

FabFAQ

*A demand-driven
learning platform for
the personal
fabrication domain*

Diploma thesis at the
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Aachen, April 2013
Radek Paluszak

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Abstract

Inspired by the growing interest in personal fabrication of people from diverse domains and with different sets of skills, this thesis paper analyzes the demand-driven peer learning process observed in fab labs. To better understand this phenomenon, the field of peer learning and reviewing in other domains is examined.

As a result, we extract the requirements for an online system which aids the people in the personal fabrication domain in their creation and learning process. On the basis of these requirements we describe the design of FabFAQ, a demand-driven learning platform for the personal fabrication domain. We discuss the design-implement-analyze cycles, from an early paper prototype over a refined mock up prototype to the final implementation of the system. All technology used is described in detail, along with all functions the system provides.

The evaluation process of the system with qualitative user studies is discussed and shows that the requirements are met, the system is usable and well accepted by the users.

The main contribution of this work is the transfer of the observed demand-driven peer learning process of people from the personal fabrication domain onto an online platform, allowing users to solve the problems they encounter faster and contemporary. It also provides a connection to fab labs, and can help the fab lab users and masters to assist each other in a faster and more comfortable way.

Überblick

Inspiriert durch das wachsende Interesse an Personal Fabrication aus verschiedenen Fachbereichen mit unterschiedlichem Grad an Erfahrungen analysiert diese Arbeit den nachfragebestimmten Lernprozess innerhalb der Bezugsgruppe im Fab Lab. Um das Phänomen besser zu verstehen wird das Gebiet des Peer Learnings und Reviewings näher betrachtet.

Als Resultat extrahieren wir Anforderungen an ein Online-System, welches die Benutzer im Bereich der Personal Fabrication in ihrer Tätigkeit unterstützen soll. Auf Grundlage dieser Anforderungen beschreiben wir das Design von FabFAQ, einer nachfragebestimmten Lernplattform für die Personal Fabrication Domäne. Alle Design-Implement-Analyse Zyklen werden detailliert diskutiert — von einem Papier-Prototypen bis hin zu dem finalen System. Die Technologie sowie alle Funktionen des System werden im Detail beschrieben.

Es wird auf die Evaluierung des Systems und seiner Ziele mit Hilfe einer Benutzerstudie eingegangen, die zeigt, dass FabFAQ alle Ziele erfüllt und benutzerfreundlich sowie von der Zielgruppe akzeptiert ist.

Der Hauptbeitrag der Arbeit ist der Transfer des beobachteten nachfragebestimmten Lernprozesses aus dem Fablab auf eine Online-Plattform, welche den Benutzern zentral erlaubt sich stets auszutauschen und auftretende Probleme zeitnah zu lösen. Es bietet des Weiteren eine Verbindung zu lokalen Fablabs und erlaubt so den Benutzern und Betreibern eine schnellere und komfortablere Zusammenarbeit.

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-Radek

Conventions

Throughout this thesis we use the following conventions.

Text conventions

Definitions of technical terms or short excursus are set off in coloured boxes.

EXCURSUS:

Excursus are detailed discussions of a particular point in a book, usually in an appendix, or digressions in a written text.

Definition:
Excursus

Source code and implementation symbols are written in typewriter-style text.

`myClass`

The whole thesis is written in American English.

Chapter 1

Introduction

The realization of new ideas and products has for the past decades been dominated by commercial organizations. When an individual developed a new innovative product, he was not able to reach a broad audience or market by himself. Surely, he could protect his intellectual property by patenting it (associated with costs, lawyers and much paperwork), but even if he was a very skillful craftsman, he could usually only produce a small quantity of prototypes at a very low frequency in his garage workshop and advertise locally, usually in the newspaper. It was very difficult to distribute the invention in a global manner in order to let a wider group benefit from it, further explore the possibilities or just inspire other inventions.

The manufacturing of products was dominated by commercial organizations.

A solution was to found your own company. However, starting up your own business was bound to huge financial investments and risks. Assumed you possessed the necessary skills and knowledge, you had to buy the machinery, hire the instructors, build up logistical structures and supply-chains, advertise to get access to a market, and subsist against the other participants in order to survive. Thus, the consequences of a failure could be dramatic for the individual—from personal bankruptcy even up to going to prison. You could not just share your great idea with the world, but you had to face the economical rules. So, even if you were very confident in your idea and skills, the barrier to start your own company in order to successfully

There were high barriers to enter this market for individuals.

realize and establish an innovation beyond a very locally bounded area was very high.

Innovative ideas were sold including the loss of creative control.

The other way to realize your project without taking the risks of founding a company was to canvass from door to door, and to try to sell the idea to an established company, which possessed all the necessary skills, machinery and believed in it to fabricate the product. Of course, such a company would not finance your product just because of its philanthropy, but only because they saw a sufficient possibility to earn money with it. This usually implies the loss of the creative control and right over the product in exchange for some royalties (until the patent expires).

The PC revolution eliminated the barriers for the production of digital content.

With the spread of personal computation in the 1980s and the invention of the World Wide Web in 1989 at least the digital manufacturing has taken another path. Everybody could produce digital products in his basement and share it with the whole world. Due to the missing barriers of the physical domain, the digital domain was completely open for everyone. You only needed a personal computer and an idea. This led to a major shift in the way by whom the development was done. Software for the mass market was not anymore only produced by big companies with professional developers and commercial interests but by everyone who was just interested in it — without taking any risks. The open character with all its possibilities led to an interesting phenomenon: Hobby developers organized groups of like-minded people from all around the world without ever meeting and united their skills and visions to create the software they needed. This is what became the open source community. Prominent results of this movement are the Linux operating system, the Mozilla Foundation with its prominent Firefox web browser or the Apache HTTP Server which runs most of today's web servers, just to name a few projects which are by no means inferior to similar commercial products. Anderson summarizes the benefits of this paradigm shift as follows:

What the Web taught us was the power of “network effects”: when you connect people and ideas, they grow. It's a virtual circle—more people combined create more value, which in turn

attracts even more people, and so on. That's what has driven the ascent of {...} every successful company online today. Anderson [2012]

This is exactly what the Web 2.0 triumphal march (O'Reilly [2005]) was all about: Give the users a platform and provide the possibility to create content and interaction. The outcome is very precious—if you want to see it from a monetary viewpoint just look at projects such as YouTube, Facebook, Twitter which started as hobby projects of individuals and became multi-billion companies because of their user-created content, without taking the risks a hardware-manufacturing company would have had to face.

Individuals create high quality digital products without any risk.

But actually this revolution only was happening behind a screen in the virtual world of bits and bytes floating around the globe. The world of physical crafting with all its rules remained basically untouched. This is changing right now. With the up-come of personal fabrication and the maker movement, the Web 2.0 and open source spirit is starting to revolutionize the “real” world—from bits and bytes to atoms.

The physical world remained unchanged.

1.1 The Rise of Personal Fabrication

Everything started in 1998 at the Massachusetts Institute of Technology (MIT). Neil Gershenfeld, the director of the Center for Bits and Atoms, began to teach a class with the title “How To Make (almost) Anything”¹. They assembled an array of industrial machines which could assemble other machines. The course's goal was to allow a small group of advanced students to briefly get used to the machinery (usually it would take years of learning to operate each machine in a professional manner) in order to use it for their research projects. The students' reaction was unforeseen: Hundreds from a variety of fields, with a variable level of technical experience tried to enlist (Gershenfeld [2005]). This overwhelming interest made the researchers curious about the students motivation. It turned out that

The origin of personal fabrication.

¹<http://fab.cba.mit.edu>

An unforeseen interdisciplinary interest in personal fabrication emerges.

the reason they wanted to take this class was the desire to build unique things they always wanted to possess, but did not exist. As discussed in chapter 1 it was nearly impossible to be able to fabricate in an industrial quality for your own needs and the students saw for the first time the opportunity of overcoming all these barriers. They were fulfilling their personal desires in a never before possible mass-market quality. That phenomenon reoccurred year after year and led Gershenfeld and his team to realize that there was a deeply anchored desire in the students to regain the control over the crafting process of objects. There was a parallel to the personal computer revolution in the 80s where killer application like “VisiCalc” pushed the number of sales of personal computers like the Apple II and turned the personal computer from a mysterious geek toy to the business tool it is today, revolutionizing whole industries and the way we all work. In the near future the desire for personal fabrication combined with the necessary technology becoming affordable will lead to a revolution in the production sector.

Digital photography serves as a model.

An analogy to foreshadow the personal fabrication revolution is the photography sector. In the last century our pictures were developed in photo studios. With the up-come of affordable ink-printers and digital photography, the whole sector democratized and now we can all print our pictures in high quality by ourselves at home or instantly in nearly every drugstore.

The logical next step is to transport these capabilities to the production process of nearly everything physical. This question drove the researcher at the MIT: Could they democratize the way things were created?

The first fab lab at MIT is established.

They could. In order to determine how personal fabrication would be used they developed a project called “fab lab” (it stands for laboratory for personal fabrication or just fabulous laboratory). A fab lab is a workshop equipped with machines, software and processes to fabricate things. The first ones cost about 20.000 USD, an amount which decreased over time. Thus, one major goal was the affordability even for less developed countries. The first labs consisted of a laser cutter, a milling machine and the tools to program micro controllers, supported by traditional tool

for metal- or woodwork and later extended with other tools, e.g. 3D printers. A vision was that someday the fab labs could reproduce the tools they offered by itself (this vision is today partially realized as you can craft and assemble your own open source 3D printer in the fab lab). The first fab labs were started in India, Costa Rica, Norway, Boston and Ghana. The responses were all the same. People from all over the world started enthusiastically to build objects for their local needs. A social aspect crystalized: The labs made it possible for people whose educational, financial or regional circumstances were not sufficient, to solve local problems and increase their living quality. The usage of the labs was free, the people only had to pay for the material.

The fab lab's social aspects crystalize.

