierarchical organization
- Multiple stakeholders with common and competing interests
- Accelerating rates of technological change

The Fab Foundation and the fab labs need software to help people and the organization to collaborate and develop ideas. This includes tools to share knowledge, design and do production at the fab labs. Some of the software in use for production in the fab labs is made at MIT CBA; other software is free available open source software. The Fab Foundation is based on being a distributed organization, and has up to now been using bespoke software for collaboration. The organization needs advice for the direction of software being used and how these can be used to make the work easier and for documenting best practices.
Developing fab labs worldwide brings forward a lot of different questions related to the extent of organizing, cultural differences, different needs and economical situations. The Fab Foundation is a worldwide organization that needs the tools to communicate, share knowledge and collaborate between continents and time zones.

Being part of a multinational organization which supports its members work within technology development carries great value apart from only sharing information. The shared knowledge could be used amongst other things as a basis for education, which is not limited by geography, economical or social borders. Even if it is a subject for discussion (Acemoglu et al., 2005), education is seen by most as an element to build democracy (Dewey, 1916). This can be illustrated by four areas for why it is important to preserve access to education for poor people (Vandycke, 2001, p.9); for preventing the intergenerational transmission of poverty, educational attainments, preservation of societal efficiency and for maintaining social equity.

A fab lab can be situated in a metropolitan area as Amsterdam or in the countryside in India, presenting a wide variety of demands and needs as well as an uneven distribution of the available funding for technology. The fab labs in the rural areas of the world can in the future become a base of introducing children and the population to technology and technology related education.

The Fab Academy is a spin off from the original fab lab network, and started the first education in 2008 as an independent entity organized from the Barcelona Fab Lab (Fab Academy, 2011), using academic staff from the fab lab network for the lectures [Figure 1 The fab lab network and the Fab Academy]. The basic need for education in the network should be met with the Fab Academy. This means first of all individual courses in technology related areas, but the goal is to acknowledge the courses in a degree system. Such an education will give people all over the world the possibility of taking part in an education, regardless of income, country or area of residence.
1.4 Structure of the report

Chapter one describes the incentive, the problem to be solved and the usefulness of performing this work. Chapter two gives an overview of the areas to be covered by this report from a theoretical viewpoint. Chapter three gives an account of the method to be used for answering the questions and the objective described in chapter one. The results are presented in chapter four, and the discussion of the results takes place in chapter five. Chapter six gives the recommendations and conclusion of the work related to the objective. Bibliography and references are presented in chapter seven.

There are four fab lab processes covered in this report [Figure 2 The processes in the fab lab network]; design and production, collaboration and communication, sharing knowledge and education. The structure and breakdown of these areas are identical in chapter two, four and five. Readers with special interest of one of these areas could read these sections separated from the other areas through the three chapters.

Figure 2 The processes in the fab lab network

1.5 Target group

The target group of this report is primary people in the fab lab network, but also people working with software for collaboration in other international networks.

1.6 Limitations

This report will not cover any low level system development of the different software areas.

Software will not be developed for production within the scope of this report.

This report will not cover software for the administration of fab labs as example word processing, spread sheets, accounting et cetera.
2 Theory

This chapter describes the fab lab concept and relevant theoretical approaches to design, production, collaboration, communication and sharing knowledge. The setup of a fab lab is described by both hardware and software in order to give the reader an overall understanding of some of the challenges with running the technology in a fab lab.

2.1 Design and production

2.1.1 Lab IT and networking

2.1.1.1 The staff at a fab lab
The labs have different organizing as some are part of a university structure; others are independent businesses with no organizational superstructure. The roles that have to been taken care of are primarily the manager of the lab and the assistant role. The manager role has the overall responsibility for the economy, the administrative routines and is representing the lab to the outside world. The assistant role is more of a creative role with the responsibility of the operation of the machines, arranging courses and lectures in addition to keeping the lab in a physical orderliness condition. If both roles can be filled by one person is a matter of personal interest and characteristics, but a one person lab is vulnerable related to illness et cetera.

2.1.1.2 How a fab lab is operated
A fab lab could be described by the Fab Charter [Figure 6 The Fab Charter]. A fab lab provides access to tools for rapid prototyping and digital fabrication, described later in this chapter. The machines and equipment is possible to buy for everyone with the funding to do this, but what makes the fab lab network unique is the connection between the labs and the people in a global network.

Another uniqueness of the fab labs is that many of them are situated in areas without access to other technology laboratories like a fab lab (Gershenfeld, 2005). Some of the lab equipment could normally be found in technical universities or larger companies dealing with product development. The network of fab labs and the shared competence compensates for the smaller staff at a fab lab compared to a large company.

To give a better understanding of how a fab lab is used, use cases for three possible user groups are described below.

User A: The inventor

Who: The inventor is a person with high competence in his discipline, no in depth knowledge about the fab labs and the way a fab lab operates, but he has heard about the potential of making prototypes in a fab lab.
**What:** The inventor has an idea, well considered and maybe with some drawings or 3D-models. He wants to get some investors or companies interested in his idea, but needs a physical model to prove the uniqueness or even if his idea will work at all. As an example an inventor wanted a prototype to prove if a concept for collecting oil spill worked.

**How:** The inventor contacts the fab lab with his idea and his wish for the production of a prototype. The communication between the lab and the inventor clarifies if this is a problem that can be solved within the boundaries of the fab lab. There is set up meetings between the fab lab and the inventor. The design and product is discussed. If the resources or competence is not in the actual fab lab – people in the network could help. The design of the prototype is made in iterations and the final prototype could be used by the inventor to take his idea further on

[Figure 3 Conceptual figure of how an inventor can take use of a fab lab].

**Duration:** Depending on the complexity of the prototype or model, a task like this could take from a week to several months.

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**User B: The fab lab designer**

**Who:** The fab lab designer is a person working at, or having close connection to a fab lab. This person is either a creative person or technical talented and knows the capabilities of the equipment at a fab lab. He knows the global network and knows where to get help.

**What:** This person is making his own inventions, helping other people in the fab lab or customers of the fab lab. Not all work is an invention; the work could as well be reverse engineering or a copy of existing functionality in a project. The discipline of the work is often multifunctional. An example could be sensors for controlling the environmental conditions in a building for use in educational purposes. He makes the circuit boards, solders the circuits, programs the electronics and designs casings for them. Later on these sensors are
shown to students as an example on that the everyday technology is not impossible to make even for a student.

**How:** The concept is described in the fab lab designers head and he is discussing it with colleagues at the actual fab lab, searches for present projects or connects to the network through video conference or e-mail [Figure 4 Conceptual figure of how a designer assigned to a fab lab can take use of a fab lab].

**Duration:** The duration would normally be from a day to a week.

**User C: The customer**

**Who:** The customer has the need for a product, but don’t know how or what. Even if the product tends to be low level technology there is not any places to go for the customer to get the product made. Typically the product development companies do not take this small work.

**What:** The product could be a special casing to brand a product or an acryl product to assemble pieces of equipment in a stack.

**How:** The customer presents his problem to the fab lab. The problem is solved at the fab lab or within the fab lab network in an iterative process with feedback from the customer. This process derivers from the inventor user example by letting the fab lab develop the ideas for the product, instead of having an inventor who knows what he wants. If the customer is satisfied with the product, and the fab lab is able to produce the product, this can be done at the fab lab. Another outcome is that the fab lab makes a small series production for review – and that the large scale production run is made in a separate manufacturing company [Figure 5 Conceptual figure of how a customer can take use of a fab lab].
**Duration**: The duration of a project like this could be from two weeks until years if the product is set in production within the boundaries of a fab lab.

**Figure 5 Conceptual figure of how a customer can take use of a fab lab**

![Conceptual figure of how a customer can take use of a fab lab](image)

**Figure 6 The Fab Charter**

**The Fab 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 users 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.
2.1.1.3 Computer networks

The computer network in the fab labs consists of a basic internet connection, and routers/switches to network the computers and other peripherals in a local area network (LAN). The outreach of internet connection in rural areas for some of the labs, as India or Kenya, is giving challenges with providing high speed and reliable internet connection.

2.1.1.4 Computers

Standard IBM-compatible computers are used in the fab lab network. Even if computers are easy to supply from local vendors, this has been delivered in a start-up equipment base from MIT CBA.

Computers will normally have a life-time of 3-5 years. In organizations where easy administration of the hardware is essential this could be maintained by changing all the computers at a given time, either as a preventive action or when the failure rate of the computers is raising. The cost of this replacement could be perceived as extravagant in an organization with less financial means or in areas of the world where this is impossible to do because of cost. As long as the hardware can run the applications, a computer may be used until it breaks.

Virtualization of the software and operating system running on a computer makes it possible to run the operative system without dependencies of the computer hardware. “Virtualization, in its broadest sense is the emulation of one or more workstations/server, within a single physical computer. In other words, it is the emulation of hardware within a software platform” (Menken & Blokdijk, 2008, p.7).

In principle this means that an organization could have a software package with needed software and deploy this on computers independent of the type or version of hardware running on it. The alternative is managed or unmanaged procedures to install the software on the different configurations of hardware.

2.1.1.5 Machines for production

The machines in the fab labs are standardized after proposal from MIT CBA. The different machines include laser cutters, milling machines, and other Computer Numerical Controlled (CNC)-machines [Figure 7 Conceptual hardware setup of a fab lab]. Standardization has the positive effect that user support and interconnection is easier. For collaboration purposes equal machines worldwide avoids problems with compatibility between the sites and in the capabilities of the machines at the different sites.
2.1.1.6 Software

The software in the fab lab can be divided in three groups:

1. Operating system
2. General software. E.g. software for image processing, word-processor
3. Special software, for controlling CNC machines or interface software which needs installation and maintenance

2.1.2 Computer-aided design, manufacturing and engineering

2.1.2.1 Computer-aided design (CAD)

Computer-aided design can be defined as the use of computers in drafting or drawing products, buildings or even art. Drawing can be done in either 2D or 3D.

“If we had had a circuit simulation program connected to Sketchpad so that we would have known whether the circuit we drew worked, it would have been worth our while to use the computer to draw it. We are as yet a long way from being able to produce routine drawings with the computer” (Sutherland, 1963, p.110).

The predecessor of modern computer-aided design is the Sketchpad software written by Ivan Sutherland in 1963. Sutherland invented a computer program that made it possible to interact with the computer on a graphical user interface using a light pen. This software laid the foundation for later graphical user interfaces and had already functions like zoom and scroll, but lacked modern on screen menus and functions. The solution of 1963 for this was using a hardware box with 40 buttons to initiate different functions like draw or move. This was achieved by managing the drawing as objects (Wardrip-Fruin, 2003).

The 2D- and 3D-drawings have the analogy in the drawing table. This was a time consuming process both in 2D and 3D. The re-use of the
drawings were strictly limited and the use of the drawings besides of direct scaled measurement on the paper was difficult. Several drawings from different angels were needed to replicate the 3D-object meant to be produced. Even with an imaginary unlimited time and manpower resources the process had limitations in the design process. Nevertheless, the technique made it possible to plan and build the Eiffel Tower, Titanic and the T-Ford.

The increasing processor capacity of computers in the 20 Century and the software development has not only transferred the analog process to a corresponding digital process, but also brought in a new way of working. In the mid 1980’s an estimate was that using CAD was at least four times as productive as conventional drawing (Shanahan, 1984).

The drawing board gave the engineer the possibility to make a flat representation. Modern CAD software works with models and objects. Once the object is created, it can be reused, projected in the desired angle, cut through or scaled.

For collaboration purposes in the fab labs it is possible to export the models to vendors, customers or other collaborating parties. This adds extra value to the product, as also the other parties can make use of the drawings and easily include this in own drawings. Some vendors have as well CAD generators to allow customers to configure their products before exporting the resulting CAD-files.

The computer-aided design also gives the benefit of making it possible to manufacture the product, more or less without having a human to do the production; computer-aided manufacturing. This process can be used for prototyping (Elanchezhian et al., 2007).

2.1.2.2 Computer-aided manufacturing (CAM)

"CAM is a generic term for a wide range of computer controlled machines" (Hosking, 1992, p.241).

While CAD is a computer program for designing, the computer-aided manufacturing is the process of transferring CAD-drawings to physical models through controlling machines (Elanchezhian et al., 2007). P.E. Bézier at "Régie Nationale des Usines Renault" made the Unisurf system for design and construction of cars.

"When the shape of a patch is accepted, it is sculptured, by means of the same tape, out of a plaster block set on a metal frame" (Bézier, 1971, p.214).

The Unisurf system at Renault made it possible to manufacture improved designs faster and print them in Styrofoam for easy prototyping – before printing in the material wanted for the final model.
The CAM-process is being used today for both prototyping and production. CAM is especially suitable while it is making it possible to produce small series of products, without having to instruct or educate a human in how to make it.

When CAD and CAM is combined in manufacturing this is called CAD-CAM (Daintith, 2004). The human is not excluded from the production chain, but a machine or robot could normally do work as milling or other routine work while the human role will be maintaining control of the quality in the production and carrying out service maintenance of the production equipment.

In theory the manufacturing can take place in another city, another country, another continent, far away from where the product is designed in CAD and immediate after the files are sent. This gives the flexibility to share designs between people and organizations as a mathematical recipe.

2.1.2.3 Computer-aided engineering (CAE)

“Computer aided engineering (CAE) refers to a collection of software and hardware tools integrated into a system (a computer) that is providing the circuit designer and circuit troubleshooter with step-by-step assistance during each phase of the design and analysis cycle, as well as during development, documentation, and maintenance.” (Neira, 1994)

The circuit simulator program Sutherland lacked in Sketchpad could be a CAE-tool. A CAE-tool is not only used to test against time consuming events, but also events that are not possible to simulate:

“The spacecraft designer must account for environmental rigors that are either unknown or insignificant at the earth's surface. In addition to creating a component or system to perform a specific function, the spacecraft designer must ensure that it will operate properly in the hostile space environment. The system must be thoroughly checked out to verify that it will survive and operate successfully in space that the many possible interactions between the spacecraft and its environment are each either suppressed or made benign” (Barfield et al., 1990, p.1).
CAE is an umbrella term for the different activities in computer assisted planning, CAD and CAM in engineering activities, but is not often used for software development. (Daintith, 2004). CAE can be useful especially for the design of electronic circuits in the fab labs.

The CAE-process is not only machine centered. The combination of computers, machines and human should benefit from the best characteristics of them in combination. The result can be a problem solving team (Meguid, 1987).

Even if simulation, other analyzing and testing is possible to perform with software, the need for test after manufacturing is still there. Products with subsystems and complex materials could still need physical testing to verify the software calculations. Simulation of a crash in the car industry is used to calculate structures and materials and their possible impact to a human. A calculation of seat belts, airbags and virtual representations of crash test dummies improve the process of crash simulation, but is always followed by a physical destructive crash test to confirm the calculations (Matin & Eydgahi, 2008).

2.1.3 Business platform

Electronic business can be defined as the organized effort of individuals to produce and sell, for a profit, products and services that satisfy society’s need through the facilities available on the Internet (Canzer, 2006). As a part of this definition is e-commerce. E-commerce is a narrower concept defining only the activities related to the buying and selling online. The fab labs have the need of creating income, and selling products or services may be organized using electronic business concepts.

Electronic business supports the whole value chain of a company and the different processes from the raw-materials are purchased until the payment for the final product is received. This includes services as customer management systems or content management system for the company web page.