After the huge success of the pilot projects the development took a momentum of itself. Today, 10 years after launching the first fab labs, the International Fab Lab Association² lists 185 labs—from Afghanistan to Vietnam. All working in a global network with principles stated in a charter. The main principles focus on the open character to give everyone the opportunity to work in it and underline the obligation to contribute the knowledge to the community, and shift commercial interests to the background (The complete charter can be found in the appendix A).

New fab labs are opened all around the globe.

In contrast to mass production, where several identical items are manufactured at a time, it is possible today to create unique products in a fab lab, crafted from different materials with integrated logic, at affordable costs. This decrease in cost means that the tools already became affordable for home users, as increasing numbers of early adopters and technical enthusiasts show. With the support of various open source software and communities to help in the virtual design process, freely upload, share and modify designs, personal fabrication got possible for everyone. Just like creating software, we can now imagine physical things at home and manufacture them in the next fab lab around the corner or even in your living room. We can easily create atoms out of bits.

Everyone can manufacture in nearly industrial quality, even at home.

²<http://fablabinternational.org>

Excursus:
The Fab Lab Aachen

THE FAB LAB AACHEN:

The first fab lab in Germany was established in December 2009 at the RWTH Aachen. The Fab Lab Aachen³ offers an open lab day every Tuesday, where everybody has access to the 3D printers, laser cutters, and CNC (Computer Numerical Control) milling machines. Depending on their needs and lab supplies, the users can bring their own material or buy it for original costs. Since currently there are only one or two machines of each kind the users have to check availability and reserve one hour slots for each machine through the fab lab master. If the job requires longer slots the people are asked to split their work into several one hour sessions to maintain fairness in the allocation process. The technical staff guides un-experienced users through the process and record the project information for the community. The rest of the time the lab is used for projects related to the fab lab and its software or other research of the chair, especially for rapid prototyping.

Most users are not
experts in personal
fabrication.

Users learn from
each other when a
problem occurs.

The experience with the fab labs taught us, that most of the users are not experts in personal fabrication. They have to learn how to use the programs and they have to get used to the way the machines are operated. More generally, most of the problems they encounter they did not know of until they occur. And here another interesting phenomenon crystalized: Unlike the old-fashioned way to learn a pre-selected subject in a class, which hopefully would become useful somewhere in the future, the students and users have to analyze and solve the problems as they occur. This is called a “demand-driven learning process”. MacDonald et al. [2001] define it as a “constructivist theoretical paradigm to meet the learner’s demands for quality content, delivery, and service within an evolving technological environment. Learners {...} are active learners and encouraged to participate in and interact with the environment to construct their own meaning of knowledge”. Usually, once a user mastered a task in a fab lab, he had the eager need to share his knowledge with others. When the users needed a new skill, they learned it from their peers, who had already mastered the problem before. This model turned out to be very effective—no class could achieve such an amount of progress in such a short time with a heterogeneous group.

The next chapter considers this peer driven learning process in more detail.

1.2 Peer Learning and Peer Reviewing

Peer reviewing has its origins in the 17th century. The editor of the “Philosophical Transactions” journal, a theologian, did not feel capable of judging the quality of the submitted essays. He delegated the evaluation to experts from the corresponding field to reassure the contribution’s high quality (Rockwood [2007]). This procedure was later adapted in several domains.

The origins of peer reviewing go far back.

Today, for example, peer reviewing is a common method in science to identify suitable submissions for conferences or journals. A group of researchers from the adequate field get the (anonymized) papers which were sent in and rate their quality. Afterwards, the open slots are filled with the best papers and the rest gets rejected (or gets the opportunity of rebuttal). This procedure leads to higher quality and reduces the probability of irrelevant submissions in the proceedings. There are many other fields where peer reviewing is professionally done to periodically check the state of a project or company. This is done for example in the medical sector to check the quality of the hospitals care by independent experts (Brook and Appel [1973]). But also lawyers, engineers and many other professions use variations of peer reviewing for quality assurance.

Peer reviewing is used in many domains.

Another relevant field is the education sector. There are different models which can be combined. According to Dochy et al. [1999] the peer reviewing process can consist of different forms: The student can rate other groups, groups he is also a member of, and only rate himself. This can reach from solving problems and discussing the attempts in groups up to simple peer marking. There are various combinations of these methods. Overall their analysis of 63 studies on the subject indicated an improvement in learning quality through peer reviewing techniques. Main findings were the students increased ability to perform, growth in the awareness of the quality of their work, more reflec-

There are forms of peer reviewing in the educational sector.

There are Advantages for the learner through peer learning.

tion on the subject, the increase in the students performance and learning output. Through the reviewing process, the individual gets feedback from peers (who have an expertise on the topic) and especially when he is uncertain of some aspects or has a problem, he can learn from the feedback. The peer reviewing process is strongly related to peer learning. This explains why it is gaining importance in the educational field.

Peer reviewing can be time consuming.

We can now state that peer reviewing techniques increase the product quality in a broad variety of areas and support the individual's learning process. On the other side the process itself, especially when the review is a written physical essay and not just a grade, can be quite time consuming. Imagine someone wants to publish a paper in a journal. He has to wait until all reviewers get a copy and approve it. The peer reviewers have professions and other obligations so it can last weeks or month till he gets a response. As a consequence the so called "open peer review" form emerged. Here it is possible to publish work, it is rated afterwards and as the work receives more reviews it can be enhanced qualitatively. The reviewing process is open for everyone. Of course, this technique can also be used to constantly improve and update the work's quality based on the last reviews (König [2010]).

Digital peer reviews shorten the amount of time needed, but can reduce quality.

With the up come of new communication technologies the peer reviewing and learning process went online. This step reduces the amount of time the work is in review and the resulting reviews are shipped faster. It is possible to access a massively bigger peer group in less time and without any effort. On the other hand, open online peer reviews can be biased, since it is only under very strict and closed conditions possible to determine who is reviewing. Was the person a peer at all? Does he have knowledge of the subject? Has she personal interest in a good review? But with growing numbers of participants these side effects and irregularities are expected to become negligible (König [2010]). Van Rooyen et al. [1999] even showed that revealing the reviewers identity to the author had no significant impact on the reviews quality, what is very important for online reviewing, since it is not easy to prove someones identity. Other very common derivations of online peer reviewing and learning can be found in the open source software com-

munity. For example, Stack Overflow⁴ is a very popular demand-driven learning platform or resource for people involved in programming. It allows one to post faulty snippets of code for which one seeks help. The peer community (consisting of other coders) reviews it and posts possible solutions to the problem. The question and solutions can easily be found by everyone interested (see for details chapter 2.3.1).

Peer learning is implicitly used by online platforms

Many open source developers use the community as a quality insurance instance. A case study on the open source Apache Server⁵ code reviewing paradigms conducted by Rigby et al. [2008] indicates patterns for successful open source software development through peer reviewing. They postulate that "early, frequent reviews of small, independent, complete contributions conducted asynchronously by a potentially large, but actually small, group of self-selected experts lead to an efficient and effective peer review technique" (see for details chapter 2.3.1).

Code inspections are a popular form of peer reviewing.

As we already discussed in chapter 1.1 the learning and creation process of most of the users in a fab lab consist mainly of many peer reviewing and learning processes.

1.3 Objective

The intention of this thesis is to recognize suitable peer learning aspects and transform them onto open hardware design. We will derive the affordances for an online peer learning platform, and as a result we will present a solution for the personal fabrication context. The main goal is to provide the fab lab's physical demand-driven learning environment ubiquitously. We call this system from now on FabFAQ.

The goal is to provide a peer learning system for personal fabrication.

⁴<http://www.stackoverflow.com>

⁵<http://www.apache.org>

1.4 Thesis Overview

In chapter 1 we gave an overview about personal fabrication and peer reviewing and learning concepts which are the basis and motivation of this thesis. In the following chapter we focus on the concepts of several existing peer learning systems and related scientific work. It will introduce the theoretical framework for our system. In chapter 3 we develop the requirements for a peer learning, demand-driven learning platform and describe in detail the development process of FabFAQ with all its functions and technologies. In chapter 4 the concept is evaluated with the help user studies and we determine if the requirements were met. The last chapter 5 provides a summary of the whole work and its contributions, and shows how the system can be improved in the future.

Chapter 2

Theoretical Background and Related work

In the following part we will take a closer look at related work. We start in section 2.1 with two approaches to extract patterns from code peer reviewing. In section 2.2 we examine several existing peer learning systems from the educational sector, followed by section 2.3 where we discuss the peer reviewing approaches of related web services. And finally, in chapter 2.4 we present a model for successful online demand-driven platforms. This is the basis for the requirements for FabFAQ, which are closer described in chapter 3.

2.1 Patterns

We will now describe two approaches to extract general patterns from software source code reviewing.

2.1.1 Open Source Software Peer Review Practices: A Case Study of the Apache Server *Rigby et al. [2008]*

Code Inspections are
infrequently utilized
in industry.

The software development in industry utilizes inspections (formal peer reviews) for quality assurance. Developer have to schedule the head-to-head meetings and need to study the code prior to it being reviewed. This preparation is time consuming and hence expensive for the company. Due to tight schedules and financial pressure, this method is not very frequently adopted, often only for big milestones, which occur every few month.

Open source
software
development mainly
uses code
inspections.

In the open source software (OSS) Apache Server project code reviewing is surprisingly the most frequently used technique for quality assurance. Since the Apache Project is a very mature product and has about the same defect density as industrial products Rigby et al. [2008] tried to empirically analyze the peer reviewing process, compare it to formal industrial inspections, and identify patterns which, once adopted, could optimize the reviewing process in other domains.

There are two
techniques:
Commit-then-review
and
review-then-commit.

The Apache project was started by globally distributed volunteers who never met face-to-face. Therefore it was a natural decision to examine each others code before uploading it to the repository. This technique is called review-then-commit, short RTC. They agreed only to successfully upload the code when at least three core member delivered a positive review. Even though the feedback was given asynchronous through a mailing list, it was time consuming. This led to another technique: Commit-then-review (CTR). It is used when a trusted developer feels confident with his code. RTC was then only used when a core member was uncertain of his contribution or a non-core member wanted to contribute code. Nevertheless, some members argued that CTR could become commit-than-whatever. A variation was proposed, a submission for review had a commit countdown (e.g. 2 days) and would be committed automatically when there were no complains within that period. In addition, Apache uses other important policies: The contributions are small, independent and complete in order to reduce reviewing time. Every core developer has

a veto right, which can prevent a commit or in case of CTR means a removal of the change. In summary, there are two barriers for submissions. Significant changes or non-core member changes have to pass the reviewing process. All other changes can be reviewed afterwards and removed. These processes force the developers to track and review changes instantly.

Rigby et al. [2008] had five research questions:

1. Are developers able to maintain an adequate level of reviewing during times of increased development activity?
2. How many reviewers respond to a review? How much discussion is there during the review? What is the size of the review group?
3. Are the artifacts under review smaller than the one used in formal inspections?
4. What is the review interval?
5. How many reviews find defects?

The research questions of the case study.

Because the Apache developers work asynchronously through a mailing list, the researchers analyzed their recorded communication. They examined 84.784 mails on 23.409 threads with following results:

1. With increasing numbers of code submission there were also increasing numbers of CTR and RTC reviews. However the amount of accepts was only weakly correlated to the commit activity. This indicates that there is no commit–than–whatever for CTR submissions and that the developers are able to maintain their reviewing level even in peak times.
2. Since it is not possible to count reviewers who did not find any defect and therefore did not comment on the thread, this is a difficult question. The researchers assumed that every reviewer finds in a certain period at least one defect. On that base they counted how many

The reviewing level is maintained in peak times.

Reviewer groups are rather small.	<p>reviewers found at least one defect on a monthly base to determine the size of the active reviewer group. They compared this group to the number of developers and emails per review. RTC had slightly more reviewers than CTR. The median of RTC was 2 individuals and 2 messages (indicating that the 3 positive reviews from core members policy is not always strictly followed), the CTR median was 1 individual and 2 messages. For the reviewer group the median is 14 (RTC) respective 15 (CTR). These findings indicate that individual personal expertise on different topics is of more importance than the number of reviews.</p>
Code changes are small.	<p>3. Apache changes are smaller than changes in industrial projects. A solution for several problems is, due to the policy, broken down into several parts.</p>
Reviews and discussions happen fast.	<p>4. The last review on 80% of the RTC submissions was made in less than 3.8 days. For 50% of the submissions in even less than 19 hours. Time to the first response was for 80% less than 3 hours and for only 9% more than 1 week. This indicates that ignored contributions are rarely reviewed. For 50% of the CTR submissions the time for the first review (the time the commit was discovered) was within 1.7 hours and for 80% smaller than 11 hours. The discussions full interval (time to the last response) had a median of 8.9 hours, 80% were done in less than 11 hours and only 5% lasted longer than one week. This shows that the reviewing process and the discussion are happening really fast.</p>
Slightly more than half of the contributions are faulty.	<p>5. Apache has comparable defect rates to those in industry. The researchers took a random sample of 100 reviews. 51% of the RTC commits had at least one defect, respective 66% of the CTR commits. It also crystalized that even though the code parts were very small and local, the discussion often involved very global viewpoints. This indicates overall code knowledge of the members.</p>

In summary the Apache project reduces the time required for preparation of the reviewing sessions and has smaller more frequent reviews. CTR has shorter review intervals

than RTC and a similar amount of defects. Nevertheless CTR is not superior because it is used in a different context. RTC provides more security for bigger, more severe changes. The main patterns derived from the Apache project for an efficient and effective peer review technique by the study are:

Patterns for effective code reviewing.

- Early, frequent reviews
- Small, independent, complete contributions
- Reviews conducted asynchronously

2.1.2 Contemporary Peer Review in Action – Lessons from Open Source Development *Cleary et al. [2012]*

The approach of this work was similar to the work of Rigby et al. [2008]. They analyzed more than 100000 peer reviews in open-source-software(OSS), in this case from a variety of projects. They also state the contrasts between OSS peer review structures and the formal inspection methods used in industry and derive from this some patterns for efficient peer review in general and suggest some software approaches which could support the process.

1. Asynchronous Reviews

In industry, defect detection is mostly done with collocated, synchronous meetings. However, studies showed that reviewers found almost all defects in their preparation stages for the meetings. The meetings itself generated few additional defects and were responsible for 20% longer inspection intervals. This lengthens the development process and costs money. It also was observed in research settings. In the collocated meetings, the focus was strictly on finding erroneous code and not on solving it. This limits the group's ability to collectively solve the defects. The asynchronous OSS review style, however, encourages synergy between the developers, as they discuss solutions and the problems.

Asynchronous reviews are more effective than synchronous ones.

2. Frequent Reviews

The longer a defect is not found, the more embedded it becomes. This means it is harder to spot and fix and, thus, again costs more money. In industry, the frequency between the review sessions is not very high (as seen in chapter 2.1.1). A huge amount of new code is inspected at specific milestones that often are months apart. In contrast in the OSS, reviews begin within hours after the submission of the code and usually do not last longer than a few days. The review cycle is so fast that it is often considered as a continuous reviewing process.

Frequent reviews prevent defects from embedding deeply.
3. Incremental Review

Large software parts are often very unfamiliar to the reviewer, which can cause issues if the writer is overwhelmed. The results are often of low quality. Small code sizes give the reviewers a better overall picture of the changes, and they have to invest less time in understanding it. In OSS projects this is done through a divide-and-conquer strategy. The changes are broken down to several independent, small, and complete chunks.

Small code sizes improve the understanding.
4. Invested, Experienced Reviewers

Without experience with a project and detailed programming skills, the reviewers cannot be expected to understand the changes and, thus, produce qualitative feedback. Even the best patterns and techniques will not turn a novice into an expert. Programmers, who depend on each others' code to develop their own or incrementally work on the same module, tend to have a deep understanding of the functionality of the code. They are experts in that field. Studies indicate that they are very efficient reviewers. In industry, there is a technique known as "reviewer as bug fixer". Here, developers are periodically assigned to inspect another developer's code. Through the inspection process, they become familiar with the code and become in fact co-developers. This combines the peer reviewing concept with the bug fixing task.

Reviewers have to be familiar with the module in review.

5. Empower Expert Reviewers

It is often difficult to decide who should be the reviewer of a certain part of software. The expertise of the developers has to be balanced with their workload. It is suggested to let the developers self-select the piece they want to review. This results in a natural mapping of knowledge on the right topic and a balanced workload. On the other hand, this could result in pieces which eventually get ignored.

Self-selection of the topic to review can increase effectiveness.

In the next step the researchers propose some software techniques which could support an effective peer review process and eliminate some flaws.

1. Lightweight Review Tools

OSS developers use minimalistic tool support on the traceability of their discussions and changes—mostly mailing lists. It is difficult to track the reviewing process, especially when bigger changes are broken down into small chunks and discussed in several fragmented threads. Tools can help to monitor these activities. Typical functionality which could be provided is:

Minimalistic tools can improve the reviewing process without adding overhead.

- Side-by-side highlighted changes
- Inlined discussions linked to a line in code
- Possibility to show or hide additional code
- Code update ability
- Central place to collect artifacts of discussions
- Dashboards to show pending reviews
- Notification and assignment of reviews
- Metrics to see efficiency and effectiveness

2. Nonintrusive Metrics

In order to control, understand, and direct a software project one needs metrics. These are often disruptive for the developer as he has to interrupt his primary work to fill out forms and document his work. Formal recordings are complex tasks, which need a lot of time. It is suggested to mine the information trail of

Automatically mining informations can save developers' time.

the reviewing discussion automatically. In this case the developer is not distracted. It is easy to log the discussion and associate it with the changes. Highly controversial parts will be discussed heavily, indicating problems. Parts, which are fixed quite easily and not controversially discussed, can be seen as qualitative code without defects and do not need much documentation.

Industry can learn from the open source software development.

The advantages of the OSS peer review style can be transported to an industrial setting. Large organizations may benefit from the shorter reviewing cycles, finding more defects earlier and in a smaller amount of time. However, a company needs some control tools. In combining all principles in this paper, the researchers propose a lightweight, asynchronous tool-assisted peer review strategy (see Figure 2.1) which is located in between both worlds.

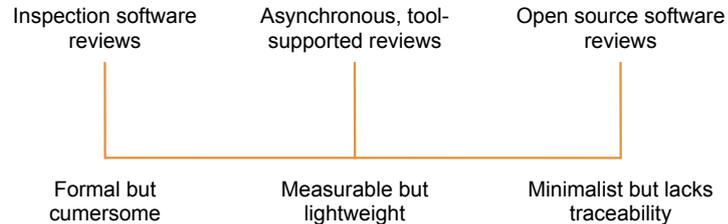


Figure 2.1: The spectrum of peer review techniques, from formal inspection to minimal-process OSS review. Tool-supported, lightweight review provides a flexible but traceable middle ground. [Cleary et al. [2012]]

2.1.3 Conclusion

In summary, the influences from the previously described work which can be transformed onto our peer learning platform are:

- Encourage the users to frequently present small pieces of their work or their problems in order to support a fast and overhead-free reviewing process.

- Encourage reviewers to not only examine the contribution and state a defect, but to also provide a possible solution.
- Users should be able to self select what they want to review.
- The expertise of users should be visualized to give their contribution a bigger weight.
- Support light-weight traceability to provide a fast overview of the user's contributions.
- Provide a central place for discussion.
- Notify users about new reviews concerning their work.
- Highlight unreviewed work.
- Show the amount of discussion around one topic to indicate its relevance.
- Support asynchronous reviewing processes.

2.2 Peer Learning Systems

After taking a closer look at software developer's peer review techniques and their patterns in the last chapter we will now present an overview of the tools for peer learning and grading in the educational sector and finally analyze suitable aspects for FabFAQ.