A low fidelity e-commerce solution consists of a web-server connected to the internet with an e-commerce application for displaying products or services, a database with the data stored and a database management system on a database server to manage the data.
2.2 Collaboration and communication

2.2.1 Video conferencing

2.2.1.1 About video conferencing

The distributed network of fab labs has a need to communicate through face to face video conference. One definition of video conferencing is: A video conference is a set of interactive telecommunication technologies which allow two or more locations to interact via two-way video and audio transmissions simultaneously. Video conferencing uses telecommunications of audio and video to bring people at different sites together for a meeting. Besides the audio and visual transmission of people, video conferencing can be used to share documents, computer displayed information and whiteboards (Allasia et al., 2007, p.25).

The improvement of video conference technology has made some of the video conferencing capabilities available as web applications and web conferencing has been introduced as a definition of the video conference conducted on the web. The web conferencing has advantages over the traditional video conferencing as these services are easier to set up by the user and don’t require any proprietary software or hardware installed at the client side (James, 2010). This gives possibilities with having multipoint videoconferences without having a MCU, and the MCU function can be a web application. The centralized software makes it easy for even not skilled computer users to connect a web camera to the computer and attend a videoconference, not unlike the instant access that a phone may give (Spielman & Winfeld, 1993). This makes a solution like this suitable for educational use. The web application can combine different communication categories and make the attendees interact with each other or the conference manager.

The use of the conferencing can be divided into three categories (Shepard, 2002, p.4) [Figure 9 Three concepts of video conferencing :]

- One-to-one
  Two users are connected with the help of dedicated video conference hardware or computers with software applications. The connection can be direct between the two clients or through a web application. A one-to-one Skype call is an example of one-to-one video conferencing.

- One-to-many
  One user is sending to several other users, ideal for IP video or a lesson (Bing, 2010). Virtual classrooms as the commercial Nefsis (Nefsis, 2011) or the open source BigBlueButton (BigBlueButton, 2011) provides the students to interact by text chat, voice and share video with the lecturer. The technological boundaries between the one-to-many and the many-to-many are partly removed as interaction is possible. The one-to-many videoconference is a conceptual way of thinking how the video conference is conducted, however not limiting the use of interaction from the other participants.
Many-to-many

Several users are able to have a two way video conference. A Multipoint Control Unit (MCU) is used in traditional video conference systems to interconnect and bridge three or more terminals and gateways. Instead of sending all video streams to all of the participants, the MCU collects the video streams and sends one single information stream to each of the participants (Halsall, 2001). In a web conference, a web application could have the same functionality as a MCU.

Figure 9 Three concepts of video conferencing (Shepard, 2002, p.4)

2.2.1.2 Definition

The quality of video conference solutions has raised and the price has decreased. Desktop video conferencing is widely used (Halsall, 2001). The introduction of consumer high-quality web cameras and computer performance has contributed to that the boundaries between the different video conference categories have been lowered and the limitation of quality is dependent on the bandwidth available. The need for a definition of video conferencing in this report needs to cover not only the two-way conference (Allasia et al., 2007), but also one-to-many (Shepard, 2002) video conferencing concepts used in educational purposes. The technology to transmit the conferencing sessions whether it is traditional protocols for video conferencing or web conferencing (James, 2010) should be included in the definition as they both are able to provide video conferencing functionality.
Video conferencing is defined in this report as:
Video conferencing is the functionality for two or more users to communicate and share video and voice through web or protocols for video transmission. Additional functionality for sharing of data as documents, lectures and desktop sharing could be included in the functionality.

### 2.2.2 Project management, distributed development and collaboration

#### 2.2.2.1 Project

A project could be defined as “a temporary endeavor undertaken to create a unique product, service or result” (Project Management Institute, 2011). The term project should not be used for tasks that are routine, could be managed in the line in the organization or is limited in cost or need for resources.

Some characteristics of a project are (Kerzner, 2009):

- A specific objective to be completed within certain specifications
- Defined start and end dates
- Limits for costs
- Consume human and nonhuman resources
- Multifunctional, including several disciplines

#### 2.2.2.2 Project management

The Project Management Institute (PMI) defines nine project management knowledge areas (Project Management Institute, 2011):

1. *Project Integration Management:* The process of creating the charter and the plan for the project. In the running phase of the project this knowledge area focuses on monitoring and controlling the work.

2. *Project Scope Management:* The collection of requirements and making a good work breakdown structure is important to define the scope. Later in the project the verification and control activities related to the scope are important activities in this area.

3. *Project Time Management:* This area is about defining and estimating the activities, duration, resources, dependencies and sequences. The output in the planning phase is the project schedule. The control of the schedule during the project is important to reach the project goals.

4. *Project Cost Management:* Cost management is how to estimate the project costs, establishing a budget, monitoring and controlling the costs.

5. *Project Quality Management:* The standard of the project delivery and the project work is important from start of the project to the final delivery. The work starts with planning the quality activities, and performing quality assurance and control during the project. The quality management is of interest for the
Theory

project as well as the receiver of the project delivery. The quality management could be the only practical solution to follow up a project, as it is difficult to follow and control all the work that is done in a project. Quality management will control that the standards decided for how the work shall be done is followed.

6. *Project Human Resource Management*: The area is about making a plan for which personnel that shall be involved in the project. In the running phase of the project this consists of acquiring, developing and managing the project team.

7. *Project Communications Management*: Stakeholders involved in the project should be identified and a communication plan developed. During the project is distribution of information, managing the stakeholder expectations and reporting of performance in the project important tasks.

8. *Project Risk Management*: The risks in a project should be identified, analyzed and responses to the risks planned. Monitoring and controlling the risk during the running phase of the project is how the risks are controlled.

9. *Project Procurement Management*: Procurement is how procurement is planned, conducted, administered and closed. This includes both goods and services needed to perform the project.

There is no formal project model or way of conducting projects in the fab labs. The ideas are ambitious without any regards to consciousness about cost or the need of resources to conduct such a project. A corporate approach to project management could be too complicated and trigger a need for education in the project model itself which will add further steps in order to conduct work in the projects. A feasible definition of project management could be "the supervision and control of the work required to complete the project vision" (Phillips, 2006, p.13). Even if projects in the fab lab network are not often of a commercial kind, some of the practices for project management should be applicable in the fab lab network: The scope of projects has to be defined, and a plan for how, when and who should conduct it.

2.2.2.3 **Project management software**

Microsoft Project (Microsoft Project 2010, 2010) is standalone software for project management and provides possibilities of planning activities and their resources.

Project management software should be used with care. Errors could be made by users not understanding the concept of the software and being able to adapt their project to the project management software (Schwalbe, 2010). No software has been in use in the fab labs for project management, and to have a successful implementation the software must fit to the actual needs. Nevertheless, the need of planning and displaying this information for the project participants requires supporting software both for the process of planning and the later follow-up in the project phase.
2.2.2.4 Collaborative project management software

While calculations and resource planning for the project manager is the main objective in traditional project management software, collaborative project management software provides tools for collaborating between the project manager and members of the project team in several locations (Binder, 2007). Integrated web based software could have more advanced functionality as collaboration, document management, following up, tracking issues and interface with other business software.

Examples of collaborative project management software are commercial software as Projectplace (Projectplace.com, 2011) or Easy Projects .NET (Easy Projects.NET, 2011). Both software can be delivered as Software as a Service (SaaS) with all functionality available on a web interface. SaaS has the advantage of requiring small investments in both hardware and license to get started and the maintenance of the software is done by the vendor of the software. As a web interface may decrease functionality compared to local installed software related to functionality and user interface, Software + Services is a combination of locally installed software and cloud computing with elements from SaaS, service-orientated development and Web 2.0 (Shelly & Rosenblatt, 2010, p.284).

Open source alternatives for collaborative project management software are available, e.g. phpGroupWare (phpgroupware.org, 2010). However, such software will require either a partner for hosting and maintaining the software or an in-house installation.

2.2.2.5 Distributed development

Distributed development in its extreme is projects and tasks running 24 hours a day worldwide. The coordination has challenges with socio cultural differences, time zones and the physical separation of the team (Ågerfalk et al., 2008).

Table 1 The benefits of global software development (Ågerfalk et al., 2008)

<table>
<thead>
<tr>
<th>Organizational benefits</th>
<th>Team benefits</th>
<th>Process/Task benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost savings</td>
<td>Improved task modularization</td>
<td>Formal record of communication</td>
</tr>
<tr>
<td>Access to large multiskilled workforces</td>
<td>Reduced coordination cost</td>
<td>Improved documentation</td>
</tr>
<tr>
<td>Reduced time to market</td>
<td>Increased team autonomy</td>
<td>Clearly defined processes</td>
</tr>
<tr>
<td>Proximity to market and customer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Innovation and shared best practice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resource allocation</td>
<td></td>
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</tr>
</tbody>
</table>

The exchange of experts without the boundaries of time and geography could make project teams that are impossible to achieve with a traditional organization both in cost and in available experts. China,
India and Eastern-Europe have a large number of highly skilled people, and the cost of this labor is lower than if the same task should be performed in high-cost countries.

The challenges of global software development (Ågerfalk et al., 2008) introduce disadvantages for the development process related to communication. The use of asynchronous communication makes it difficult coming to conclusions and more likely to introduce misunderstandings. Work is duplicated or not done due to lack of coordination, and the expectation of short response time for the decision maker, not leaving time for people being offline, makes project plans fail or could start time consuming discussions (Coar, 2003).

Less knowledge about the experts at the remote sites restricts communication and non-modular architecture gives conflicts when the development of a module is conducted on several locations (Mockus & Herbsleb, 2001).

The cost is not the motivation for distributed development in the fab lab network, separate and shared interest should be the result of the collaboration (Cutcher-Gershenfeld, 2007). This should not prevent the fab lab network to learn from best practice in other distributed development projects.

2.2.2.6 Management of software projects
Projects or parts of projects where software coding is the main activity, brings up challenges which is different from other disciplines of development projects. The process of Software Configuration Management (SCM) can be defined as an “organizational framework – that is, a discipline – for managing the evolution of computer systems throughout all stages of systems development” (Keyes, 2004, p.1).

As a part of SCM is revision control, which makes it possible for several developers to work concurrency on the code files in the project. There are two approaches for version control systems; client server and distributed version control.

A client server version control system has a central repository containing the code. Users or the software conducts actions as checking the code files in and out, lock and merge (Loeliger, 2009, pp.4-5). This requires a network connection to the central server. An example of a client server version control system is the Concurrent Versions System (CVS). While code files are the main purpose of CVS, the software also has the possibility to record the history of other files as documents (Price et al., 2006).

A distributed version control system (DVCS) is independent from having a central repository and makes the developer able to work offline unless a synchronization of the code is required. The developers can combine versions of the code directly peer to peer without server software (Loeliger, 2009, p.119). Git is an example of a DVCS and is in use in the fab lab network. As there is no central repository; integrity and trust must be maintained by the DVSC software, in Git handled by a cryptographic hash function (Loeliger, 2009, p.3).
2.2.2.7 Collaboration

"Collaborative engineering (...) is about the development process in its organization, management, and methodology, integrated with innovative development technologies" (Zhuk, 2004, p.1). This is a view on collaboration including both humans and the technology.

"Technology tends to fragment. To focus on pieces and omit the glue" (Zhuk, 2004, p.1). The fragmentation is about fragmentation in design principles and best practices for development. This applies especially to software development but is also transferable on other engineering activities. Lacking possibilities in a project to interact with other products, lacking interfaces and non-standard solutions could affect the life cycle cost for the product and reduce the usability of the product.

The collaboration in the fab lab network consists of shared use of software, hardware and know how between the fab labs (Cutcher-Gershenfeld, 2007). The shared use of the same soft- and hardware gives a basis for collaboration, input on design errors and improvements from several fab labs.

2.2.2.8 Collaborative technologies

The collaborative technologies should make the process and progress visible to the members of the team. The team members could have to post daily and weekly reports, plans and status, and reminders could be sent to the members if the reports are not posted (Zhuk, 2004).

The challenge with the approach of forced automatic follow up of the team members could be the motivation and the feeling of being a machine. The motivation to deliver and contribute could be a driving factor and an argument for not having the project to have strict routines for reporting. This is according to the fab lab network doctrine of leadership by influence, and not authority (Cutcher-Gershenfeld, 2007).

Using collaborative technologies and distributed development gives benefits as a result of the different organizing of the work. The record of communication which is necessary in a global project, the increased documentation and need for clearly defined processes are process/task benefits. The coordination cost could also be reduced as the coordinator could be in another time zone than the developer team. The coordinator can send a request for work and leave for the day, and the development team can have the work finished before the coordinator returns the next morning. The modularization of the tasks is a requirement for being able to split the work between the different teams. As the project team is modularized geographically this could facilitate the modularization of the tasks (Ågerfalk et al., 2008). These principles could be difficult to practice in the fab lab network, as participation in the projects is more or less voluntary work. The participants have personal interests for the projects and take part in the projects on a voluntary basis. However, such an approach for project work gives few means for the project management to demand a time limit to be held, or that a participant must give priority to the project. Cultural and personal differences are also
affecting how the individuals in the project group are being motivated and dedicated to the work (Markus & Kitayama, 1991).

The collaboration techniques used in the fab lab network is video conferencing and use of the Siteserver application, one of outcomes of this report is if these techniques are the most suitable for the fab lab network.

2.3 Sharing knowledge

2.3.1 Fab lab knowledge base

2.3.1.1 Knowledge
The concept of information and knowledge could be distinguished by that knowledge is personalized information, possessed in the mind of individuals, while information is processed data (Alavi & Leidner, 1999).

In the network of fab labs, knowledge could be how to run a fab lab, how to use a 3D-software or experience with using a specific material for production. The network of fab labs as an organization could be called a knowledge system for creation, storage, transfer and application of knowledge (Alavi & Leidner, 1999).

2.3.1.2 Knowledge management
Knowledge management could be defined as an organization specific process for acquiring, organizing and communicating knowledge so other employees can take use of it to be more effective and productive in their work (Alavi & Leidner, 1999 Volume 1).

As there is no central management of the fab lab network, an interpretation of knowledge management for the fab labs would be how the knowledge system is managed by the fab lab network itself for common use.

2.3.1.3 Knowledge management software
Internet, intranets, extranets, data warehouses and software agents are examples of tools for knowledge management (Alavi & Leidner, 1999). Software to support knowledge management in this report will be called the fab lab knowledge base.

Conzilla (Conzilla - A concept browser, 2010) is a tool to model knowledge flows in an organization and enables the user to view and edit a model using the Resource Description Framework (RDF Working Group, 2004). The semantic web is a way of describing the relationship between metadata through using ontology (Naeve, 2005). This software is useable to plan and design a RDF approach for the knowledge structure in the fab lab network. A tool like this is also feasible to model the information flow between the actors in the fab lab network.
2.4 Education

2.4.1 Academic platform

An academic platform can be described as the software and processes needed to support the process from enrollment of a student, activities related to lessons, exercises and test, examination results until the students diploma can be printed. A system like this is called a course management system (CMS), an automation of some of the processes found in academic environments, many which have been tradition for nearly a millennium (Katz, 2003).

The quality control of an education can be easier to accomplish with an academic platform supporting all the needed activities. Manual control over student data would be time consuming for both for administration and the academic personnel. With a well functioning supporting system at hand, more time can be used for core activities that support the education and the academic work. Results can be that learning outcome will improve, but the role of academic staff inevitably becomes subject to change (Katz, 2003).

Another important advantage of an academic platform is the possibility of being able to communicate and work from other places than in the traditional classroom. Decentralized educations or asynchronous part-time studies can be managed by the academic staff and the students without having the need for a physical meeting. The lessons can be done with video conference technology and be available whenever the student has time to study.

A decentralized approach of education consists of both decentralized education and decentralized technology for education. Instead of investing in stationary learning environments as a computer lab, a personal learning environment can be made accessible for the student (Wilson et al., 2007). For the fab labs such a strategy is feasible as general lectures can be conducted from a lab and students can follow the lectures by video conference in a virtual classroom (Fab Academy, 2011). However, the operation and training on the machines requires a physical meeting at the fab lab. This work can be done individually and independent from other students. Even a small lab with few machines and computers can host many students with this strategy.
3 Method

This chapter describes the methods used in this report to collect information about the fab lab network and the workflow in the network.

3.1 Choice of method

The fab lab network has an informal organization. A yearly international conference was held for the sixth time in 2010 and this conference is the place where the people in the organization meet once a year. Formally there is no manager of all the labs, and no formal administration. The methodology to collect data should support this background.

3.2 Literature review

3.2.1 Accomplishment

A literature review was conducted in order to get knowledge of the technological areas applicable for the fab labs. These areas were proposed from key personnel in the fab lab network and the result is described in Chapter 2.

3.3 Observation

3.3.1 About observation

Observation can be divided into five degrees (Key, 1997):

- External participation, the observer is watching video, live or recorded
- Passive participation, the observer acts as a spectator at the observation area, but does not interact or participate
- Balanced participation, the observer participates in some activities
- Active participation, the observer learn the rules and take a full role in the activities
- Total participation, the observer is a natural participant

3.3.2 Suitability

The observation study was performed during the international Fab Boot Camp located in the fab lab in Lyngen, in the north of Norway. The camp involved in total between 30 and 40 people connected to the fab lab system in one way or another. The mission of the Fab Boot Camp was training in how to use the machines and software in a fab lab, discussion about the concept, how to run a fab lab and workshops in how to bring the fab lab network further on. Observation of how the fab lab worked, the issues related to how the collaboration worked and how the existing software solutions worked was expected to give a good understanding of how the future system should be. A passive observation approach was planned.
3.3.3 Preparations

The plan for the content of the observation period was reviewed. The program had different topics related to how a fab lab is working:

- Outreach to local schools, special projects, how to teach visitors at the lab
- Lab IT and networking
- Fab lab International networking and documentation (Siteserver, documentation in general and lab setup)
- Lab management and administration
- Fab Software:
  - Cad.py
  - Blender
  - Gimp
  - Inkscape
  - Scratch
  - OpenOffice
  - Cam.py
  - Sketch-up
- Additive technology:
  - Building a 3D printer (Fab @ Home)

3.3.4 Accomplishment

The role at the Fab Boot Camp was intended to be a passive observation on how the network collaborated and shared information. This role was soon changed to being a balanced participation. Assisting the lectures and give help in challenges with the software being operated was wanted. While this was not the initial purpose of the observation, it gave a wide knowledge about the organization, both operational and organizational. This was the first Boot Camp in the network and the structure and the pedagogical concept was therefore under development during the whole Boot Camp.

The interim manager of the Fab Foundation gave a preface of the history of the Fab Foundation and the preliminary plans. This involved economically, organizationally and aspects related to the scope of the organization.

As both MITs establishment of fab labs and the running of the labs worldwide more or less is based on governmental funding, ideas related to this was broadly discussed. Fab labs operate in countries with different levels of salaries, different opportunities for getting funding and under a wide variety of political forms of government. The control of means for activities and knowledge about how the resources are spent was important to discuss.

The fab labs bottom up organization and workflow gives the possibility of structures of managing the network that is not normal in other
Methodology

businesses. The concern about how to not over manage and overrule the network and the people was a point of discussion.

3.4 Interviews

3.4.1 About interviewing

The research interview has the goal to obtain information and understanding of issues relevant to the aims and the specific question in a research project (Gillham, 2000).

Having the interview structured or unstructured could be dependent of how much background information there is available to ask the correct questions. Unstructured question can make the interviewed person better possibilities to give information that was not considered by the interviewer. A closed question in a structured setting is on the other side adequate if there is a need to convert the questions to quantitative data or if time limits the interview. Open questions could need further questions and the interviewed may need to be lead in the desired direction.

Table 2 The verbal data dimension (Gillham, 2000, p.6)

<table>
<thead>
<tr>
<th>Unstructured</th>
<th>Structured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Listening to other people’s conversation</td>
<td>Structured questionnaires: simple, specific, closed question</td>
</tr>
<tr>
<td>Using ‘natural’ conversation to ask research questions</td>
<td>Semi-structured interviews: multiple choice and open questions</td>
</tr>
<tr>
<td>‘Open-ended’ interviews; just a few key open questions, e.g. ‘elite interviewing’</td>
<td>Recording schedules: in effect, verbally administered questionnaires</td>
</tr>
<tr>
<td>Semi-structured interviews, i.e. open and closed questions</td>
<td>Semi-structured questionnaires: multiple choice and open questions</td>
</tr>
</tbody>
</table>

The setting with an interview is comparable with a conversation between two or more persons. There are advantages and disadvantages with making a formal interview. The formal interview could make the interviewee feel important and that some is interested in his contribution and listens to his opinions. The disadvantage is that the preparation time and time to set up the formal interview could limit the possibilities that an informal interview may give.

3.4.2 Suitability

The users of the proposed solutions of the software roadmap have interests in having the solutions user friendly and relevant. Observation can reveal the present practice in the organization. Interviews can give a better understanding of the challenges with the technology than only observing and participating in the work may give.

3.4.3 Preparations

Some of the software applications, as the cad.py, are specific to MIT CBA and the fab labs. Knowledge about how this software works is not well documented and the participation in the observation could expose topics to be covered during the talk with the attendees. The background of the group was both experienced participant as well as newcomers to
the fab lab network. This leads to an unstructured interview with open questions.

### 3.4.4 Accomplishment

The role as assistant to the lecturers made it easy to address questions to the attendees during the work sessions. The sessions revealed that the variance in knowledge about the machines and the motivation to learn software gave possibilities to understand the different needs for the different types of users.

There are several sources of error in a qualitative interview situation to be aware of. The interviewees can act or answer different because of being in an interview situation or monitored, the Hawthorne Effect (Jones, 1992) or a measurement bias (Experiment-Resources, 2011). This source of error was not likely to happen as the interviews was conducted informal and as part of a normal conversation.

A more probable error is bias during the accomplishment of the observation and interviews (Experiment-Resources, 2011). A design bias would be if only a limited user group was interviewed, a sampling bias. E.g. if only fab lab managers needs were part of the identification of requirements in this report and the result was presented as the needs for all users.

A procedural bias in context is if the participants were forced to take part in an interview at the sacrifice of the lectures, with the result that the participants were trying to finish up the interview as soon as possible. The interviewer bias is a source of error as the interviewer’s body language or personal interests can influence the interviewee. A response bias is if the interviewee responds what he or she think is the wanted answer.

It is more or less unavoidable that biases influence an interview situation. To be aware of the existence of these sources of error is crucial to reduce the impact they may give on the final result.

The daily schedule at the Boot Camp was lectures followed by practice in the actual subject. The lectures itself were mostly suited for observation. Practice sessions gave time for discussions and the interviewing. The main objection to how the interviews were planned and conducted was that choosing an unstructured interview to complement a passive observation gave a wide amount of information width too little depth. However, the depth of the information would have been better if a structured interview had been conducted and the questions had been more specific. The results of the interviews were more characterized as an extension of the observation rather than a standalone interview to extract other information not easily collected in an observation.

One factor of success with using unstructured interviews was that the scope of the software roadmap was difficult to know in advance of the Boot Camp and that an open interview gave the possibility to learn about
all software and projects requirements, not limiting the process with structured questions. The Boot Camp was conducted during a three week period and this gave sufficient time to get the necessary overview of the organization and the requirements for the software roadmap.

An improvement of the process of interviewing would have been taking the interviewees out of the lecture situation and conducted formal interviews as a review of the processes in the fab lab network and questions directed as “what are your needs for project documentation software”. Such a method would have made possible to get the equivalent amount of information in less time than conducting the interviews informal.

As it was difficult to have detailed information about the fab lab network ahead of the Boot Camp, a structured interview from the first day would have been difficult. Instead of running unstructured interviews the whole period, the interviews could gradually have been changed to more structured interviews as experience of the network was gained.

### 3.5 Prototyping

#### 3.5.1 About prototyping

Software prototyping can be defined as a rapid software development for validating the requirements (Puntambekar, 2008). The prototyping can have the goal of both elicitation and validation of requirements. The process can give results as:

- Discover missing elements of the software
- Improvements in usability
- Risk reducing as the user can discover bad system design in an early stage
- Be a part of the specification and requirement refinement

The usefulness of prototyping could be in situations when there is (Neufelder, 1993, p.53):

- An extensive user interface and user requirements are not decent stated
- When performance is critical for the software
- For a brand new concept and there is risk if the concept will work

#### 3.5.2 Suitability

The time factor and available resources to produce prototypes make limitations on the extent of use of prototypes. Further on could prototyping be an activity in later development stages, and the appliance for prototyping activity for this report is less than in a design phase of software.
3.5.3 Preparations
The need for prototypes is dependent from discovering a need. The observation and interviews gave an overview over the challenges with the current software applications.

3.5.4 Accomplishment
- Coding of a simple PHP tool for project web-pages
  - The software for documenting projects, Siteserver (Editing Websites with Siteserver, 2011), requires HTML knowledge for establishing and maintaining the project web-pages. A tool coded in PHP was tested in order to be quicker and easier able to publish information within the Siteserver framework on the basis of a model-view-controller pattern (Fowler, 2003).

- Prototype for an academic platform
  - Setup of a Learning Management System on the Fab Foundation server in order to explore how such a system could support the activities in Fab Academy.
4 Results

This chapter describes an overview of the practice in the fab lab network related to use of software from controlling machines to collaboration.

4.1 Design and production

4.1.1 Lab IT and networking

4.1.1.1 Gained experience

4.1.1.1.1 General

Program manager Sherry Lassiter at MIT-CBA was head of the lectures in fab lab IT and networking. This includes install and setup of normal IBM-compatible desktop computers with operative system and the necessary software for running the design and manufacturing process at the labs. The intention of the lectures was to make the computer and networking for a complete fab lab working from scratch.

The software was installed according to a list made by Sherry Lassiter based on requirements for running the equipment. This works well as a recipe for how to set up a computer in a fab lab environment. However, the install is time consuming and would assume that the user has the basic knowledge about operative system setup.

4.1.1.1.2 The client computers and setup

The fab labs are using an Ubuntu-Linux-distribution as a basic operative system and normally as a dual boot with the Windows XP. The basic install of the operative system brings few or no problems.

Synaptic is a software tool to automatic download and install programs in a Linux desktop environment. The install using this tool is working well, but can sometimes bring up problems with prerequisite software not being installed or not being possible to install with Synaptic.

In addition to software being downloaded through Synaptic, there are software and components that needs to be installed manually. The install is basically not hard to do, though require some experience in the handling of operative system and knowledge of alternative ways of installing and copying files. While this can be a threshold level of performing the installation work, it can raise the level on troubleshooting and understanding for the personnel at the fab labs. Working with computers and being able to “make almost anything” should also include being able to fix minor computer problems. Nevertheless; troubleshooting computer software can make a lot of frustration for the staff and users of the fab lab.

Normally there are not made automatic install routines or an image of the computer to help later quick reinstall or being possible to copy the
image to other computers at the lab. In bigger computer environments it is normal to use automated routines for rolling out new configurations of software in use.

A special fab lab distribution of Linux has once been created, but this is not updated with the newest tools or maintained in other ways.

The result of the manual process of installing is that time is spent on doing routine installation on the labs, not having the possibility to maintain the install or reinstall in short time.

4.1.1.1.3 File server
A file server was set up for storing user files, projects and other files related to the production. The server was an Ubuntu-server, and the other computers connect to this with a SSH-protocol. This is a supported way of connection to a server in Ubuntu, but need special tools with Windows XP; an SSH-client.

Storing the user files at a server gives the advantage of being able to back up all the user files from one location. As there are not any client accounts at the client computers files are stored at the desktop of the different clients or at memory sticks. The user profile of the fab labs with many people visiting and using the equipment would make it time consuming to set up user accounts for all the users with a dedicated place for storing the files at the server. There are usually no information security issues on the client computer that requires the users to authorize themselves.

4.1.2 Computer-aided design, manufacturing and engineering
4.1.2.1 Gained experience
Cad.py is written by Neil Gershenfeld and is a combined CAD/CAM-tool along with cam.py. This is software for import and editing script files for making CAD-models.

This software is important in the education of the lab-staff and students that are using the fab labs. The way this software works is that the user defines the shapes in the model they are going to design. This tool is much used to draw circuit boards to be milled on the Modela. The software gives the user the possibility of displaying a graphical model of the designed product, but the interface with the programming of the model is not drag and drop or similar to other modern software with a graphical user interface. When the model is finished it can be printed, milled or cut on a laser cutter, Modela or a vinyl cutter.

The models have to be coded mathematical with text, and the software gives little feedback on eventual errors that are done in programming [Figure 10 Part of script for making a hello-world serial communications circuit board ]. On the positive side, this software gives the user a motivation to learn the structure of both mathematical coding...
and principles of coding. The total amount of code available for cad.py is limited. The example code made and available online could be modified, or parts of the code can be used as objects in other script files. The user experience with this was that the use of the software introduced three low level knowledge areas that were partly unknown to some of the participants at the boot camp; mathematics, programming and electronics.

Figure 10 Part of script for making a hello-world serial communications circuit board (Gershenfeld, 2009)

```python
# define shapes and transformation
# circle(x0, y0, z)
# cylinder(x0, y0, z0, z1, r)
# cone(x0, y0, z0, z1, r0)
# sphere(x0, y0, z0, r)
# torus(x0, y0, z0, r0, r1)
# rectangle(x0, x1, y0, y1)
# cube(x0, x1, y0, y1, z0, z1)
# triangle(x0, y0, x1, y1, x2, y2) (points in clockwise order)
# pyramid(x0, x1, y0, y1, z0, z1)
# function(Z_of_XY)
# functions(upper_Z_of_XY,lower_Z_of_XY)
# add(part1, part2)
# subtract(part1, part2)
# intersect(part1, part2)
```

The logic of the software is good and once learned, it is possible to program CAD-objects easily. The user experience was that some of the participants never learned the software or never understood. This is the negative part of the low level of the program. If the users don’t get the motivation to learn the software – the observation was that they gave up. The software has the possibility to import 2D png-files from other software as Blender or Inkscape. The users who gave up learning the programming technique made models in other image editing programs and did the import and printing from these.

The problem with such an approach was that these users lost the understanding of personal fabrication and some of the possibilities of the equipment. Instead of being possible to mill models from different angles, these users limited their work to 2D print-outs and more or less art related work. Losing the technological approach for using the software gave also less understanding of the whole fab lab concept.

This observation could divide the users in two user groups:

- Design orientated
- Mathematical, programming orientated

At the end of the courses and practice-lessons the design orientated users had skills of making typical signs or other artwork suitable as advertisement material. The mathematical and programming orientated were able to design own circuit boards and understand the logics in the circuits they made, as well as multi angle CAM. In a fab lab, the multi angle CAM has to be performed with manual processes to turn the material to be machined. The understanding of this process adds value to the equipment related to being possible to make more advanced models.
Cam.py [Figure 11 Screenshot from cam.py] is the interface to the machines and has the following capabilities:

- Input: SVG, DXF (2D,3D), Gerber PCB, Excellon drill, JPG, TIFF, STL
- Output: G code, Roland mill & cutter, Omax waterjet, Epilog & Universal laser cutter, FEI focused ion beam, Haas machining center, Resonetics excimer micromachining

**Gimp**

Gimp was used as an open-source alternative to Adobe Photoshop. The experienced Photoshop-users at the course learned the basics of Gimp but kept on using Photoshop for their further work.

Gimp worked well as an open source tool for the users in the lab for art related CAD-work in 2D.