2.2.1 WebCom: A Tool to use Peer Review to Improve Student Interaction *Silva and Moreira [2003]*

At the University of São Paulo, many courses use the peer reviewing technique. Usually the students join in small groups and complete assignments proposed by their teacher. Afterwards, the groups exchange and review their work (e.g. a programming assignment) with each other,

At university, peer reviewing is used in many courses.

following certain public and pre-established criteria. After a time period, they publish their reviews and the groups debate the quality and shortcomings of the work and defend their own view points. On the base of the quality of their discussion and their arguments, the teacher grades the groups. The students improve their social skills and get a deeper understanding of the material.

To relieve the teacher from managing the process, WebCoM was developed.

Even though the teacher has usually not to do the reviewing of the assignments, the preparation of the physical group activities can be very time consuming and complicated. He has to print the assignments and reviews on paper for every student, control the deadlines and group formation and manage the whole process. To make the initialization and the management easier WebCoM (Web Course Manager) was developed. It is a set of tools, developed as a Java applet, to provide graphic interfaces to retrieve, store, manipulate, and present information that is generated by students and teachers through the internet.

A usual peer reviewed assignment with WebCoM consists of the following steps:

Workflow of a peer reviewing session using WebCoM.

1. Setup

The teacher has to create a course web page using content generating tools, containing instructional material (slides, calendar, etc.) and a list of assignments (Figure 2.2). The students can access this course page and download the WebCoM applet.

2. Group Formation

In the next step the students have to form groups, since the assignments have to be done in (fixed sized) groups with the tool shown in Figure 2.3. At this point, they can pick the project they want to work on on a first-come-first-serve basis.

3. Assignment Upload

The students can upload their work as many times as they wish until a given deadline using the WebCoM FTP tool. The tool automatically sets up a directory and uploads the file. The students do not have

Assignments

Assignment	Deadline Date	<input checked="" type="checkbox"/> Use Review	Weight	Review Date
1 of 1	06/07/2003		1	06/12/2003

Assignments Projects:

Project Name:

Max. Number of Groups:

Min. Students per Group:

Max. Students per Group:

Projects List:

- Project Foliotracker MaxGroup 5 MinStudents 2 MaxStudents 3
- Project Text_Editor MaxGroup 3 MinStudents 2 MaxStudents 3
- Project Video_Store MaxGroup 3 MinStudents 2 MaxStudents 3
- Project Course_Applet MaxGroup 4 MinStudents 2 MaxStudents 3

Buttons: Add, Remove, Send, Cancel, << BACK, NEXT >>

Figure 2.2: WebCoM's interface to define assignments. Each assignment can consist of several projects which can be distributed among the students. [Silva and Moreira [2003]]

Group

Group Creation for:

Group Name:

Projects:

New Member:

List of Members:

- michel
- jaoliveira
- valeria

Buttons: Add, Remove, Send, Cancel

Figure 2.3: WebCoM's interface for group formation, consisting of assignment ID, group name info box, space to add members, a project dropbox and a list of students per group. [Silva and Moreira [2003]]

to care about a place to save their files, this is managed through the system. The files finally are made available on a WebCoM HTML page.

4. Review Group Allocation

After the deadline, the teacher determines which group is assigned to review another group's work. It is not done automatically to allow the teacher to use the allocation strategy he wants (e.g. to avoid cross reviews). For this purpose WebCoM offers the review allocation tool (Figure 2.4).

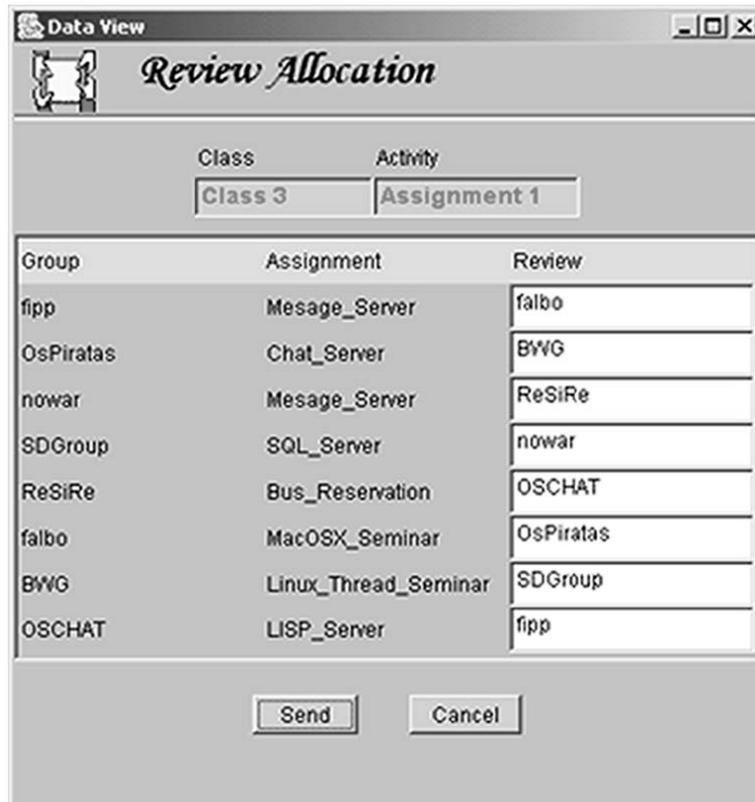
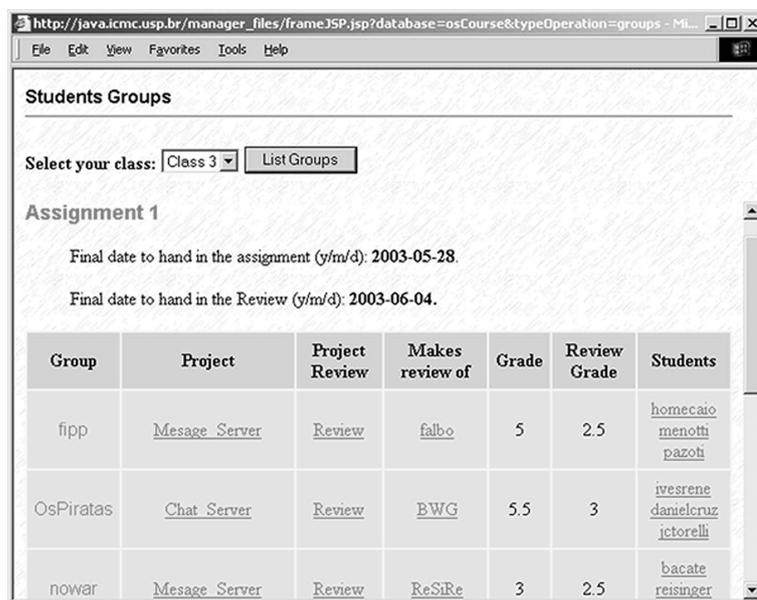


Figure 2.4: WebCoM's interface for group allocation used by the teacher. Here he can associate groups to assignment of other groups. [Silva and Moreira [2003]]

5. Review Upload

In the next step, the students inspect the other group's work and write their reviews. They have to answer

specific aspects, earlier published by the teacher. After completion they upload their work again with the WebCoM FTP tool. The files also are made available on the WebCom HTML page (Figure 2.5).



The screenshot shows a web browser window with the URL `http://java.icmc.usp.br/manager_files/frameJSP.jsp?database=osCourse&typeOperation=groups`. The page title is "Students Groups". Below the title, there is a "Select your class:" dropdown menu set to "Class 3" and a "List Groups" button. The main content area is titled "Assignment 1" and contains two lines of text: "Final date to hand in the assignment (y/m/d): 2003-05-28." and "Final date to hand in the Review (y/m/d): 2003-06-04.". Below this text is a table with the following data:

Group	Project	Project Review	Makes review of	Grade	Review Grade	Students
fipp	Message Server	Review	falbo	5	2.5	homecaio menotti pazoti
OsPiratas	Chat Server	Review	BWG	5.5	3	ivesrene danielcruz jctorelli
nowar	Message Server	Review	ReSiRe	3	2.5	bacate reisinger

Figure 2.5: WebCom's HTML overview page, containing all informations including grades. [Silva and Moreira [2003]]

6. Debate

The last part of the peer reviewing process is a classroom debate. It is usually done in person in the class (although the authors suggest it could also be done online via chat). The two groups involved in the reviewing process debate about the review and their work and defend themselves. On this basis, the teacher can see how deep the understanding of the assignment and the key theory was and form the students final grades, which are also published on the WebCom HTML page.

2.2.2 Web-Based Peer Review: The Learner as both Adapter and Reviewer *Liu et al. [2001]*

The web-based peer-review (WPR) system was developed in 1998 by researchers from the University of Taiwan in order to manage students' peer review activities. They describe the system only very briefly.

WPR moderates and distributes peer reviews.

First, the teacher posts the homework assignments. The students prepare their solutions in HTML format and upload it to the WPR system. Now the system randomly assigns six students as reviewers to each student. Everyone rates and comments the others' work. The system assigns the ranks and comments back to each student's work and informs the teacher about the general status. The author of the homework has to revise his work according to the reviews. This process is repeated three more times. Afterwards, the teacher gives the student a mark based on the 6 reviews of his assignment and the quality of the reviews the student has written himself.

The system offers automated file management.

In addition to the function as a distribution channel and management center for peer reviewing, the system also provides a bulletin board to express opinions about the course and system. It also manages all the files and directory structures. When a teacher creates a new course, directories and all relevant homepages are automatically produced. Each student's upload is copied anonymized with a serial number to another location before it is cleared for review. Every version of the assignment is stored so that its evolution can be analyzed afterwards.

2.2.3 On-line Peer Review in Teaching Design-oriented Courses *Ning et al. [2003]*

Reviewing each other's ideas is crucial in design classes.

In design-oriented courses, held at the Massachusetts Institute of Technology, interactions between the student are very important, perhaps even more important than with their instructors. Reviews and comments from other students are crucial to help to develop design concepts. To conduct this solution finding process with its possible iter-

ations and phases which systematically evolves into a design, the courses adapt the Rohrbach 635 method.