**Inkscape**

As Gimp is an alternative to Adobe Photoshop, Inkscape is the alternative to Adobe Illustrator. The introduction of Inkscape was an overall introduction, and Inkscape was not used for work after the lessons.

### 4.1.3 Business platform

#### 4.1.3.1 Gained experience

The fab labs have been started without having a commercial platform. The basic idea was that MIT wanted to see what happened when they made prototyping tools to make almost anything available for communities in different parts of the world (Gershenfeld, 2005). Financing the different labs has been done partially by MIT, partially by local governments or organizations.
What a fab lab is in commercial terms is not easy to define. The attendees at the boot camp had different approaches to running business at the fab lab, as examples:

1. Sale of products made at the fab lab  
   The machines at the lab are well suited for prototyping and making commercial advertisement articles.

2. Sale of creative courses and education  
   This can be sold to local schools or businesses

3. Sale of use of the fab lab  
   The fab labs can be used by visitors to make their own prototypes or products

The economical sustainability question was however not answered. Royalties for inventions made at the labs could give some money. Terms related to property rights are issues with challenges to manage. Even a large amount of inventions would not generate money to make the fab lab network sustainable by itself.

Most of the work and ideas at the lab consists of rapid prototyping. The machines at the lab are not built for high number serial production, but could easily be used to make small scale production of products. Personalized production is a key word in the fab lab – and the possibility to share the knowhow of making the products worldwide makes it possible to produce small series of a product locally with less effort.

The process of earning money on the fab lab concept is not easy. Salary to the manpower and the cost of buildings and machines requires income. Production of different kind of packing and brackets made by the use of the machinery is examples of small scale production that has had success at the Norwegian Lyngen fab lab, the Kisusmu lab in Kenya has produced personalized t-shirts by silkscreen printing.

4.2 Collaboration and communication

4.2.1 Video conferencing

4.2.1.1 Gained experience
The different fab labs are located across the globe, both in rural areas with low internet bandwidth as well as large metropolitan cities. The video conferencing equipment is already an important part of how the fab labs collaborate, share knowledge or conducts meetings.

Today’s systems are delivered by Polycom and the hub in the system is a MCU located at MIT Center for Bits and Atoms in Boston. The idea is that the different fab labs connect to this MCU when people are present at the lab, and this can make an online community where it is possible to have a chat with the people at the other labs. Program manager Sherry
Lassiter at Center for Bits and Atoms is more or less always online on the MCU when she is at work and some of the other labs. Not all of the labs are present at the MCU and this is limiting how the people are able to connect to each other through the MCU. A commercial video conferencing endpoint is not affordable for a fab lab in e.g. a rural part of the third world, and the network is dependent on the MCU at Center for Bits and Atoms. The cost of the MCU nodes itself makes it not realistic to have several MCU-nodes and limits the possibilities to make regional video conferencing hubs. The endpoint cost makes a border between the labs that can and cannot afford an endpoint. This border is attempted removed by using software on regular computers to provide access to the MCU. The experience is that the hardware endpoints are connected on regular basis, and the software clients are only connected when a meeting is scheduled, still leaving a border between the fab labs.

The concept of having the fab labs always connected to the MCU makes the user avoid having to schedule a video conference and the level to connect to another lab is lower. It is possible to see if there are people in the remote fab lab and what is happening in the lab. This is a mechanism that could give the feeling of that the remote fab lab is in the neighborhood and possible to interact efficient with. Most of the discussions are related to agile methods of working with projects or tasks, and the concept of being online at the MCU supports these methods as there is no need of long planning in front of taking contact.

A meeting for discussing the business model and how to make the fab lab network sustainable was held with remote participants from USA, the Netherlands and South-Africa. This included even participants attending from their breakfast table, a large meeting room in Norway and medium size conferencing systems at the other sites. The difference in video quality from the participants was obvious, but the topics in the meeting was easily discussed and understood. The experience was that a lot of effort needs to be taken in order to make multinational meetings like this, and also the different time zones gives challenges with people being able to meet at the same time.

The video conference equipment is expensive and tied to a location in the lab. A test was made using Skype and a commercial available web camera of good quality for collaborating with a student participating in a student group in the North Norway. The system setup was as easy to use as the high-end systems, and made it easy to locate in a more silent part of the lab. The limitations to this was first of all no possibility in Skype at that time to share a desktop, this was solved using a VNC-setup with remote desktop. The next limitation was that this was a 1:1 connection without the possibility of connection more students to the group. A commercial solution was tested for this purpose, ooVoo (ooVoo.com, 2011). This was online software at that time free of charge. To use this service, a log in was required on the web page, and the availability that Skype gives you with the easy possibility of being online and visible to other users was limited.

Other free open source products like Ekiga (Ekiga, 2011) proved to have a higher need of user competence in installing and setting up. Ekiga uses
the H.323 protocol and needs to connect to a MCU to work or alternatively by Session Initiation Protocol (SIP). This was not easy to get to work and the software had a less intuitive user interface than Skype.

Polycom has a commercial program called PVX which is their PC-client version of the codec for video conference. The PVX was easy to install, but also the configuration of this software proved to be difficult. Problems like having to disable the firewall or open a port at the computer firewall is not common user knowledge and can possible introduce security threats for the user if not carefully configured.

Google chat (Google Chat, 2011) provides audio (VoIP) and video chat capabilities for users of Gmail. The requirements are that the user has a Gmail account and installs a plug-in on the computer for voice and video chat. The plug-in is available for both Windows, OS X and Linux. Both Skype and Gmail require the user to have a user account. The difference is that Google Chat requires a plug-in on the computer while Skype uses a software client. Google chat gives easy access to a video call for a user already logged in at Gmail, while Skype needs a login on the software client.

A high bandwidth alternative is the free available McGill Ultra-Videoconferencing software (McGill Ultra-Videoconferencing Research Group, 2007). The software runs on a Linux-platform and has the capability of using images from several sources connected to a computer. A high definition video camera can be connected through a 1394 interface, and serve as the video source in comparison with Skype that has an USB-camera as input source. This alternative could be feasible for a planned meeting with demands of high quality video.

Comparable to the Ultra-Videoconferencing software is Digital Video Transport System (DVTS) capable of sending video from a fire wire source without any compression. Bandwidth requirement is 30 Mbps and makes the software feasible for remote instruction, music performance, remote recording or remote collaboration (Fineman, 2010).

Dirac is free available video compression software developed by BBC Research and uses wavelet compression. The compression can be lossless, virtually lossless or lossy and be used for broadcast, to distribute clips or archive video et cetera (BBC Research & Development, 2011). Hardware implementations of this software are made by NuMedia Technology Limited and consists of an encoder and decoder using Dirac (NuMedia Technology Limited, 2011).

An alternative hardware solution for high definition video conferencing is produced by T-VIPS. This is a Norwegian company delivering video gateways to transfer serial data interface (SDI) video on an IP network (T-VIPS AS, 2011). These gateways could connect nodes in the fab lab network with high definition video and audio.
JackTrip is software for transferring high quality audio through internet, to allow control of, receiving and sending uncompressed to chosen destinations on the internet. JackTrip works with OS X and Linux (Caceres & Chafe, 2009).

4.2.2 Project management, distributed development and collaboration

4.2.2.1 Gained experience
The projects at the Boot Camp were not only easy to define as projects. Some at the task worked on were projects that had been running for several years, e.g. the Internet 0-project or the antenna project.

Internet 0 has the origin at Center for Bits and Atoms and has the idea that different parts of the everyday life should be able to interconnect on an IP-network. A small server could network with light bulbs, sensors and ventilation and even make the shoes tell the door knob to open a door (Gershenfeld, 1999). The motivation to do this is that networking lights and switches has serious implications for the economics of building construction (Gershenfeld & Cohen, 2006). The interconnection of units could form an “Internet of things”, also called “Internet of objects” as it connects the everyday objects (SRI Consulting Business Intelligence, 2008).

The idea grew in the fab lab network to have this Internet-0 also to act as a thin client computer not only being possible for things to use, but also humans. This use could be especially relevant to a family, a village or a school in poor areas of the world where electricity and an internet connection could be not existing or too expensive to use. The server is actually inside an inexpensive network router, and this router could then interconnect with other Internet-0 devices and form a network. The different nodes will then be able to form a Wi-Fi-network giving the users internet connectivity for free.

Antennas were needed in order to be able to connect these nodes in a network. A project between fab labs started to design an antenna possible to manufacture at a fab lab with small costs, being able to connect nodes on several kilometers distance. A FabFi-project has been successful in Afghanistan in 2010 giving a network with antennas built of items that could have been considered as garbage (FabFi - FabLab Jalabad, 2010).

The two mentioned projects have the basic in solving a problem. People need inexpensive access to computers and to network. The people working with the projects are like an open source community. The idea is to share the information and improve the system based on sharing knowledge. One of the challenges with this method is that the goals of the projects are not clear and there is no owner of the project. The progression of the projects are more likely to be random than planned and it seems hard for people to commit to work with the projects. Neil Gershenfeld himself made a working implementation of the Internet-0
thin client during the Boot Camp, but there were not any organized way of taking the ideas further on.

Other projects performed at the Boot Camp could be called individual projects to make art or technology based prototypes, as making furniture with the machinery and software available, wind-mill implementations or solar-energy towers. These types of projects gave a motivation to explore technology, the theoretical base of the technology, and to learn to use the equipment at a fab lab for making this technology. The motivation to participate in the projects was good and the project groups worked hard to make the projects. One of the motivating factors in these projects was the lack of requirement of planning. The idea was conceived, and the work with the projects was started immediately. The work was conducted in iterations and the knowledge requirements for the project work followed the on demand principle. The need for knowledge triggered the hunger for getting the knowledge.

Neil Gershenfeld has the idea that all information about the projects and the fab labs shall be able to have offline and portable in a file archive. The reason for this is that user with no internet connection should have access to the same information as other users in the fab lab network and that it should be possible to synchronize their files with the network making distributed development possible.

Linus Torvalds had the same needs for the development of Linux and made the software called Git for software code files and with version control capabilities. Torvalds has since April 20 2006 used Git as a concurrent version system (CVS) for Linux (Loeliger, 2009). Torvalds made this tool to have a repository with the Linux Kernel with several users, working on the same files with the repository offline at their own computer and updating the files they have reworked to other Git archives. There is no need of having a centralized archive to connect to and no need for a dedicated version control server to track the changes in the repository files.

The Git-archive matches the idea of the fab labs as a network to share information and knowledge. The clients can connect to each other without having a central server. Well suited for development in a university in Boston as well as at the countryside in Kenya.

One of the learning goals at the boot camp was how to use this Git-archive to document the project and project progress. The user interface of Git is made by and for users with in depth knowledge of computer science and the students at the Boot Camp had little understanding of the advantages and use of the Git system. Once the repository is downloaded to the computer it is easy to understand, as the files are stored in a normal file structure.

Gershenfeld has developed a web server implementation of the Git-archive in order to make a GUI to traverse the Git-archive and edit a Git-archive online. This makes the Git-archive act as a Content Management System (CMS). The system called Siteserver (Center for Bits and Atoms
- Editing websites with Siteserver, 2011) needs a level of understanding to learn how to use, but once learned it is intuitive.

Figure 12 Graphical User Interface of Siteserver

The Siteserver has the fundamental functionality of a normal content management system, but requires basic knowledge about HTML. Through the interface it is possible to upload files and edit content [Figure 12 Graphical User Interface of Siteserver]. Hyperlinks have to be inserted manually.

To serve as documentation of projects this functionality is adequate, as long as the users are willing to learn the basic principles of HTML.

What happened during the boot camp was that the users were asked to document, but the Git-archive and the Siteserver was not the preferred place to document the activities. The attendees at the Boot Camp used their own homepages or other preferred social medias to post content about their projects.

“There should be functionality like Instructables in order to document the projects”. The quotation is from one of the instructors at the Boot Camp commenting how documentation of a project could be conducted. Instructables (Instructables - Make, How To, and DIY, 2011) is an online tool for documenting and making DIY and other instructions.

The idea with using a Git archive is to have the documentation and files easy available without having the information hidden in XML-structures or in a database server. Using files in a file structure has the disadvantage that there is no design attached to it. The appearance of the HTML files will have an appearance of unformatted text unless the users spend time in formatting the text with HTML code.

The formatting of the content with HTML code gives also disadvantages. The content of the files will get overhead with the HTML-code, and are harder to read unless displayed in a web browser. A software tool was made in PHP in order to make the users able to make a design and navigation bar on their project files, and keep the
content free from HTML text. The tool was based on a model-view-controller pattern (Fowler, 2003). This prototype maintained the functionality of the Siteserver as all content files still were HTML-files, but it could be more difficult to browse the documentation of one project without reading the content through a web server and the functionality of the PHP-code.

The existing Siteserver has not any functionality for collaboration exceeding the capabilities of sharing files and content through the Git-archives and the content displayed through internet. Project plans or progress status of the projects have to be made in HTML or linked to report plans from other software.

A version of phpGroupWare (phpgroupware.org, 2010) was set up at the Fab Foundation server. This software has calendar functionality, can upload files and has functionality to make, assign, comment and finish work tasks. The graphical user interface is modern looking and intuitive. Even if these are some of the disadvantages with Siteserver, the phpGroupWare is not used.

4.3 Sharing knowledge

4.3.1 Fab lab knowledge base

4.3.1.1 Gained experience

The knowledge about the fab lab and the production is scattered on several web pages. Fab central (Fab Central, 2011) is the official CBA web page for the fab labs, and Fab Folk (Fab Folk, 2011) is one of the user made web pages. Knowledge about projects and production could be found on several other web pages. The Git-archives presented by Siteserver is another source of knowledge and a part of the Fab Central web page.

Fab Central contains a database of how to program electronic circuits or examples of CAD-code. There is not any webpage or knowledge base that is the universal fab lab web page to gather information from.

The information about events and ongoing work in the network is done through the newsletter "CBA News & Notes". The newsletter is published by e-mail from CBA.

There are a limited group of people in the network that serves as instructors and teachers for new labs and on the conferences, most of these are present or former CBA-students.
4.4 Education

4.4.1 Academic platform

4.4.1.1 Gained experience

4.4.1.1.1 The knowledge

The classes at the Boot Camp were mostly well prepared and resources were either handed out before or during the lesson. The knowledge was elsewhere available on several sites at the Siteserver network, but was not easy to find as the different lectures had different approaches to store the information.

The knowledge stored in the Siteserver software is easy to access even when being offline from internet, as the whole file structure is possible to copy to a local computer. All the web pages for the students and the stored lectures are available through browsing the folder structure, or by traversing files with plain HTML links in the stored documents.

Search functions in the users operating system will also make it easy to search for content in the files or file names offline, possibly easier than if the files and pages had been in a database structure. As the information is stored as files in a file structure there is no system or database to attach meta data as key words or subject area to the document and files, compared to the possibility of marking knowledge in a XML-based system according to a RDF system.

Courses are not connected to the students and there were no possibility to follow up the progress of the student work or the information they had perceived. This gave some problems with the progress of the courses for some of the students. Basic programming skills had to be learned in order to use the machines. Not learning these topics gave a limitation of what the students could do later on and what level they reached.

4.4.1.2 The students

The attendees at the course had various backgrounds spending from some knowledge of computers, to students already working with the topics covered. This had the advantage that the skilled students could help the less skilled students, but also tended to slow down the learning process for the other students.

The goal for the students was also ranging from creative people curious about the fab lab concept to coming managers or employees at fab labs. This compounded group of students made some of the lectures uninteresting to part of the students, but this was not a problem as students with less interest in how to manage a lab used the time to improve in other areas as milling 3D-objects.

4.4.1.3 The result and competence

The attendees at the Boot Camp were given no formal competence or papers. This was asked for by some of the students at the boot camp. Especially the students with no technological background or education
could benefit from having either a diploma or certificate from the education.

A basis in digital fabrication should be given during the Boot Camp and the personnel attending will be resources in their local communities. There was no examination or formal requirements for doing the Boot Camp and some of the attendees stayed only for a period of time. To formalize the education there is a need for documentation the work being done by the students.

The Boot Camp was successful as it was the first big training session held in the fab lab network and presented an education plan for how to educate people going to work in a fab lab. It networked a lot of skilled persons and gave benefits to the fab labs in this way, and valuable knowledge for later training sessions.

4.4.1.1.4  Education as an activity in the fab labs
The fab labs are suitable for education and the Boot Camp showed that the combination of machines available and technical competence needed to operate the machines gives the motivation and need for learning technology related theory. Discussions about having an education within the fab lab network discovered that education can possibly be a large part of the activities in a fab lab. The participants and discussions at the Boot Camp showed that education is not always available to people for reasons as distance from formal learning institutions, lack of money to pay a school for education or lacking formal competence to attend a school. The competence needed to run the education in a fab lab could be achieved by using different lecturers at different geographical locations through the world, and then both sharing knowledge and lectures between the labs.

4.4.1.1.5  Setup of a prototype learning management system
The discussions at the Boot Camp identified the need for having an automated management system for handling the students, their work and the content from the lessons. The work with laying the foundation for the Fab Academy started simultaneously. The lessons learned from the Boot Camp related to tracking the student work and administrating the students in relationship to having the various courses to end in a Diploma could be solved by having a web system. A learning management system is a system for administrating students and content and the progress of the students and their work.

The idea of having the possibility to have all content offline and not storing the information in a database, introduced a big issue, as commercial and open source software use a database as the platform of the software. In order to move ahead and test software, the Learning Management System Moodle (Moodle, 2011) was installed at the Fab Foundation Server. This software is database based, but has also the possibility of storing the lecture files in a file structure. The technical solution was set up at the Fab Foundation server, but the later implementation and development of how to use the Learning Management System was done by Fab Academy in Barcelona.
5 Discussion

This chapter includes discussion of possible solutions for the fab lab network related to processes [Figure 2 The processes in the fab lab network], a feasible roadmap for software usage and strategies for the implementation of this roadmap.

5.1 Design and production

5.1.1 Lab IT and networking

5.1.1.1 Possible solutions

5.1.1.1.1 Linux distribution
A special configuration of Linux with preinstalled software is a good idea. The challenge with such a solution is that the responsibility for the software updates must be ensured by someone. The organization has a lot of people supporting in their spare time, but this could often lead to work not being done on a regular basis. A solution like this will also need time for being installed, and obsolescence after a time will introduce installation or security problems.

5.1.1.1.2 Virtual machine
A solution with running virtual machines on the computers could be a better solution than making a special Linux distribution. This means that a snapshot of an installed operative system is saved and could be played in virtual machine software. This has the advantage that it is not dependent on which operative system or what sort of computer the virtual snapshot is being played at. There will also not being a need for an internet connection out of the snapshot, therefore not having the same challenges with security as an obsolete Linux distribution. The virtual image can be downloadable from a central website and/or distributed to other labs by the internet or on an external media for areas not having the necessary bandwidth.

Running a virtual machine can introduce hardware challenges with performance of the computers CPU or memory (Improve Virtual Machine Performance, 2009) as a virtual machine is running an operative system within another operative system. This may also add performance problems to demanding operations as 3D or video rendering. Problems with connecting the virtual machine with the physical I/O ports are also problems that are known for virtual machines. Problems with such a connection will have to be solved in order to use the CAM machines in the fab labs.

5.1.1.1.3 Deploying an image of the operative system and installed software
One machine at the different labs can be installed and an image of this installation copied to the other computers. The disadvantage with this is that this often requires that the computer’s hardware must be equal. It is not always possible to maintain a fleet of equal computers or this can be...
a cost driving factor for the labs. Making the configurations on the labs worldwide equal could be limited by the different labs needs for using their first language for the operative system. At other side; using a joint language can make exchange of information, online help through video conferencing and documentation of the work easier.

5.1.1.1.4 **File server**

The system with using a file server for storing files has the disadvantage that all information can be lost after a breakdown of the server. A backup system is therefore needed to maintain the data security. This will need an extra computer, external hard drive or equivalent. Users of the lab are not always well skilled with computers, and it could be a problem to convince them of why they should use the server instead of the local machines when saving their data. Each fab lab has to secure their administrative documents and files against data loss. To avoid liability issues it could be a good practice that the users of the fab lab are aware that they have to store their own files on own media or online collaboration tools.

5.1.1.1.5 **Management of the configuration**

Regardless of some of the other solutions are chosen, there should be a list of how the “fab lab setup” is done, and where to get the programs not being available from other open source websites. This gives users that want an adjustment of the installation enough knowledge and means to do this. The background for having this list is not that one or more persons shall decide what the other fab labs shall use, but recommend a configuration that could save time for the fab labs and ensure interoperability.

5.1.1.2 **Proposed structure**

A virtual machine implementation of software for local software at the fab labs will make the setup and maintainability of the fab lab computers easier [Figure 13 Overview of a roadmap for lab IT and networking]. Possible performance problems with performance the introduction of using virtual machine have to be examined.

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**Figure 13 Overview of a roadmap for lab IT and networking**
5.1.2 Computer-aided design, manufacturing and engineering

5.1.2.1 Possible solutions

The cad.py is used both for modeling electronic circuit boards and other construction related work. The Kokompe project (Kokompe, 2011) has been running since 2008 in order to establish software to succeed cad.py in the fab lab network. One of the big challenges with making a software for CAD/CAM/CAE is that the industry standard software vendors has invested years of competence and money in functions and the graphical user interface.

The goal of the Kokompe project has to be considered. It is an ambitious task to make a complete CAD/CAM/CAE-software with functionality ranging from design to machine interface. The resources of making and maintaining such software could take a lot of resources which could be used in other important areas of the fab lab concept.

Even if the development of a complete CAD/CAM/CAE-software was successful the user community has to be established and kept alive. For software as Blender (Blender, 2011) there are a lot of tutorials and user groups to get help and share knowledge. Without good user documentation and user groups it can be more difficult for the users at the different fab labs around the world to take the full advantage of the software capabilities. Other professionals use different tools for different tasks, and there will still be use of a palette of software for doing the CAD/CAM/CAE work (Gershenfeld, 2005).

Special tasks as advanced circuit board design could be done by a freeware version of software as Eagle (Eagle layout editor, 2011). This software can import models and technical details provided by the vendors of the electronic components, in order to be able to design advanced circuit boards with support of the software in the logical design.

From the discussions and experience at the Boot Camp these improvements could be the important to focus on:

5.1.2.1.1 Integration and support of the machines in the fab lab

For basic use of a fab lab, users should not have several software programs to deal with in order to perform a task as designing and printing a circuit board. E.g. one program to do the design, and having to perform a command line operation in order to send the design to the CAM equipment. The Kokompe software should have the necessary drivers and connections to all the machines in the fab lab. This means that having a basic user course in a fab lab could focus on using only the Kokompe software to demonstrate the advantages and possibilities of the Modela milling machine or using the laser cutter for a prototype test.

Introducing too many software programs in the early education at a fab lab could possibly confuse the student and take focus from the basic
skills to understand what a fab lab is and the potential of combining techniques at the different machines.

Understanding the concepts of possibilities of 2D and 3D design and transferring this to a physical model in the real world is important to understand the concept “How to make almost anything”.

5.1.2.1.2 A graphical user interface for basic use
Non-skilled users should have to possibility to drag and drop different objects when designing their first projects. For milling circuit boards this could mean having different IC’s and components as objects possible to drag and drop, for other design purposes a basic image editing capability with circles, rectangles and ellipses will be helpful.

This functionality has close connection to the integration and support of machines. An easy to use graphical user interface could facilitate the further interest of the students to learn more and dig into the functionality and concepts behind the graphical user interface. This could require more knowledge about mathematics and geometry and will not normally be suited for students in the phase of being introduced to the fab lab. The work of such students consists of 2D milling or cutting objects where the workpiece is machined from one axis.

The CAM machines which would benefit from a graphical user interface for basic use is the laser cutter and the Modela (Roland Modela, 2011). These are suited for introduction courses in a fab lab and they are low risk, low cost for use in training.

5.1.2.1.3 Support of a programming language for advanced use
The current cad.py has the advantage to support advanced users with a programming language to make design. This introduces the students to advanced use when they master the basic skills.

Designing in a programming language has advantages for the experienced user. Drawing a circle or a sphere with code is not only efficient for the user; it also gives a mathematical understanding. This mathematical understanding showed to be important at the fab lab. The design of a 3D-model at a computer screen will need to have a transformation to a 2D model in order to show the picture on the screen. For 3D operations at a fab lab which includes work at the workpiece from more than one axis, the 3D model has to be transformed. These are not suited operations for beginners in a fab lab, and experienced user will manage to do this more efficient with coding this in a programming language and get a preview of the model in a viewer.

The manual process of milling an object in different axis with tools like the one-axis tool Modela needs the knowledge of viewing and transforming the 3D-objects in different angles both on the mathematical model at the computer and for making the physical model at one of the machines.
An example of this could be the workflow for how to make a 3D object, make two casting moulds on the Modela milling machine and the final casting process to have a plastic 3D physical model. The casting process has some limitations, and the process of making of the moulds has to consider this. The user of the software has to understand how to project his 3D-model in order to obtain the right projection of his object.

Multi-angle design, milling and production could be easily implemented with obtaining software and machinery designed to perform these tasks. The idea with the fab lab is that even with small investments it shall be possible to perform these tasks manually. Having a programming language to support the workflow could give a better understanding of the concepts behind the 3D-production workflow.

5.1.2.1.4 Import and export of drawings and objects
Import and export of drawings and objects from other CAD/CAM/CAE-software has to be considered more in depth before planned and implemented.

A proposed solution is that the Kokompe software shall be able to import from one other software, as example Blender. The different conversions for many CAD-software could be time demanding and need more resources in order to be programmed.

The export and import features from different CAD-formats are implemented in the existing commercial or open source software packages. There is no need to duplicate this functionality in the Kokompe-software.

5.1.2.2 Proposed structure
Software functions for covering a complete CAD/CAM/CAE workflow are big software projects, not needed to be custom made for the fab labs. The basic functionality of making 2D/3D models and project these through an interface to the appropriate machine at the lab is a reachable goal for Kokompe software [5.1.2.1.1]. The software is developed in an initial version, still has to be developed in regards to the user interface.

The advanced CAD/CAM/CAE-work should be conducted in existing software designed for such work. Kokompe should have the possibility of importing the content from one or more of these software packages. Kokompe shall be a hub between the CAD/CAM/CAE-software in use and interface with the machines in the fab lab to produce the physical models.

An overview of which software the fab lab user can take use of in the design and engineering process and how the result of the design process is interfaced with the CAM machines is shown in Figure 14 [Figure 14 Interfaces for a fab lab user for the processes of CAD/CAE and CAM].
5.1.3 **Business platform**

5.1.3.1 **Possible solutions**

5.1.3.1.1 **Local adaptations**
Making a global business platform for fab labs in different parts of the world, with different needs will need local adaptation. The process of selling a product or a service has the same principles. The need of the buyer has to be fulfilled, and the fab lab has to get the agreed payment.

5.1.3.1.2 **The intention of a fab lab**
The economical sustainability question should be an issue in any commercial or non-commercial enterprise. But one issue should be taken into account regarding having a fab lab to be a factory for products; a fab lab is a creative arena for learning and development. The need of earning money could possibly choke the creative part of the activities of a fab lab.

The discussions at the Boot Camp introduced the idea of the fab lab being a sort of a public library – where the population could seek knowledge, learn and explore technology. A basic setup of a fab lab with a fab lab manager and an assistant as a minimum staff will have an expense of approximately 200,000 USD in US/West-European countries including cost for renting premises, electricity et cetera. This will require a funding each working day of 800 USD.

The machinery could be usable for production of small series of custom designed products. The disadvantage with such a production is that the small amount of produced articles needs a great amount of human labor even if the cost of the product could be higher than a serial produced product. The machinery is not built for serial production and could be
The combination of labor cost and machine cost could make it difficult to earn money on production.

5.1.3.2 Possible solutions

The outcome of a fab lab is not a product as in a manufacturing industry and it is not consultant hours as in a consultant company. The product is a creative network that is able to share knowledge. The knowledge can be used to small scale digital manufacturing and advising users of the fab lab in technology related questions.

As the product itself is unclear, the idea should not be what product or service to sell and how to sell it, but rather how to share the information about what products that can be sold, and how other fab labs are earning money and funding their business.

A video conference meeting was held during the Boot Camp in order to discuss approaches to a business platform and facilitate exchange of experience within this topic. The structured result of this cooperation and interchange of information could possibly be published on a portal online. To avoid too many portals this should be integrated on a central fab lab wiki. The main problem with the existing wikis in the fab lab network is the low amount of users and contributors. Reducing the amount of wikis and giving the users better training for how to access it and publish information can reduce this problem.

Amazon (Amazon, 2011) and eBay (eBay, 2011) are established market places on the Internet – even if a web shop is made within the fab lab system or at a single fab lab it will take a big effort in marketing to make this sales channel known to people. Personalized production could be a niche that is possible to utilize with the machinery at a fab lab. This means not necessary to sell or manufacture a product – but to personalize it, a semi personal fabrication (Gershenfeld, 2005).

5.1.3.3 Proposed structure

At this stage it is not advisable to conduct any work on a common business platform, before the actual need for this is further discussed. The experience in the different fab labs with approaches for running business at the fab lab [4.1.3.1], should be investigated, including partnership with other businesses for commercial use of the fab lab when it is not being used by other users.
5.2 Collaboration and communication

5.2.1 Video conferencing

5.2.1.1 Possible solutions
The main areas of improving the use of the video conference as a communication platform is to ease the access of the equipment, the way people connect and the cost of the technical solutions.

5.2.1.1.1 Level of use of the video conference
The users in the fab labs have different needs for communication in a video conference environment. Not all levels of video conferencing are suitable in all situations and a functional leveling of the video conferencing (Gough & Rosenfeld, 2006) is suitable to systematize the needs. This gives that it is not only one software application that is suited for all video conference needs.

5.2.1.1.2 What the systems should not do
The system for video conferencing in the network should not try to replace the use of mainly Windows Live Messenger (Live.com, 2011) or Skype (Skype, 2011) which are commonly used. These are well known applications which are updated, maintained and working properly for personal video conferencing.

A video conference system not supporting the H.323 protocol could cause compatibility issues and limit the possibility to connect to other video conference systems outside the fab lab network.

5.2.1.1.3 Cost of the video conference solution
Cost is a factor that is not irrelevant for an organization as a fab lab. Commercial video conferencing equipment could have an initial cost as well as a periodic license fee, support, upgrades et cetera. Neil Gershenfeld addressed that it should be possible to make a free video conference client for use in the fab lab network. The advantage of having a software client is that a computer and a standard web camera can be used. Such a camera can be bought for about 150 USD and is basically comparable to high end cameras at ten times the price related to the theoretical pixel count. However, for high bandwidth videoconferencing at large screens, characteristics as less lag, better low-level lighting and sharper optics will part the cheap cameras from the expensive ones. The low cost cameras have the image compression internally, losing the capability of raw/lossless data transfer and with generally poor compression quality compared to a video conferencing codec or with software compression at a computer. The use of non proprietary equipment for video conferencing gives in addition to the possible use of low cost equipment, also freedom of exchanging the equipment with low cost cameras if the hardware gets errors. This may avoid that a video conference system is unable to work because of problems funding repairs of it.