ROHRBACH 635:

Originally developed by Professor Bernd Rohrbach in 1968, the 635 method is a group creativity technique based on ring exchange. In the original proposal, the group consists of six members. Every member gets a sheet and has to write down three ideas on a specific topic. After five minutes the sheet is passed on to the person to the right. Now every participant writes down three further ideas using the ones on the sheet as stimulus. This process is done five rounds—hence the name of the method 635.

Definition:

Rohrbach 635

Rohrbach 635 is used in the courses as a peer review evaluation technique. It proves very efficient in sharing and compiling ideas generated by all students. It suppresses the dominating group member problem and creates an atmosphere where everybody is equal. Shy individuals are less intimidated in expressing themselves. The process itself provides a documentation on itself.

The Rohrbach 635 method proved to be effective in the classroom.

Because of these advantages, the Rohrbach 635 process became the base for the Peer Review Evaluation Process (PREP) tool. Written in C#, it is basically a collection of online user controls which allow to start, edit or delete a Rohrbach process and upload or download documents.

The PREP system implemented Rohrbach 635.

The main control element for the Rohrbach process is the PREP matrix (Figure 2.6). The file symbols appearing diagonally in the matrix indicate that the ideas of the user have been uploaded to the system. The closed or open lock associated to the file shows if the file is currently checked out for review. If it is closed, the review process will have started and other users can download it by just clicking on the file symbol and start reviewing it. The green ticks indicate that a user has reviewed another's document. After a full iteration of the Rohrbach process the lock symbol becomes open and the user can edit their documents. By clicking on the 'H', older versions of the document can be accessed. Unlike the face-to-face Rohrbach method, with the history feature it is not only possible to see the final result documented but

The main control element is the PREP matrix.

Ideas	user1	user2	user3	user4
user1	 (H)	✓	✓	✓
user2	✓	 (H)		✓
user3			 (H)	✓
user4		✓	✓	 (H)

Figure 2.6: The PREP matrix used as main hub for the peer reviewing process. [Ning et al. [2003]]

the document's whole evolution by browsing through the different versions.

There are improvements for PREP.

The developers state that prep has a lot of room for improvement. For example, they would like to see a display for the ownership of every single word or sketch a user has written in order to even better recognize the the path of the evolution of the idea.

2.2.4 Peer-to-Peer Learning with Open-Ended Writable Web *Kurhila et al. [2003]*

Students gather information mainly through the internet.

In common university classes the students have the responsibility to find suitable material by themselves. Today, this is usually done via web search. This means that communicating course material does not solely lie on the teacher's shoulders, instead the responsibility is moved to the students. Because many students often have to explore the same field, this learning process can strongly benefit from exchanging each other. Then the students do not need to reinvent the wheel every time, but can profit from each others' work. The pool of sources becomes bigger and hence should the quality.

To support this style of learning, the researcher from the University of Helsinki invented EDUCOSM. It is used as

a course platform to support the peer-to-peer communication which lives in the web browser. The main paradigm is transparency: Everything a user does should be visible to the others in order to guide each other through others actions.

A central feature is the possibility to bring arbitrary web documents to the course area. Due to legal constraints they are only linked and indexed. This empowers the students to build a course and topic specific, open-ended knowledge database. Linkage is done by simple right-clicking a website and clicking on "Add to EDUCOSM". It does not matter where in the world the document is located. Another important feature is the possibility to collaboratively highlight and comment any web page brought into the system. These operations are also accessible through the browser's pop-up-menu. The highlighting can be seen by anyone using the system. If there are annotations it is possible to hover above the automatically highlighted text, so that a tooltip pops up, showing the annotation(s) with ownership and date (Figure 2.7). In case of highlighting, only the own-

To exchange the information found, EDUCOSM was developed.

EDUCOSM empowers users to build topic-related, open-ended knowledge bases using linkage.



Figure 2.7: The EDUCOSM user interface showing highlighting and annotation pop-ups. [Kurhila et al. [2003]]

ership is displayed. Of course an active user base can easily flood a document with annotations and highlights. To remain readable, the system offers the possibility to filter or switch off the highlighting. For example, one can activate only selected users content. To enable users to have extensive discussions on topics, it is possible to enable a news group for every document in the system. EDUCOSM also offers a start page, where everybody receives personalized information about new contributions related to his field.

Filters lower the cognitive load for users.

This kind of system lets the students implicitly communicate with each other and share their knowledge only through their usual literature research. It also conducts a feeling of not being alone, thereby motivating the students.

2.2.5 Electronic Peer Review: A large cohort teaching themselves? *De Raadt et al. [2005]*

A variety of media formats can be reviewed by the system.

The next system was developed by the University of Southern Queensland. It also is a tool to assist students in peer reviewing each others' work in order to empower higher order thinking and reduce the managing costs for the educational staff. The focus of this system is on creating peer review relationships for each class assignment independently. Usual class assignments consist of word-processing documents, spreadsheets, presentations, and HTML documents. The students submit their solutions electronically to the system before a given deadline. It is possible to work in advance and submit early. As students see each others' work after submitting, only one submission is permitted. Nevertheless, there is a training submission at the beginning of the course, which can be done as many times as it takes the students to get confident in using the system.

Reviews focus on completeness with a predefined checklist which aids in the reviewing.

After the submission, the system automatically and anonymously allocates two other students' assignments to be reviewed. The reviewing process is guided through predefined criteria (see Figure 2.8) in order to provide a fair and easily trackable marking scale. The criteria, therefore, focuses more on completeness than on quality. Even students who could not accomplish a task should be able to recognize if the others have succeeded. The two marks from the reviews become the marking base for the students' work. When the two marks from the reviews differ, a moderator inspects the work. The moderator has a broader range of information available in his tool, so it is possible to detect plagiarism or dependencies between the works (Figure 2.9). The moderator also inspects random samples from the review pool. The consistency between the users marks increases with their experience in using the system.

USQ AUSTRALIA **CSC1402 Foundation Computing** **DEPARTMENT OF Mathematics & Computing**

Home Lectures Resources Staff Assignments Submit Marks Bulletin Board

Users Online

- Michael*
- Michael
- Shun
- Michelle
- Emma

* Denotes Instructor

Manual Refresh

Complete Review

- Check (click in the box) if each criteria has been fulfilled.
- Checking a criteria box indicates that the criteria has been met; do not try to judge the quality of the submission through the criteria

- The document uses heading styles
- The document uses paragraph formatting and word wrap
- Headers and footers are used
- A table of contents is shown
- The document does not contain any obvious spelling errors
- An image is included

- You must enter a comment.
- Please offer praise or positive suggestions for improvements.
- Do not suggest that this student is not competent.
- Remember, this student is learning just like you.

Save Review...

Figure 2.8: Checkboxes for predefined criteria and guidelines to provide an easy, comparable and complete student's review. [De Raadt et al. [2005]]

Assignment 2: 0 to 3

Moderation Main Page...

Key: Moderation required Altered since mark saved Unsaved mark

Order	Student Number	Name	Email	File	Size	Date	Time	Log	Review by Student		Reviews of Student by Peers or Instr.	Do Review	Mark	Set	Late	Set	Final
									0	1							
0	deraadt	Michael de Raadt	✉	📄	3180	8/2	15:28	📄	👍	👍	3.0 3.0	Review	5.0	Set	%	Set	5.0
1	addie	Ron Addie	✉	📄	3180	8/2	15:28	📄	👍	👍	3.0 2.5 2.5 3.0	Review	4.5	Set	%	Set	4.5
2	lai	David Lai	✉	📄	3180	8/2	15:28	📄	👍	👍	2.5 2.5	Review	???	Set	20%	Set	No Mark Set
3	house	House, Ron	✉	📄	3180	8/2	15:28	📄	👍	👍	2.5	Review	3.5	Set	20%	Set	2.5-4.5=2.0

Moderation Main Page...

Figure 2.9: The moderator's have more information about the students involved in the reviewing process. [De Raadt et al. [2005]]

2.2.6 Conclusion

Many aspects of the presented systems build on the fact that their users are forced to participate in order to successfully complete a course or achieve a good grade. In our peer learning platform, it will not be possible to pressurize the users, since it will be open to everyone. Nevertheless, there can be some suitable aspects derived which need to be considered in constructing an open peer learning platform:

- Group discussions on a topic are important for the learning process.
- The users profit from each others work.
- Providing the possibility for many iterations improves the work.
- Motivating people to participate needs to be considered.
- The system should run on multi-platforms in order to not exclude users and provide a service which is available from everywhere.
- The system should automatically manage the reviewing process.
- The system should automatically manage the resources the users want to include.
- Providing a form of moderation can improve the quality of service.
- A software system helps shy individuals to express themselves.
- Through storing all submissions and making them public, a knowledge-base can be built and all user can profit by finding solutions that already exist and do not need to redo them.

2.3 Web Services

In the previous chapter we have seen a few approaches to utilize peer learning and reviewing processes. Now we will take a brief look at web services which are available today and present user generated content and utilize—at least not-implicitly—peer reviewing and learning techniques or are otherwise connected to the field.

2.3.1 Stack Overflow

Stack Overflow¹ is a homepage created in 2008, where registered users can post questions related to different aspects of programming. Other users (peers) try to solve these questions.

Platform for solving programming problems using peer reviews.

Treude et al. [2011] describe some of the design decisions which help to filter and organize the whole process and motivate other users to participate. The most important elements are visualized in Figure 2.10. Through voting, good answers are distinguished from bad ones. They then appear on top of the answer list and are instantly visible. This voting can be done by any registered user. Additionally, the user creating the original question is able to flag one answer as the best solution for his problem. All received votes and other community-supporting actions generate points which reward the user with badges. This adds a game aspect to the reviewing process and motivates the user to provide useful contributions and keep the whole system alive. It is possible to edit both questions and answers to improve the quality through iterations and the feedback received. All questions get specific tags (e.g. Java, Objective-C, HTML) to support the organization. The whole homepage is designed minimalistically in order to be optimized for search engines and performance.