Even if there are commercial solutions available for non-proprietary use
of equipment, the license cost is an issue. Nefsis (Nefsis, 2011) is a multipoint video conference system from Cisco having monthly fees to be paid for licensing of a solution. Even if this sum is divided on the different fab labs, it will be uneasy for some of the fab labs to use this sum of money for software licenses, knowing that the income of a person in e.g. Ghana could be only a few USD a day (International Labour Organization, 2007).

The system should have the multipoint capability and give the user an easy access to toggle and display the participants in a conference. One of the limitations of the free versions of MSN and Skype is the lacking possibility multiperson connectivity. Skype has business or individual premium versions which are capable of conducting multipoint video conferences for a monthly fee.

The existing video conferencing solution with the hardware MCU fulfills the requirement for having a multipoint video conference. An open source software MCU is developed (H.323 Plus, 2011), but has not had recent release activities since June 2009. As long as there are funding for having hardware based MCU, no effort should be used in replacing this.

A client should be available to download free of use being able to connect to central MCU’s in the system or directly point to point. Basic functionality as video broadcasting and desktop sharing should be available. The client should automatically connect to the network of other clients in use in the network and the user be presented a map of the sites around in the world and click down to the user level.

Ekiga has the features to connect to a H.323 MCU, but lacks the possibility of sharing the desktop. Software for emulating a web camera and showing the desktop as a web camera could be used with Ekiga, but would introduce steps for participating in a video conference that is less user friendly than having this as functionality in the software. An alternative method is using e.g. VNC or other desktop sharing software in parallel.

5.2.1.1.4 Use of video conferencing in education

For lessons, courses and training in the labs the Polycom video conference equipment could be used as now. Adobe Connect (Adobe Connect, 2011) or the former open source Wimba and Elluminate (Wimba, 2011) are suited alternatives. An open source alternative for having lessons online has been developed, Big Blue Button. Big Blue Button is a virtual classroom with screen sharing, whiteboard, functionality for uploading presentations, video sharing, chat and audio capabilities (BigBlueButton, 2011).

Big Blue Button [Figure 15 Big Blue Button - Web conference for educational purposes] is a web conferencing system built especially for having lessons online. There is no need for special endpoint hardware beyond a normal computer and users with or without a web camera can participate. The students can interact through public and private chat,
and there is a “raise your hand” button to push when wanting attention from the presenter. This system has the analogy in the physical classroom and is better suited for education than the Polycom system that is primary a system to arrange meetings between video conference endpoints.

Figure 15 Big Blue Button - Web conference for educational purposes
(BigBlueButton, 2011)

5.2.1.1.5  Future improvements
The effort to program and maintain a separate system for the fab lab network may seem to be extravagant as long as there are already systems which provide this functionality. Even if a tailor made video conferencing software was developed, the fab lab network would not benefit from improvements in the other open source systems available. As an example could compatibility problems with the introduction of future operative systems cause the need for a patch or update to the system. With a commercial or a widespread open source system the fab lab network would not need to rely on one person or a small staff to perform the work.

The technology to support the video conferencing should be as transparent as possible to the user. Communication is the goal and the technology is the mean to perform it. Simplicity is a key, and the video conference system should be easy to use without a designated technician to set up, or connect at either side.

Another key issue is how to browse to the different sites and places with video conferencing capabilities and how to connect to these sites. A central and searchable list should be available in an application, giving the users the ability to share contact and availability information, ongoing projects and their knowledge area [Figure 16 Competence matrix requirements]. In this way it is possible to find the people you want, basically without knowing their competence and skills from before (Mistrík et al., 2010).
A calendar function should make it possible to book meetings and automatically send e-mails to the attendees with reminders of the meetings or updates. This could add extra functionality to the system and have the users to have one place to go to see which meetings they should attend. This extra functionality to connect the users, collect the contact information and location in the world and the scheduled meetings could be a front end to the three proposed combinations of video conferencing.

AccessGrid is a toolset for collaboration with 324 nodes in 31 countries (AccessGrid, 2011) and similar to the need of video conferencing capabilities in the fab labs. AccessGrid has made a list of all the nodes and a calendar function for the nodes (NCSA AGSchedule, 2011). This functionality would cover the need of the fab lab network except the knowledge matrix and the personal contact info. Until such functionality is made a combination of online tools as Doodle and Google Calendar could be used to schedule meetings.

As the difference in quality from the high end dedicated systems to the possibly low cost alternatives decreases, introducing higher bandwidth systems as Mc Gill Ultra-Videoconferencing software to the fab lab network may enhance the impact of video conferencing in the network. Meanwhile the high quality Polycom / MCU system existing today should be used for video conferences between the fab labs.

5.2.1.2 Proposed structure
A modified breakdown of the different types of video conferences (Gough & Rosenfeld, 2006) can be used to level the needs for video conference capabilities in the fab labs [Figure 17 Overview of a roadmap for video conferencing]. Three different software platforms can be used for the different requirements for communication.

Personal video conferencing
Skype is used in the fab lab network and has support for mostly any operating system and computer platforms. Skype covers the requirement to communicate one-to-one without the need of manual software setup.
or problems with traversing firewalls or other network related issues. This is the easy way of connection to a colleague. Skype has got functionality for desktop sharing, making Skype a good tool for collaboration.

*Fab lab high bandwidth video conferencing*

This is the primary video conference capability between fab labs on the H.323 protocol used today. The hub in the system is the MCU at MIT and the H.323 clients in the network connects to this. Hardware based clients can connect to MCU. The Ekiga client is an open source client and available for Linux and Windows and can also connect to the MCU. The primary goal using this solution is good quality and conducting meetings with many participants.

*Web conferencing*

Web conferencing will be used for educational purposes or even meetings. The complexity of a system like this makes it not feasible to develop this. Big Blue Button (BigBlueButton, 2011) is an open source project that can be connected to the Moodle Learning Management System (Moodle, 2011) and be set into production with low effort.

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**Figure 17 Overview of a roadmap for video conferencing**
5.2.2 Project management, distributed development collaboration

5.2.2.1 Possible solutions

The challenge with how to run projects in the fab lab network could have improvements with a software solution to support it. However, before a software system is introduced some considerations have to be taken into account.

5.2.2.1.1 Decide what is a project and what is individual work

The word project is used for tasks as building a circuit board with basic not advanced functionality. The name of the task should not be important, but there is a lacking consciousness about what should be worked with as an individual task. This gives no or little focus to what tasks should be worked with as projects, collaborating between people at different fab labs in several countries. One of the elements which are typical for a project is that the work to be done is unique. The uniqueness of a project could add the need to explore knowledge and new inventions to reach the goal of the project. Sometimes with scientific methods and sometimes with a practical approach. Processes like this may take days, months or years to perform; as bringing the first men to the moon during the 1960’s (National Aeronautics and Space Administration, April 1975).

The decision process when separating what is a task and what is a project can be supported of relating the decision to the characteristics of a project [2.2.2.1]. To perform a Work Breakdown Structure (WBS) of the work is another approach to this decision process. Such a process can be supported by a mind mapping tool as Freemind (Freemind, 2010) or project specific software as dotProject (dotProject.net, 2011).

Quality is seldom a result of coincidences; this also applies to how to work with a project. The complexity of the tasks to be performed would probably need a minimum of planning and a core group of people would need to follow up the progress of the work and point of the direction of the further work. To identify this need could be what separates a good idea from being realized.

The project or task performed by a single user could be called an unmanaged project to describe that this is not a task that needs a project organization. It is not possible or intended to disallow persons within the fab lab network to call their work a project. Some of these projects or individual task is stored in different fab wikis, giving easy access for all internet users. The long term project could be exciting to participate in, but from a pedagogic perspective there will be a need for students or visitors in a fab lab to be able to perform tasks with the machines and finish it the same hour or the same day. These tasks are important for the fab labs, because they are performed daily and give the users understanding of the machines and the processes in a fab lab.

5.2.2.1.2 How are the projects organized

The bottom up way of organizing the fab labs makes it difficult to make formal structures as a project would be organized in a commercial
organization. Work is mostly not paid by fab labs and there are few mechanisms that commit the project team to work. As there are no economical or other consequences if the projects don’t have progress, the project team must have another motivation to make progress.

5.2.2.1.3 How could the projects be organized

Within research and development it can feel difficult to make plans. The feeling of having freedom without tight boundaries can be a factor in creative work. However, without planning a project is more likely not to succeed. The projects in the fab lab network are not conducting best practices for project management and work [2.2.2.2]. This is making the project work inefficient and when even not the scope of the project is defined, nor the time when the undefined work shall finish; the result will not be able to evaluate. The fab lab network needs successful projects in order to be attractive for investors and governments in other areas than just being an expensive playground for use of rapid prototyping tools. The fab labs are still a new invention, but in five years they will have to prove their reason for existence. The technology in the fab labs is not advanced, it is not different and it is not special.

The fab lab network has to succeed in organizing multinational projects. Projects have to be accomplished and the network has to show the rest of the world that the fab labs are not only an expensive playground for having fun.

When developing practices for project work in the fab lab network, considerations related to who is going to use these practices has to be evaluated. Only deploying software tools will necessarily not change the habits of how projects are worked with. The fab lab network is attracting creative people and there are no economical resources to engage personnel only to work as project managers. A practice of project work has to be adapted to personnel in the fab labs.

In order to manage to come to this result a project group should be established to explore how to succeed in projects. This pilot project shall have the scope of making a “Guideline for project work in the fab lab network”. The project group has to be handpicked and represent the labs at the different continents. In order to succeed the participants have to commit themselves to a project plan and it is crucial that they have the motivation and resources to follow up the project plan. The project manager has to have leadership abilities and be willing to structure the work and explore principles and methodologies for project management.

The comparative chart between traditional and agile project management [Table 3 Comparative Chart - Traditional vs. Agile ] shows the differences between a traditional and an agile methodology for software development, such as eXtreme Programming or SCRUM (Hoda et al., 2008). These two principles of conducting projects should be considered especially for the fab labs projects in general, not only for software related projects. Categories like facilitating activity instead of managing the projects is in accordance with projects performed on a voluntary basis.
Table 3 Comparative Chart - Traditional vs. Agile (Hoda et al., 2008, p.219)

<table>
<thead>
<tr>
<th>Categories</th>
<th>Traditional</th>
<th>Agile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development model</td>
<td>Traditional Iterative</td>
<td>Iterative</td>
</tr>
<tr>
<td>Focus</td>
<td>Process</td>
<td>People</td>
</tr>
<tr>
<td>Management</td>
<td>Controlling</td>
<td>Facilitating</td>
</tr>
<tr>
<td>Customer involvement</td>
<td>Requirements gathering and</td>
<td>On-site and constantly</td>
</tr>
<tr>
<td></td>
<td>delivery phases</td>
<td>involved</td>
</tr>
<tr>
<td>Developers</td>
<td>Work individually within</td>
<td>Collaborative or in pairs</td>
</tr>
<tr>
<td></td>
<td>teams</td>
<td></td>
</tr>
<tr>
<td>Technology</td>
<td>Any</td>
<td>Mostly Object Oriented</td>
</tr>
<tr>
<td>Product Features</td>
<td>All included</td>
<td>Most important first</td>
</tr>
<tr>
<td>Testing</td>
<td>End of development cycle</td>
<td>Iterative and/or drives</td>
</tr>
<tr>
<td></td>
<td></td>
<td>code</td>
</tr>
<tr>
<td>Documentation</td>
<td>Thorough</td>
<td>Only when needed</td>
</tr>
</tbody>
</table>

Every meeting in the guideline project group shall have an item on the agenda about sharing experience and introduce improvements for both the project work and software tools to perform this work. The project manager shall have a particular responsibility to catch up the gained experiences and propose new methodologies of performing the project work.

The project group shall explore software tools for project work and the effect of this among the project participants. The experience of this shall be documented and included in the guidelines for project work.

The endeavor of this pilot project is not reached when the guidelines are finalized. The result of the identification of feasible project work approaches must be transferred to the rest of the fab lab network. This includes participating in workshops and conferences organized in the network and support of other project groups with implementing the experienced best practices for project work.

5.2.2.1.4 Special considerations related to collaboration

Siemens Corporate Research conducted a software engineering project called The Global Studio Project in 2004 to gather experience from distributed projects (Mistrik et al., 2010). The experiences from this project were:

- Extensive use of wikis and video conference
- Team building activities to create relationships
- Formal specifications
- Small teams on each location
- Long start up times affected by cultural differences as cultural driven working habits, timeliness, directness, friendliness, meeting processes and attention to details.
- Communication shifted from site-based to task-based throughout the project because of better knowledge on work and competence on the remote site.
These elements are all applicable for project work in the fab lab network, and should be considered when starting new projects.

5.2.2.1.5 Siteserver, collaboration- and project management tools
Siteserver has the basic features of saving text, documents and sharing this among the users. The graphical user interface is not modern looking, however possible to use. Siteserver does not invite the users accustomed to modern web applications to utilize it, but once learned it could do the work.

An alternative to Siteserver is using Dropbox (Dropbox, 2011) for document and file sharing, but the sharing of the documents outside the project group could be an issue. Google Docs (Google Docs, 2011) is another alternative for collaboration and provides file sharing as well as an online office suite. While Dropbox is suited for working online or offline with a virtual folder on a computer, Google Docs is best suited for working in a web interface. For archive purposes, finished projects should be transferred to the Siteserver repository.

The projects process in the fab lab network may not be ready for introducing collaborative project management tools [5.2.2.2.2]. For the more creative orientated members of the fab lab network experiences from GroupHub (GroupHub.org, 2011) should be explored to accelerate the interchange of creative ideas in the network. GroupHub is a creative design community much like the fab labs and organized by Creative Lancashire in Lancashire County, Great Britain (CreativeLancashire.org, 2011). Ideas are exchanged at the GroupHub web page and creative seminars are held with both individuals and businesses where “create, design and innovate” are the main objectives. This is more of a concept of how to collaborate which only uses software tools as a part of the concept. The limitation for the fab lab network is that the possibility of physical meetings is restricted by the distance between the fab labs.

5.2.2.1.6 Software for managing source code
Git has been used in the fab lab network as an overall revision system for all files using two Git repositories, Fab World and Fab Content. However the use and management of the Git files is only done by few users as the entry level for taking use of the Git repositories is considered to be difficult. Only a minor part of the two Git archives is containing source code.

In order to cultivate the source code approach for using Git archives, code projects should be extracted to isolated Git archives for the individual projects.

The term “Social Coding” has been introduced by tools as GitHub (GitHub, 2011). GitHub combines the version control capabilities of Git with functions in other collaborative project management software. Functions as collaboration and project tools, a wiki, issue tracking, and code review integrate hosting of Git repositories with the process of software development (GitHub, 2011).
Google Code is an alternative to using Git and GitHub. Google Code interfaces with the users with a similar system to the client server software CVS, Subversion (Apache Subversion, 2011). Window users can utilize e.g. a Subversion client as TortoiseCVS (TortoiseCVS, 2011) and several clients are available for other operating system. With the support of Mercurial (Mercurial SCM, 2011), Google Code has an alternative for distributed version control as in GitHub.

In the same way as GitHub, Launchpad (Launchpad.net, 2011) is a collaboration platform much like GitHub. Launchpad provides in general the same functions as GitHub regarding code hosting, bug tracking and code reviews. Launchpad uses the version control system Bazaar. Bazaar is a hybrid of a distributed and a client server version control system and has the capability of operating in both modes (Bazaar.canonical.com, 2011).