The system offers a point system to reward constructive participation.

The peer reviewing context is given since all user are developers with different knowledge levels, and assist each other in solving problems and, thus, building up knowledge.

¹<http://www.stackoverflow.com>

The screenshot shows a Stack Overflow question page titled "jQuery to add a class to image links without messing up when the link passes variables". The page includes a question, two answers, and various UI elements like tags, votes, and user profiles. Red boxes and letters A through G highlight specific features:

- A:** The question text and a code block showing a jQuery selector: `$(document).ready(function () { $('a[href*=".png"], a[href*=".gif"], a[href*=".jpg"]').addClass('zoom'); });`
- B:** The tags "javascript", "jquery", and "html" below the question.
- C:** The "share" and "improve this question" links.
- D:** The upvote system (arrow icon) for the first answer.
- E:** The checkmark icon indicating the selected best answer.
- F:** The answer text from another user: `$(document).ready(function () { $('a[href*=".png"], a[href*=".gif"], a[href*=".jpg"]').each(function() { if (this.href.indexOf('?') < 0) { $(this).addClass('zoom'); }); });`
- G:** The user profile of the answerer, Fabrizio Calderan, showing a badge and points (25k, 2, 17, 36).

Figure 2.10: A: The question generated by a user, including highlighted source code display. B: Tags referring to the field of the question to ensure a structured organization. C: Possibility to edit a question after initial posting. D: Upvote system to distinguish useful answers. E: The person asking can flag the answer he finds most useful. F: The answer by another user, which was flagged as best one. G: User profile including different badges and points for constructive participation.

2.3.2 Thingiverse

Thingiverse² is basically a database for free and open CAD designs of physical things. It is possible to browse through diverse categories or collections in order to find useful designs, which can be used and altered for own purposes, when posted under free license. The platform was established in 2008 by the company MakerBot Industries. Most of the designs can be produced in fab labs or at home with 3D-printers, CNC mills or laser cutters and can be downloaded from the homepage. The models are uploaded by both highly skilled experts, unexperienced users and everything in between. The focus of the homepage lies on the exchange and clean presentation of the designs (Figure 2.11), there are no sophisticated peer reviewing possibilities, since the homepage only offers simple commenting functions which are often only used to congratulate to a nice design. It has a clear representation of the objects and even offers dynamic 3D views of STL models.

Established platform for the exchange of personal fabrication designs.

Thingiverse has a huge user-base from the maker and personal fabrication community. Recently, they added an REST and JavaScript API to provide developers with an interface to access their user- and database and create stand-alone and mobile applications.

Thingiverse provides an API.

2.3.3 Conclusion

Stack Overflow introduces some interesting aspects: The tagging system allows sorting, which makes it possible to overview the questions' general topics without utilizing any other tools. The voting system, with its points and tagging, allows to differentiate the submissions' quality and organize the representation implicitly. It has the potential to solve the motivation problem. These approaches need to be considered for any peer learning platform.

Thingiverse, on the other hand provides a big heterogeneous user-base, related to the personal fabrication sector and can manage all important resources related to the open

²<http://www.thingiverse.com>

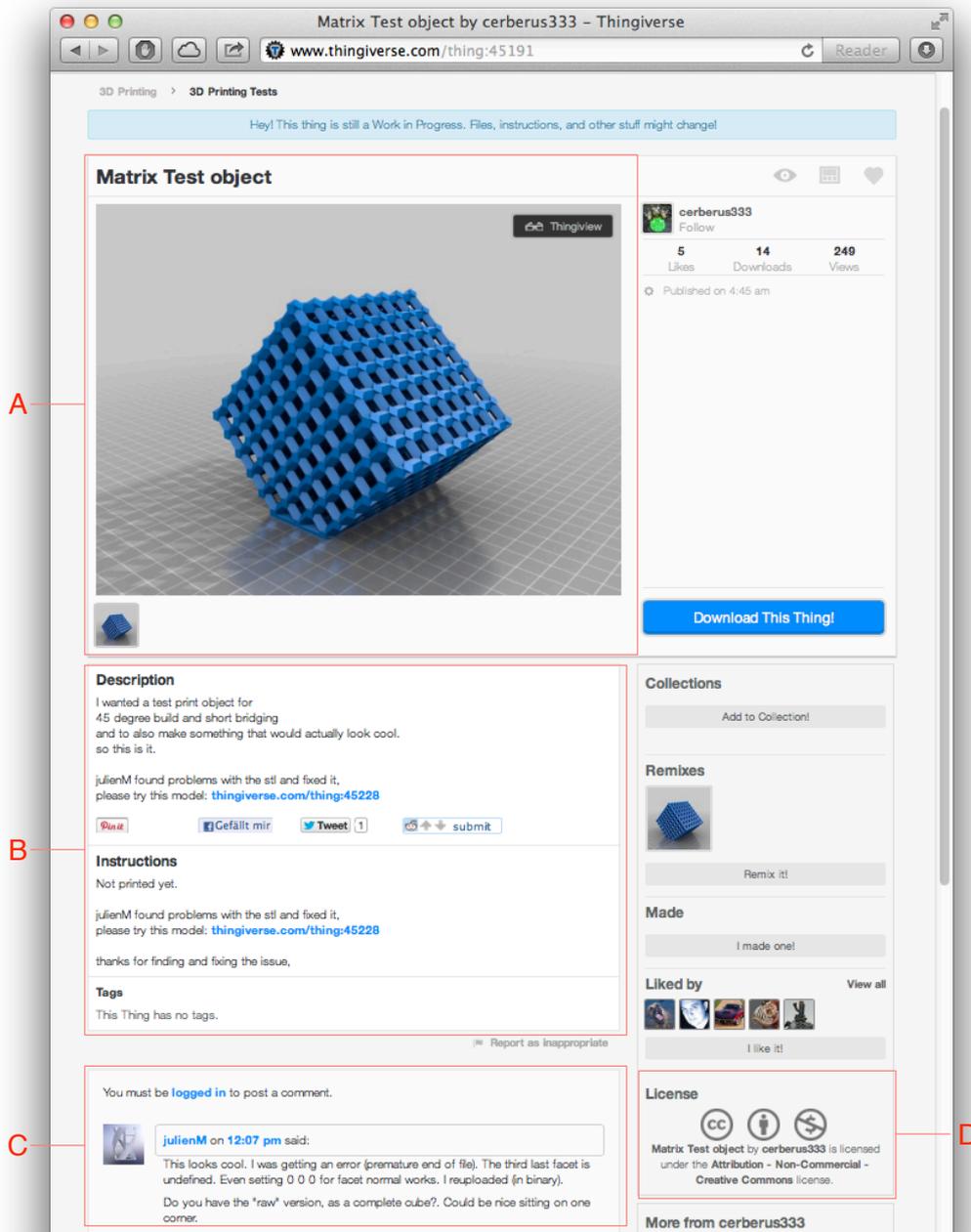


Figure 2.11: A clear view of the object a user uploaded to thingiverse (A). It contains some instructions from the creator (B), licenses under which it is published (D) and other user's comments (C).

design field. With the help of their API a peer learning platform could be build upon these advantages.

2.4 Framework for demand-driven learning platforms

In this section, we will describe a work from the University of Ottawa, which gives an overview of the target group of demand-driven web-based learning platforms and develops a theoretical framework for successful implementations.

2.4.1 The demand-driven learning model – A framework for Web-based learning *MacDonald et al. [2001]*

New technologies changed traditional learning forms. With the up-come of the internet, a lot of web based learning platforms emerged. The basic ideas behind their concepts are to allow people learning at any time and at any place. The basic concerns about these platforms are that they could isolate learners because of their impersonal and often not very interactive character, and in conclusion be less effective than traditional learning. Nevertheless, there is a demand for web-based learning platforms. Especially adults, who have no time to attend in physical courses due to their working life, people with economic disadvantages, people from developing countries or otherwise isolated from educational institutes, or students who seek an alternative to on-campus programs for a variety of reasons are interested in this form of learning. Their demand creates a market for education which is more accessible, convenient, flexible and effective than the traditional ways. This gap can be filled by cautiously designed web-based learning platforms. Their design has to be driven by pedagogical principles, critical thinking, and the possibility of exchange.

There is a demand for demand-driven online learning platforms.

There is a great potential for properly implemented platforms.

MacDonald et al. [2001] analyze the possibilities of existing learning platforms and come to the conclusion that they have the potential to deliver convenient, flexible and cost effective environments. They can allow access to a wide range of resources, which are up-to-date and expandable, and they are able to provide the possibility to interact and create a meaningful experience, if designed properly. On the other hand, if not designed very well, there is the danger of lower quality of instructions, use of uncertain materials and an exclusivity due to a leak of required technology. The analysis reveals strong evidence for the benefit of effective learning platforms for adults.

Researchers worked closely with the industry to develop a model for learning platforms.

This was the motivation for the development of a standard to guide the design process of future online programs. The goal was to set a quality standard for online learning grounded on the needs of the learner group as well as the needs of the instructors and designers. To achieve a superior model, the researchers first tried to identify the factors which impact the effectiveness of learning from education literature, and to guarantee the relevance and practicality of their model worked closely with international commercial web-based learning companies. The result was the demand-driven learning model (Figure 2.12).

The model consists of five basic parts: The “superior structure”, the three consumer needs (content, delivery and service) and the outcome. Additionally, it proposes a quality assurance process through ongoing evaluation which results in continual adaptation and improvement. The main parts in detail:

- **Superior Structure**

The theoretical foundation of the model.