As Git is already in use in the fab lab network the possibility of using GitHub should be explored within a software project, e.g. for one of the proposals in this report which needs development of bespoke or adapted software. Code review and collaboration can take advantage of having a supporting system as GitHub. It will be easier to make the software projects visible as separate repositories at GitHub compared to having the source code within one of the two existing fab lab Git repositories.

### 5.2.2.2 Proposed structure

#### 5.2.2.2.1 Unmanaged projects

The basic need for presentation of tasks performed by users could be implemented by using open-source wiki software to store and present projects [Figure 19 Overview of a roadmap for project management, distributed development and collaboration]. This kind of presentation is already in use in the fab lab network, but fragmented on several web sites. This information is the knowledge of how to use a fab lab and what it is possible to do with the technology present. The main reason for using a wiki tool is that it is well known, easy to use and navigate.

The value of the wiki will be increased as more content is added to the database and the users worldwide should be encouraged to use common wiki in order to have one place to go to search for information. As more projects and tasks are added, the idea of having a group of people to supervise the structure of the wiki could be essential to make the best value of the information.

The offline functionality is not impossible, but also not easy with a wiki tool. The data is usually stored in a database and this database itself will have to be copied or exported. For use in areas without an internet connection an offline version of the wiki can be distributed (Arunachalam, 2006). This will ensure the idea of having the information decentralized for those locations.
As for February 2011 Sherry Lassiter at CBA informs that the fab lab in Ghana still lacks internet connection. Most of the African and Indian labs have poor or irregular internet connection, including Pabal, Soshanguve, Kisumu, COEP in Pune and the fab lab in Delhi.

Tom Okite, the manager of Aro Fab Lab in Nyanza, Kisumu has tried to share the costs of an internet connection with other users in the area: “We wanted to start a project of connecting the nearby schools and colleges to the net at a fee to help us pay this amount, and opening cyber cafes for many people to get access to a pay internet.”

MIT has paid for this connection for a test period, but the project has met resistance from the ISP’s, according to Sherry Lassiter: «We enabled this connection in order to see if the FabFi project could be implemented there, and whether or not there was a sustainable business model that could be developed (two or three tiered bandwidth access, low bandwidth free for everyone, then paying clients) (...) «They couldn't even do videoconference.»

As for the Aro Fab Lab, MIT has paid the internet line with the price of approximately 2000 USD a month. Even with this cost, the performance of the internet connection is limited.

The cost of an internet connection is many times the salary of an engineer in such an area, an economical sustainable business model is difficult to achieve with this level of cost. Until the cost of the internet connection has decreased, the only sustainable way to operate a fab lab in such areas is with offline solutions.

Kiwix is software that makes it possible to read web content offline and suited for wiki’s (Kiwix, 2011). The challenge with an offline approach like this is that the snapshots of the wiki will need to be updated.

Figure 18 Open Workbench screenshot (Open Workbench - Softonic.com, 2011)
5.2.2.2 Managed projects

The managed projects will be projects running over time, and with a project team working with the project. The proposal is to find a pilot project and have documentation and collaboration as a secondary goal for the project. The existing Siteserver could be used for storing files and reports.

The need of software to plan and follow up the project is dependent of the art of the project and the project group. Open Workbench (Open Workbench - SourceForge.net, 2011) is an open source alternative to Microsoft Project. Open Workbench gives the possibility to make Gantt-charts and follow the project progress [Figure 18 Open Workbench screenshot ]. The drawback of using software in the Microsoft Project-family is that all the users will have to have the software or a viewer installed to watch the plan, unless the plan is exported to PDF or an image format when changes are made. In small projects the plan could be visualized well even in a spreadsheet or a simple table in a document.

Special collaborative software as phpGroupWare is not advised at this stage, as one new system to learn, manage and maintain knowledge of. It is better to use the resources for managing the pilot project and describe what requirements the existing system with Siteserver does not cover in order to support collaboration. The principles of phpGroupWare should be examined during this work.

The main issue with projects in the fab lab network seems to be how the projects are organized and conducted. A software tool to support projects should be based on needs from the projects. Projects ran in the fab lab system are not theoretical different from how other corporate projects are conducted and if another system than the Siteserver should be used, there are no need to have a custom made project management software. PhpGroupWare or equivalent will fulfill the requirements as support software for project work.

The experiences from The Global Studio Project in Siemens (Mistrik et al., 2010) should be considered. Especially use of video conference and a wiki to make personal relations between the team members.

In order to support the sharing between fab labs and projects, a design principle is that all information shall be stored in a shared environment. Information should only be stored locally or separate when security or intellectual property rights (IPR) are in concern.
Figure 19 Overview of a roadmap for project management, distributed development and collaboration

5.3 Sharing knowledge

5.3.1 Fab lab knowledge base

5.3.1.1 Possible solutions

5.3.1.1.1 Fab lab wiki
A common fab lab wiki is discussed in 5.2.2.2 as a tool for collaboration. The technology of setting up a wiki software tool is not complicated, and wiki tools are freely available. A common wiki is not only important for collaboration in running activities. This is also important as a public showroom of the fab labs and the activity.

The challenge is the implementing of the wiki as not only a tool for knowledge sharing, but being the tool for knowledge sharing. In this way more knowledge could be available in one wiki.

5.3.1.1.2 Newsletter
The newsletter comes on every second month, but is dependent on resources at CBA to collect and edit the content. As much of the information and knowledge exchange is in between the people in the fab lab network, the CBA editor has not access to all the events in the network. The newsletter is manually edited and relevant for the fab lab network.
5.3.1.1.3 Alternatives to the newsletter

The fab lab users contribute with knowledge and information every day on the different web pages in the network. This publication is limited to the readers of these pages.

An approach for an e-mail newsletter is building an automatic newsletter from the contributions on the different web pages. The disadvantage with this is that the lack of editing would dilute the existing newsletter. The contributions from persons unknown from the reader can make the content be understood as unreliable (Szulanski, 1996) and the newsletters are perceived as spam mail.

Sharing information and knowledge could make the user fear losing ownership, position, take too much time or the user does not feel that the investment in sharing is rewarded (Szulanski, 1996). These elements also exist in the fab lab network and together with the different labs need of having an identity; the knowledge is spread and duplicated on several web pages.

There has to be one central hub of posting news, knowledge and general information from the contributors in the network, still maintaining the local ownership of the content. A technology for conducting this is using a web feed format as Really Simple Syndication (Mishra, 2011). A design for implementing RSS is that the different fab labs or personal contributors maintains a RSS feed for own publishing, and a central RSS-feed combines this feed in one or several category based feeds. With this design the contributors can decide what information they post to the feed and for what information the reader has to navigate and visit their web page for. In this way the newsletter can keep the position as the formal information channel, while the RSS feed takes care of the day to day events and information sharing [Figure 20 Communicating events and news in the fab lab network]. The different fab lab web pages should have the RSS-feed on their front page to show news and updates from the other labs.

Figure 20 Communicating events and news in the fab lab network
5.3.1.1.4  Important people for sharing knowledge
The growth and widespread of the fab lab idea has been dependent on central people origination at CBA. These are the people that has designed the fab lab concept and conducted research within the scientific domains related to the fab lab. Seen as one virtual organization, the fab lab network has been dependent on these gatekeepers of knowledge (Allen & Cohen, 1966) for establishing the network.

A gatekeeper is an extrovert person, who makes relationships with others, collects information and translates the knowledge for use in the organization. Even with the introduction of the internet and new ways of communicating, research proves that the need of these gatekeepers is still there to filter the information (Eoin Whelan, 2010).

The gatekeeper is a person compounded from both personal characteristics, practice in the fab labs and interests. Zhuk (Zhuk, 2004, p.1) mentions the technology that tends to fragment and omits the glue. Enhancing the knowledge transfer in the fab lab network could also omit the glue. The facilitation of knowledge transfer is not only dependent of the software tools available, and the people in the fab lab network have to be aware of the importance of the knowledge gatekeepers.

Figure 21 The importance of gatekeepers in the network
The gatekeeper theory is of importance for several reasons in the fab lab network [Figure 21 The importance of gatekeepers in the network]:

- Seen as an organization, the fab lab network is dependent on those people to introduce new technology, external contacts and knowledge into the network.
- Seen as an organization of organizations, the different fab labs needs to have one or more gatekeepers to keep the lab running and renewing. This includes keeping in contact with other labs, participating on fab lab conferences, being a facilitator and a resource at the local lab. This seems to have been a success factor for the fab labs which has stable activity for several years.
- Even with all information and knowledge online, well structured and understandable; the gatekeeper is of importance for realizing this knowledge into activity at the fab labs.

5.3.1.2 Proposed structure

The knowledge in the network has to be available on a common platform, proposed on a wiki tool. The information exchange between the fab labs about ongoing projects and activities is advised to take use of RSS-feeds.

The facilitation of knowledge sharing is dependent of the gatekeepers in the network. The gatekeeper function can be formalized as the appointment of one person at each fab lab with this responsibility, an information coordinator. The formalization can give a better understanding of the importance of this function and the information coordinators can form a network. The possible drawback is the filter effect if this person is not suited for the role. Instead of filtering the information, the role itself can be a filter against getting information in the fab labs.

5.4 Education

5.4.1 Academic platform

5.4.1.1 Possible solutions

5.4.1.1.1 The organization

MIT has through the course "How to make almost anything" taught students how to use programs and software through both lectures and lab work at MIT. The students from this course have worked worldwide to train personnel at the different labs. This approach was not sustainable as this required the MIT students and staff to feed the growing network with education and training, not being their primary role.

The plans for establishing an academy for the education in digital fabrication has evolved and the first test of educations started in 2008 and the courses in digital fabrication are now being held with base in Barcelona. The idea was to have the academy decentralized with
professors and teachers making lessons through video conference from all over the world, and this has proven to be successful.

5.4.1.1.2 The software

Such an education needs a system for both maintaining the students, their work and grades, in addition to organizing the resources for the courses so the students easy can find the needed resources for their course.

Professor Gershenfeld wanted to have a system where the resources are available for the students anywhere, independent from having an internet connection available. There are several issues to be solved for making an offline Learning Management System.

First of all is the complexity of a Learning Management System. Handling of student information and their results, connected to the lecture content, applications and examination results introduces administrative work. This is also information that should not be open to everyone and basically has no value for other than the academy staff. Several commercial applications are available as Fronter (Fronter - Learning Together, 2011) or Sharepoint LMS (Sharepoint 2010, 2010).

Having an offline system will also have a need for software installed on the client computers of the students, which could introduce problems with running the content on different operating system platforms.

Figure 22 Overview of a roadmap for an academic platform
5.4.1.1.3 Current status of the academic platform

Fab Academy has launched and set up a Moodle Learning Management System on servers in Barcelona to serve as a portal for Fab Academy. This platform consists of lessons and theory documents belonging to the lessons.

The lessons itself are performed by video conference and stored for later review. Some of the content and information of the lessons are stored at Site Server on CBA, some in the learning management system and the video stream for the lessons on a media server.

5.4.1.1.4 Improvements of the current system

The lessons and information connected to lessons are only partially possible to have distributed the way they are currently stored. Instead of adapting the Learning Management System to such an approach the responsible for the course can plan to make a distributed version of the course in parallel with the course files and video. The distributed version of the course would require large disk space because of the video content. A separate Git-archive should be made for course content to isolate the courses from the rest of the Git-files in use. Students with only occasional access to an internet connection could then synchronize to another Git-archive when having an internet connection and be able to work offline. Applications could still be delivered to the Learning Management System when online and the administration of the students should not need to be distributed.

Moodle or other open source Learning Management Systems are good to serve as a platform to publish and collect information related to the courses, but could also limit the access to the information as a login could be necessary to reach the content and information.

The courses will have the full value when the video from the lessons are connected to the text content and reports from the student projects performed during the course. This will make a joint course packet with value even when the course has ended. Big Blue Button has been introduced as a virtual classroom with an interface to Moodle, and can used either as a virtual classroom [5.2.1.1.4] or for other collaboration activities.

5.4.1.2 Proposed structure

To duplicate and reprogram the functionality of a Learning Management System would take huge resources and focus from running Fab Academy. Moodle is also being used by universities and educational organizations worldwide and has user forums and support free of charge this way. The software is also updated regularly with both functionality improvements and security patches. Moodle should be used together with the virtual classroom Big Blue Button in order to make a course packet with both video and resources from the Learning Management System [Figure 22 Overview of a roadmap for an academic platform].
5.5 Development of software

5.5.1 Custom made or using available software
An approach for implementing software could be using commercial off the shelf (COTS) products, open source or custom made, bespoke. COTS software has advantages (Voas, 1998) as: Immediate access to the software, lower price or free and the software is developed by an expert in the field. The disadvantage with COTS could be that it is not covering the exact needs, has too much functionality or could have problem with being supported in the total period the customer needs it. If there is a need to have control over the complete functionality and the source code is not available, this could also be an argument for making bespoke software. If it is not resources or competence to maintain bespoke software, this is an argument against having bespoke hardware.

For the fab lab network the resources has been limited to develop software, and there are none of the software packages proposed in this report which is business critical related to end of the support from the development team. Most of the requirements for software could be found in different existing open source solutions.

5.5.1 Distributed storage of data
What is the real impact on the fab lab network with not having the capability to have all data offline and distributed data storage?

The idea is good. However, such a strategy limits the available software which can be used. Projects in the fab lab network are more likely to be design of products than programming, and the need of CVS functionality in Git should be considered. Even with an offline system as the Git Siteserver combination, people store and edit their project files on their own computers.

5.5.2 A possible strategy for software
5.5.2.1 Take use of existing open source software and web applications online
The development of the software roadmap for the fab labs has one big challenge; the engagement in the activities is either a part time employment or as a part of studies or other work at the fab labs. There are a core amount of people that has worked with the fab labs for several years, but mostly on the creative side. This point to that it could be difficult to run development projects to make and maintain software in the organization and that reuse of existing solutions would be preferable.

Google Docs, Dropbox and other collaboration software are free and easy accessible online. If the software requires payment in the future it will most likely be possible to move the data and find equivalent and free software. An export strategy needs to be in place in order to support the migration of the data if it is decided to discontinue one of the services in use. This strategy must at least include how the data is moved.
and a plan for how the users shall be noticed and ready to work on the new software platform.

This will give fast access to the software without the lead time of the software development and the need of man power to do the job with programming

5.5.2.2 Find solutions for the users without regular internet connection only when it is necessary

The basic idea that all information and knowledge should be able to have distributed makes some challenges related to using software and software concepts already existing both commercial and open source. Distributed information means that there shall be no dependency of a central hub to store the information, and possible to have the information available regardless of having an internet connection available. Most web infrastructure is based on one or more servers with the content and logics to present and administrate the content. Having the content disconnected from the web applications would need the information to be well structured in an offline solution, still losing the functionality of the control software. The benefits an offline system can give to the few, when they are without an internet connection, are possibly degrading the functionality for having progress among the rest of the users. Only when there is a need to have files or systems available offline, a concept to support this should be made.

5.5.2.3 Establish a group which is responsible for the software tools

Like an open source network; the fab lab network is dependent of having a core of people contributing to take the idea one step further regarding the software in use to support the fab labs. The fab lab network is crowded with skilled people. However, it is required to have a group working with the development of these tools.

Fab Foundation could be a natural hub in order to recommend software and be in lead where software development is necessary. The fab lab network is about sharing information and knowledge, and having the tools to interconnect and sharing this knowledge is essential to make the network grow.

5.5.1 Plan for implementing the software tools

5.5.1.1 Discovered needs of software

The requirements for software discovered within this report are summarized in eleven software tools [Figure 25 Plan for a roadmap for the software tools]. The tools will come in addition or replacing the existing software tools in use.