This structure is the required theoretical foundation for the system to provide a desired level of quality. The consumers’ motivation and needs for content, delivery and service need to be anticipated and appropriately coined onto the learning environment, and the necessary pedagogical strategies to transport the content need to be chosen. The superior structure is an ongoing process which constantly incorporates the evaluation of the learners’ experience and convenience. Only after all details are successfully deter-

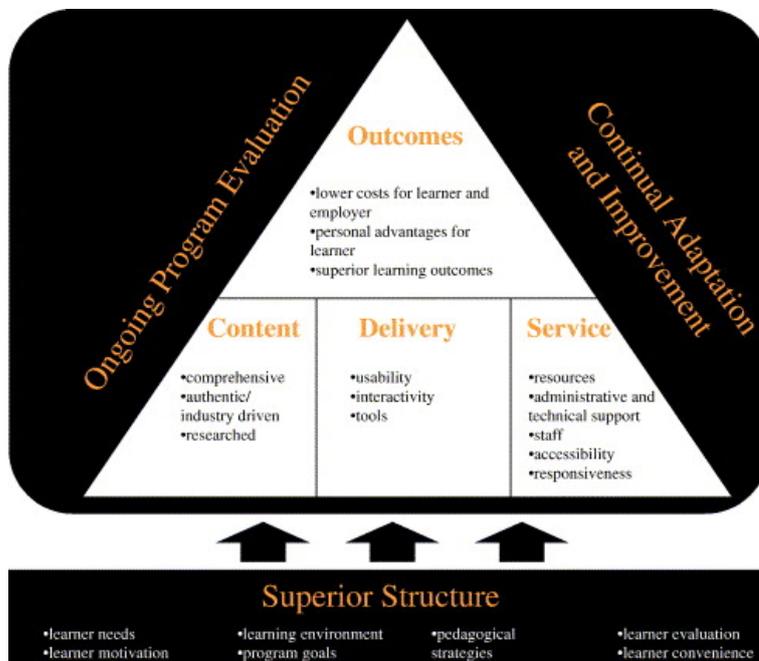


Figure 2.12: The demand-driven learning model for web based learning platforms [MacDonald et al. [2001]]

mined, a high quality learning environment system can be designed.

- **Content**

The need for high-quality content is part of the consumer needs. It has to be presented objectively, unbiased and should match the user's level of understanding. It needs an appropriate form and depth. The content should be authentic and cover subjects which arise in the field the user is interested in. It has to present concepts and skills which are meaningful in that particular area for the learner's goals. The content also should be researched, which means it needs direct input from professionals and needs to be validated or empirically researched.

Requirements for the system's content.

- **Delivery**

Delivery is another basic user need. Usability is a very important factor. The interface needs to be carefully crafted, there should be navigational support and the appearance should follow the standard

The delivery aspects need to be considered.

conveniences. Another critical aspect is the interactivity. The system should encourage the interaction between learners, content and professionals. The last important part are the tools used. There should always be a consideration between the technologies' benefits and limitations. Technical overkill has to be avoided; it should only support the objectives of the learner. The content delivered through the system has to offer the possibility to present itself in different forms (e.g. audio, video, pictures) to support various styles of learning.

- **Service**

Requirements for the system's service.

The last user need which has to be addressed is the demand for high-quality service. The provided resources have to assist the learners in identifying their needs and the way to meet them best. They should examine concepts from multiple perspectives and encourage social interaction. Administrative and technical support has to be freely accessible, and there should be an introduction for the users. The staff has to be both experienced and empathic to the learner needs. The system has to be easy to access and unconstrained. The amount of waiting should be reduced to a minimum to provide responsiveness.

- **Outcome**

The successful implementation of the model guarantees a well functioning learning environment.

If all of the model's principles are followed, it promises lower costs for learners in comparison to traditional learning environments. It provides personal advantages for the learners, such as no financial risks, no need to leave their jobs or to move away in order to educate themselves. The learning outcomes are expected to be satisfying, and the user can easily acquire new relevant skills and knowledge.

2.4.2 Conclusion

The principles presented by MacDonald et al. [2001] promise a successful web based peer learning platform. We will take them into consideration while designing FabFAQ.

Chapter 3

Own Work

In the previous chapter we presented the related work from the peer reviewing and learning field. With the lessons learned we will design and build FabFAQ in the next step, a demand-driven peer learning platform for the personal fabrication domain. Firstly, we present the results of a user study on the expectations for such a platform and identify the potential user-groups for it, then derive the systems requirements in 3.1.3, and afterwards describe the design and implementation phase in detail in chapter 3.2.3.

3.1 System Design

3.1.1 Initial User Study

To determine the general interest in personal fabrication we conducted an initial user study. The information was gathered by means of an online questionnaire, using the forms from google docs¹, and it was published through mailing lists and social networks. We briefly described the personal fabrication field to the users and explained very generally the vision of a learning platform. The complete questionnaires are attached in Appendix B. Overall fifty persons participated. All results are visualized in Figure

Questionnaire to determine users' interests.

¹<https://drive.google.com/>

The participants were from a variety of domains.

3.1. The demographic composition consisted of approximately 40% students from technological domains, followed by 20% persons who work in the IT sector and 10% researchers. The remainder of the participants' professions were widely spread, e.g. consisting of a dentist, designer, pharmacist, lawyer, social pedagogue and economist. The age span was between 22 and 44 years with an average of 28 years. There were 74% male and 26% female participants.

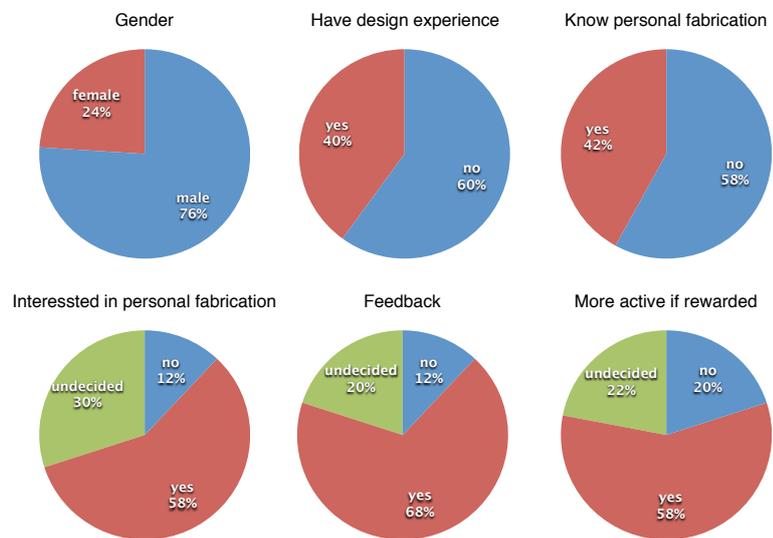


Figure 3.1: The results of the initial user study

Most users were interested in personal fabrication.

Exactly 40% of the participants had design experience of any form and nearly the same amount (42%) knew personal fabrication or had already worked in a fab lab. Since there is only a medium correlation of 0.46 between the two values, one can assume that even though there is a connection between the two domains, there are also people without any designing background who are interested in personal fabrication. This assumption is underlined by the fact that 58% would be explicitly interested in personal fabrication given there were no huge technical barriers, 30% were at least undecided and only 12% not interested at all. This supports the observations of the behavior of students in the original fab lab already discussed in 1.1. Next, the people were asked if they would benefit from a social network type platform where they could give and receive feedback of any form on their personal fabrication creation process. Nearly 70% agreed, and only 12% did not see any benefit in

such a portal. The participants were asked if they would be more active if this platform offered a reward system: 58% agreed, and only 20% did not believe they could be motivated through rewards. Finally, we optionally asked the participants how they would picture such a reward system. There were 12 responses to this question, where nearly half of them suggested a point-earning system with badges as rewards. Other popular answers were monetary benefits or the access to more resources.

In summary, the study showed an interest in personal fabrication of a heterogenous group of people from different domains. There is also a niche for a platform where the community can exchange ideas and concepts and benefit from each others' work and knowledge. As 3D printer and the whole field of personal fabrication are lately gathering more and more attention in the mass media, we expect this demand to grow even further in the future.

3.1.2 Early System Design and Prototype

The initial idea behind the work was to provide a web platform where the users would be able to store their design projects. The focus was more on reviewing than learning. The users' projects could consist of various file types, e.g. an STL-file for the design itself, a picture with a concept or a descriptive text. There should have been an automated file history to display a project's evolution through the changes in its resources. These projects should have been reviewed by other users and rated quickly on a five star scale which also gave the opportunity to write an essay about the project. All actions would generate points for the users which would result in badges and a ranking. This function was supposed to motivate the users and, after they have earned a few points, show their expertise and give their ratings a bigger weight. A key feature was the possibility to start brainstorming sessions following the Rohrbach 635 method. The results of each round would have been published to all participants after the completion of the process, to minimize the possibility of users leaving before the end. A part of the early prototype can be seen in Figure C.1 and completely in Appendix C.

Very early design ideas, including brainstorming capabilities.

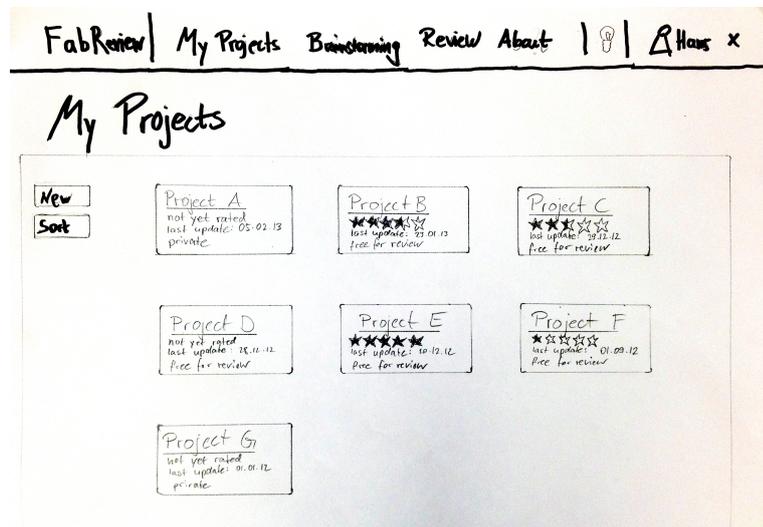


Figure 3.2: A very early paper prototype

The evaluation led to a redesign.