It is not advisable to do any software implementation for a business platform before the fab lab network has discussed the actual requirements for common software in depth.
5.5.1.2 Priority of the software tools

It is required to prioritize the implementation of the required software tools. An overall priority [Table 4 Priority matrix evaluation for software tools] is made according to a 2x2 matrix to decide the order of the implementations (Lowy & Hood, 2004). The recommendation is made on the basis of performing the high impact, low effort software implementations first [Figure 23 The Action Priority Matrix]. These software tools will be possible to implement with low effort and minimal software development and still have a high impact on the fab lab network.

![Figure 23 The Action Priority Matrix (The Action Priority Matrix, 2011)](image)

The different software tools are given points from 0 – 100 in impact. High impact is a preferable characteristic for a software tool and 100 equals to high impact. Low impact gives 0 points.

Table 4 Priority matrix evaluation for software tools

<table>
<thead>
<tr>
<th>Software Tool</th>
<th>Impact</th>
<th>Effort</th>
<th>Sum</th>
<th>Priority</th>
<th>Quadrant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporary scheduling system [5.2.1.1.5]</td>
<td>95</td>
<td>90</td>
<td>185</td>
<td>1</td>
<td>&quot;Quick Wins&quot;</td>
</tr>
<tr>
<td>Online knowledge matrix [5.2.1.1.5]</td>
<td>90</td>
<td>80</td>
<td>170</td>
<td>2</td>
<td>&quot;Quick Wins&quot;</td>
</tr>
<tr>
<td>Common fab lab wiki [5.3.1.1.1]</td>
<td>90</td>
<td>70</td>
<td>160</td>
<td>3</td>
<td>&quot;Quick Wins&quot;</td>
</tr>
<tr>
<td>Big Blue Button server [5.2.1.2]</td>
<td>80</td>
<td>70</td>
<td>150</td>
<td>4</td>
<td>&quot;Quick Wins&quot;</td>
</tr>
<tr>
<td>Implement RSS feed [5.3.1.1.3]</td>
<td>70</td>
<td>70</td>
<td>140</td>
<td>5</td>
<td>&quot;Quick Wins&quot;</td>
</tr>
<tr>
<td>Connect Moodle and Big Blue Button [5.2.1.2]</td>
<td>70</td>
<td>60</td>
<td>130</td>
<td>6</td>
<td>&quot;Quick Wins&quot;</td>
</tr>
<tr>
<td>Virtual fab lab computer [5.1.1.2]</td>
<td>60</td>
<td>60</td>
<td>120</td>
<td>7</td>
<td>&quot;Quick Wins&quot;</td>
</tr>
<tr>
<td>Implement new version of Kokompe [5.1.2.2]</td>
<td>80</td>
<td>30</td>
<td>110</td>
<td>8</td>
<td>&quot;Major Projects&quot;</td>
</tr>
<tr>
<td>Front end for H.323 [5.2.1.1.5]</td>
<td>60</td>
<td>40</td>
<td>100</td>
<td>9</td>
<td>&quot;Major Projects&quot;</td>
</tr>
<tr>
<td>Recording of video in Big Blue Button [5.4.1.1.4]</td>
<td>30</td>
<td>60</td>
<td>90</td>
<td>10</td>
<td>&quot;Fill Ins&quot;</td>
</tr>
<tr>
<td>Offline viewing of the fab lab wiki [5.2.2.2.1]</td>
<td>10</td>
<td>60</td>
<td>70</td>
<td>11</td>
<td>&quot;Fill Ins&quot;</td>
</tr>
</tbody>
</table>
Low effort to implement the software is a preferable characteristic and effort is given from 100 – 0 points. Low effort equals to 100 points, while high effort is given 0 points.

The “Quick Wins” are identified first. The internal order of the priorities is done by ranking the sum of impact and effort for the individual tools. Only ranking the tools by the sum of impact and effort would make no sense without regards to which quadrant they are belonging, as the sum of impact and effort may refer to results in different quadrants.

Figure 24 Software tools visualized in the Action Priority Matrix

5.5.1.3 “Quick Wins” within a year
The “Quick Wins” are implementations which can be done within a year and have high impact and require low effort to perform. E.g. take use of existing free available software or implementations with a minimum of development.

5.5.1.4 “Major Projects” and “Fill Ins” within three years
The rest of the software tools are within “Major Projects” and “Fill Ins”. To succeed with the “Major Projects”, long time planning is essential and these are given priority over the “Fill Ins”. The tools within “Major Projects” and “Fill Ins” are internally prioritized by ranking sum of impact and effort. The “Fill Ins” are software tools which easily can be given a higher priority if needed, e.g. the tool for offline viewing of wikis.
5.5.1.5 Comments to the priorities
The actual order of implementation of the software can deviate from this priority, as the access to developers with the right knowledge may be restricted to certain areas of the priorities.

Priority 1: The requirement of having a system for scheduling of meetings can be met with free available software on the internet [5.2.1.1.5]. This gives a high immediate effect and is a low effort task to perform.

Priority 2: An online knowledge matrix [5.2.1.1.5] can be as simple as a table online with names and knowledge areas and contact information. The effect is high and a temporary version of such a matrix can be done with low effort.

Priority 3: A common fab lab wiki [5.3.1.1.1] could take use of one of the existing wikis in the network. However, the users have to be introduced to this wiki, and adapt it as the fab lab wiki. The impact is high for knowledge exchange, but the introduction to the users will require time and effort beyond the software implementation.

Priority 4: A Big Blue Button server will need hardware and sufficient internet connection to run [5.2.1.2]. The impact is high as this can be a platform for both meetings and education. The installation itself requires low effort as the software is distributed as a virtual machine image.

Priority 5: Implementation of RSS-feeds for distribution of news and events requires both a central work to be conducted, as well as implementation on the different fab lab web pages [5.3.1.1.3]. This item is giving a high impact on the information flows between the fab labs and can be done with low effort.

Priority 6: It is important that the video conferencing system used in education is integrated with the Learning Management System in use [5.2.1.2]. Plug-ins for this functionality exists but has to be installed and tested.

Priority 7: A virtual fab lab computer will make the software management on the labs easier than manual set up of the software [5.1.1.2]. A virtual computer will require testing in order to verify that all machine interfaces works in a virtual environment. The effort to make a virtual fab lab computer requires more work than the higher prioritized tasks, and the impact to the fab labs is limited as this tool is not giving any new functionality to the users than easier system administration.

Priority 8: A new version of Kokompe will require extensive effort in software development and is not achievable in one year. The possible impact of this is high, as the improvement of this software can decrease the level of knowledge needed to operate a fab lab [5.1.2.2].

Priority 9: A front end [5.2.1.1.5] for H.323 video conferencing requires high effort in software development and is partly covered by temporary solution in priority 1 and 2.
Nevertheless, the impact is medium to high as this can bridge calendar and video conferencing functionality.

**Priority 10:** Work is in progress within the Big Blue Button project for recording of lectures [5.4.1.1.4]. Until this is achieved, the fab lab network can continue to use existing solutions for recording in Fab Academy, the impact of the action is interchange of two similar services. Postponing this activity is possibly making this implementation easier as the Big Blue Button project will be developed in the mean time.

**Priority 11:** As long as there is no demand for an offline wiki this is a low impact, medium effort task and should have low priority. If an implementation of a common fab lab wiki is successful, the impact of having offline capabilities for the wiki may increase and possibly force the implementation of this tool [5.2.2.2.1]. The software effort to have this functionality is not advanced. Administrative routines for distribution and version control of the content can be an issue. A possible solution is that an export of the fab wiki is included in the fab Git-archives. The reason for why this is a prioritized software to develop is the importance of having access to the information even for the fab labs without an internet connection. The existing solution with Siteserver supports sharing information to these labs, and an approach of using a common wiki should also support sharing information with these labs if requested.

5.5.1.6 **Impact on knowledge sharing**

The “Quick Wins” for knowledge sharing are the establishment of a knowledge matrix in order to connect people throughout the network, establishing information feeds to give users in the network an overview of ongoing activities and collecting information in one central fab lab wiki.

A web video conferencing solution as Big Blue Button connected to the Learning Management System can further facilitate meetings and education to transform the shared information to knowledge.

5.5.1.7 **Impact on making the fab labs economical sustainable**

Even if the fab lab network has existed for some years, there are problems defining the commercial aspects of a fab lab. Parts of the fab lab activity can be classified as hobby activities with advanced machines. This is a part of learning techniques and the machines; however, the network of fab labs has capabilities of conducting projects that can make a difference for people and further on create income for the labs. E.g. the work with the Internet 0 project in Kenya for making access to computers and inexpensive internet connection available [5.2.2.2.1].

To raise the level of work from what shows signs of hobby activities to multi fab lab projects needs at least that project activities are worked with as projects. As proposed, having a system to schedule meetings, a
wiki tool for documentation and easy accessible video conferencing solutions is important (Mistrík et al., 2010).

The proposed software tools will not make the fab labs economical sustainable itself. Having fab labs as only a playground for leisure is not economical sustainable. The users and managers of the labs have to focus on using the concept in such activities which can generate income.

**Figure 25 Plan for a roadmap for the software tools**
5.5.1.8 **Impact on collaboration with students and universities**

Fab labs should be interesting collaboration partners for students and universities. Some of the fab labs are already part of a university structure and well known within their organization. The Big Blue Button virtual classroom can be a gateway for further collaboration with universities. Technology and design students can follow introductory courses in digital fabrication and then visit the fab lab for practice on the machines. Such use of the fab lab is in itself interesting and students with an academic approach can possibly contribute to establishing development projects within the fab lab boundary and run these as a part of their education.

5.5.1.9 **Cost and resource requirements**

The recommendation is based on using free available software where available and development of bespoke software for special software requirements. Some hardware costs may apply to run the software. The cost for the development and implementation is mainly man hours. However, the man hours are still a limiting factor in the fab lab network. Another issue is if the competence is at all available in the network, and if available, the probability to keep these resources available to maintain the system in a running phase should be considered.
Conclusion and further work

This chapter summarizes the findings and recommendations in this report and proposals for further work are described.

6.1 Recommendation and conclusion

6.1.1 General

This report has made a study of the software tools in order to support the processes in the fab lab network. The network of fab labs as an organization could be called a knowledge system for creation, storage, transfer and application of knowledge (Alavi & Leidner, 1999).

The proposal for a roadmap for software in the network [Figure 25 Plan for a roadmap for the software tools] will support the work processes internally, between the fab labs and to the outside world. The planned priority of implementation of these software tools is based on solving the “Quick Wins” first. The “Quick Wins” are distinguished by giving high impact and with the need of low effort to be performed.

The technology in the roadmap shall support the overall requirements for communication and documentation in the network. The four processes in the fab lab network; design and production, collaboration and communication, sharing knowledge and education are all subparts of either or both communication and documentation.

The organizing of the fab lab network is dependent of having working communication and documentation. The process which facilitates the development of the interaction between the technology, communication, documentation and the organization is essential for having a successful implementation of the software roadmap, as well as the development of the fab lab network itself. The interaction and dependencies of these five elements for development of the fab lab network are illustrated in Figure 26 [Figure 26 The process of developing the fab lab network]. Each of the five elements is described below.

6.1.1 Process

The process is an iterative and infinite task with the purpose of improving the organization, the technology and to support communication and documentation.

The fab lab network has to further develop how to work with projects related to creating economical income and managing how to complete projects and ideas. Parts of the activities in the fab labs can be
considered as hobby activities. In order to be economical sustainable the fab lab network has to cultivate the ideas which are capable of living both in regards to economy and feasibility. Software tools and collaboration tools are not the only solutions for this challenge. It is recommended to conduct a pilot project for exploration of methods for organizing, use of software and the process of managing projects. This study can assist in finding a feasible model of working with the multinational projects.

Figure 26 The process of developing the fab lab network

6.1.1 Organization
The informal coupling of the fab labs is not supporting an idea of conducting multi lab projects. There has to be an organizing and commitment which supports bringing the ideas and projects further on. A cultivation of which projects is feasible and possible to work with will in addition require the organization handling to refuse a project, managing to handle the lack of progress or the termination of a project.

The responsibility for the software tools in the fab lab network should be assigned to a formalized group. This work is too complex without having a core group to conduct it. Advices to the rest of the network when changes in the infrastructure are needed or wanted can be made by this group.

A successful implementation of the software roadmap is still requiring the facilitators, the gatekeepers of knowledge in the fab lab network, for developing the collaboration in the network. Attention should be made to this role and the importance of it.
6.1.1 Documentation

Documented information is spread through different platforms and different web pages in the fab lab network. There has to be one central hub for the information in order to take advantage of all the contributors’ knowledge and to make this available for other users in the fab lab network.

The documentation itself is important to communicate with the outside world, both as courses within an academy boundary or as a searchable knowledge base online. Collaboration with schools and universities can be a way of giving proof of the need for a fab lab to other granting authorities or organizations.

6.1.1 Communication

The sharing of information on a central platform will enhance the collaboration between the labs as the information of the ongoing projects in one lab will be available for other labs. The communication tools must support an easy way of contacting people in the network, and provide information on both who to contact and the availability of the person.

A video conferencing concept which has a low user level and is possible to connect from a personal computer is important in order to improve communication and collaboration. It is proposed to take use of the open source project Big Blue Button as a web conferencing concept both for conducting meetings and as a virtual classroom.

6.1.2 Technology

It is not recommended to develop bespoke software in the fab lab network for functions which can be covered by open source or free available software. The probability of problems with lack of resources for development and maintaining the software has to be compared with the benefits bespoke software possibly may give. Even if open source software also have dues in terms of development and maintenance, the potential migration of data to an alternative open source platform is less demanding in terms of resources for the fab lab network compared to maintaining bespoke software and the competency on these tools.

The fab lab network must take use of available online tools as wikis or when needed, collaborative project management software for documenting projects and knowledge. This is necessary even if this does not support a distributed approach of handling the information. A categorically attitude towards distributed software may possible delay or block the introduction of software which can increase the information flow in the network. The need of sharing information with fab labs without internet connection is possible to fulfill without organizing the information distributed by default.
6.2 Further work

"Now, this is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning" (Churchill 1942).

The proposed further work beyond this recommendation is focused on the effects of the software roadmap and how to structure the information transferred by the tools in the software roadmap.

6.2.1 Measure the effect of the tools in the software roadmap

The work processes before and after the implementation of the tools in the software roadmap presented in this thesis can be evaluated to examine the effect these tools have on the network. The measurement can be both qualitative, e.g. surveys on how inter fab lab projects are running, or quantitative, e.g. amount of information stored in an information database after a certain time.

6.2.1 Benchmark the fab lab network against similar organizations

This report has analyzed the processes and internal information flow in the fab lab network. A study could be conducted to benchmark the fab lab network against other similar organizations, e.g. development aid organizations. The possible outcome of such a benchmarking can be an analysis of which processes and software which is contributing to a best practice for information flow and collaboration. These results can be shared with other organizations and be useful not only for the fab lab network internally.

6.2.1 Examine the possibility of standardizing information objects

The need of having a common platform for knowledge exchange in the fab lab network is one of the findings in this report. The format of the information objects stored in this platform is not decided. Research can be conducted to develop a RDF or XML-schema to describe a project or an information object. E.g. how a project from project idea, to project plan and documentation can be described in a structured format.
7 Bibliography, figures and tables

7.1 Bibliography


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7.4 Definitions

CAD Computer-aided design
CAM Computer-aided manufacturing
CAE Computer-aided engineering
Fab lab Fabrication laboratory
Git Open source revision control software, by Linus Torvalds et al
Siteserver Website content management system written by Neil Gershenfeld to run a Git archive as a database (Editing Websites with Siteserver, 2011)
MCU Multipoint Control Unit for video conferencing
CNC Computer numerical controlled