After internal evaluation and the discussion with HCI professionals most of this concept has been dropped. There were concerns that users would not like to upload their whole resources to yet another new platform and would not be motivated enough to review the work of others. For inexperienced users without resources there was not a satisfying possibility to represent their questions and allow them to learn from the resources gathered by the system. Even though an online brainstorming session was an interesting idea, its representation was not as satisfying as desired and it was very likely that the rounds would often not be finished, or would provide a satisfying user experience in their current form. The focus of the project was shifted more towards peer learning and less reviewing, and the whole user experience was expected to become simpler and, hence, more usable. The final system requirements crystalized.

3.1.3 System Requirements

The three main requirements can be listed:

- M1: Provide a usable system.
- M2: Lower the barriers for beginners and advanced users in the personal fabrication domain.
- M3: Offer a connection to the user's local fab lab and to the users' projects.

In addition to M1–M3, we define the following important requirements, which the final implementation should meet. They are closely related to the main ones:

- R1: Support many platforms.
- R2: Focus on solving users' problems.
- R3: Reward the users for constructive participation.
- R4: Include the users' resources.
- R5: Provide an organized structure.
- R6: Meet demand-driven learning model requirements.

M1: Usability

The usability is the key for all other concepts to work. A platform cannot survive if the users do not intuitively know how to operate the main functionality without much cognitive effort. This would distract a large user-group and the whole platform would fail due to lacking participation and few user-generated content. Since the goal of Fab-FAQ is to attract both beginners and advanced users the user interface has to be self-explanatory and comfortable to use, but also offer advanced functionality. The users should be able to instantly transform their knowledge of

Usability is a major goal.

standardized web user interfaces and be instantly able to access the functionality without consciously thinking about it. According to Norman [2002] the system's user interface should be designed user-centered. This means, it should at any time be easy for the user to determine which actions are possible, what can be achieved through the use of affordances and constraints. All actions, including the alternatives and outcomes, have to be visible at any time. The users always have to be aware of the state of the system it is currently in. The users' conceptual model of the system should map with the one the designer intended. We will follow natural mappings between the users' intentions and the resulting outcomes.

M2: Lower the Barriers for Personal Fabrication

The system has to lower the entry barriers for personal fabrication.

As already discussed in 1.1 and suggested by our initial user study, the interest in personal fabrication is interdisciplinary. The users do not necessarily possess the skills to design or operate the machines required and the users' skills sets are often diverse. Usually, as they encounter a problem, they share information with each other and profit from their experiences. This learning process requires the physical presence with like-minded individuals, for example in fab labs or group meetings. This form of gathering is not always available, especially when someone is employed. Of course, the internet offers a great pool of resources. But they are heavily distributed, not always exactly fitting to the personal problem, and the user feels isolated. FabFAQ wants to offer a central contact point, where a well-organized pool of resources is available and additionally can be extended to the user's special needs. The goal is to offer the personal and direct community interaction and learning possibilities independent from time and place and, hence, lower the barriers in the personal fabrication domain.

M3: Connection to Fab Labs

A connection to fab labs is important.

Users do not solely work on their creations alone at home. Only a minority is supposed to possess all the necessary ma-

chinery and tools which are needed to produce their designs. The majority of the people will at least infrequently visit labs or workshops where they craft their objects. They automatically get in face-to-face contact with like-minded people and develop relationships with them. The system has to allow them to easily find, organize, exchange, and help each other outside their labs, without being physically present. Another aspect is that a fab lab master could track questions or problems his users have and solve them faster, independent of office hours, which reduces the congestion on the open lab days, providing more slots and time for other projects.

3.2 Implementation

After identifying the requirements for the system, we began with the final implementation. Firstly, we present an interactive mock-up prototype of the final system, then describe the technology used and lastly discuss the final system's functions in detail.

3.2.1 Interactive Prototype

To craft the user interface and get a clear vision of the final implementation, an interactive mock-up prototype was created. It already had all desired functions implemented in order to evaluate the functionality and tweak the controls. To create this prototype, the Balsamiq Mockup Application² for MacOS X was used. It offers the possibility to rapidly draw user interfaces from a variety of standardized items and link functionality to the element, e.g. linkage between different views.

FabFAQ's general appearance and some minor elements, such as the navigation bar with its notification lightbulb and the user representation, were adopted from the early paper prototype. The main focus lay on tidying up the

The main concepts were evaluated using a mock-up prototype.

²<http://www.balsamiq.com/products/mockups>

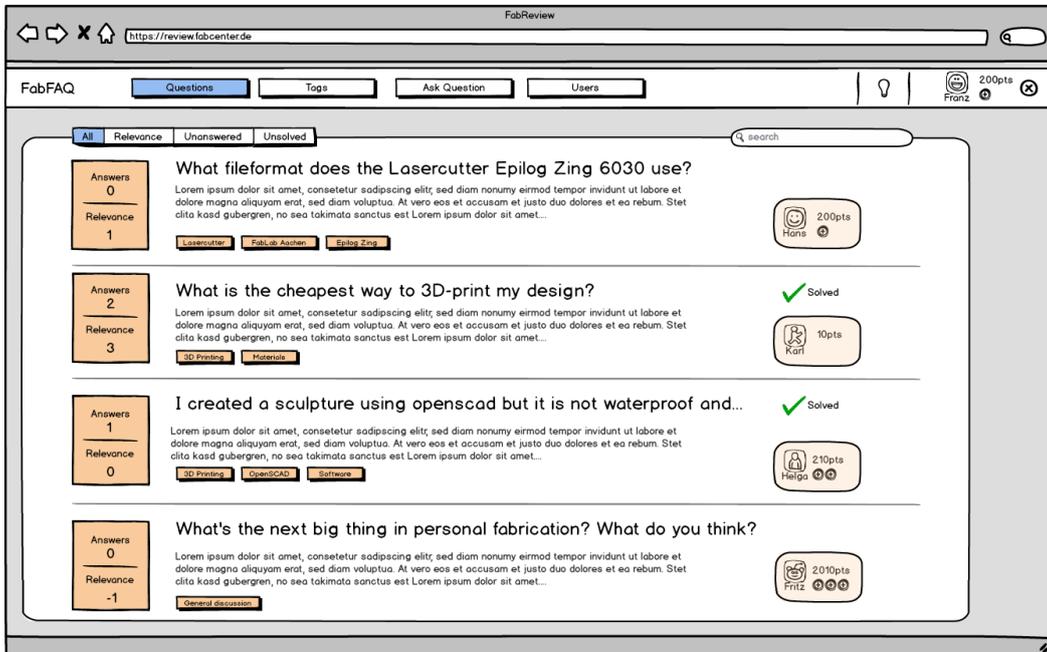


Figure 3.3: The start screen of the Balsamiq prototype

functions and concentrate on the main elements. The starting screen can be seen in Figure C.5 and all screens in the Appendix C. The basic functions “Questions”, “Tags”, “Ask”, and “Users” were located in the navigation bar. We will very briefly describe the main functions:

- “Questions” offers the possibility to browse the database for interesting submissions, which can be searched and sorted by different criteria.
- “Tags” allows to browse the database for certain catchphrases related to personal fabrication, and if they do not exist to add new ones.
- “Ask question” allows to post questions, enriched with tags and resources.
- “Users” shows a user ranking, depending on their contribution to the system.

This summary should only serve as a short overview. All functions will be discussed very detailed in the next chapter. After internal discussion and evaluation, we were confident with the prototype and decided to take it as the base for the evolution and implementation of FabFAQ.

3.2.2 Technology

In this section the technologies used for the final implementation are described.

The whole concept of FabFAQ depends on a broad and active user base, which generates content. It cannot be expected of a new platform to generate so much attention to instantly attract a huge number of people. Since Thingiverse³ released their API during FabFAQ's development phase, one very elemental design decision was to drop the concept of a standalone web application, and instead offer an extension to Thingiverse. This step offers the following advantages: Firstly, there is already a huge user base, enthusiastic to personal fabrication, which can instantly be accessed. It is one of the most popular platforms in the scene, from beginners, who only "consume" the work of others, to professionals. Additionally, Thingiverse already offers user accounts and manages and gives access to the user's resources. On the other hand, it does not support any sufficient peer learning or reviewing techniques yet, hence, FabFAQ can be a legitimate addition.

FabFAQ uses the Thingiverse API.

FabFAQ will use PHP⁴ on an Apache web server as server-side scripting language. Reasons for the decision were the maturity of PHP, the fact that it is freely available and its reliability running millions of web servers all around the globe.

FabFAQ is a web application.

Twitter Bootstrap⁵ is chosen for the web application's appearance. It is released under the free creative common license⁶ and offers a collection of HTML and CSS based

³<http://www.Thingiverse.com/developers>

⁴<http://php.net>

⁵<http://twitter.github.com/bootstrap/>

⁶<http://creativecommons.org/licenses/by/3.0/>

templates for typography, buttons, forms, and other interface components. The main reasons for this decision are the clear and visually appealing views and the standardization of the components, providing the users with known elements, reducing their cognitive load.

To extend the possibilities of the standard text areas `markItUp!`⁷ is being used. It is published under the GPL Open Source license⁸ and can be highly customized in its functionality. To ensure that inexperienced users can easily write contributions, we support BBCode. This means that a novice can basically format his question following the WYSIWYG paradigm. There is no need for any tags, i.e. a HTML `
` for a new line. On the other hand, the more experienced a user is, the more he is able to include a variety of media, links, and has a lot of typographical possibilities through using the BBCode. To display the contribution a free BBCode to HTML Parser⁹ is used.

In order to store, manipulate and access data, the server supports MySQL¹⁰. This is one of the world's most often used open-source relational database management systems.

Additionally, FabFAQ uses standard web technologies, namely HTML, CSS and JavaScript.

3.2.3 Final Implementation

In this section all functions of the final system will be described in detail. FabFAQ can be reached at <https://review.fabcenter.de>.

⁸<http://www.gnu.org/licenses/gpl.html>

⁹<http://www.jaysalvat.com/>

¹⁰<http://www.mysql.com>

Authentication

Web applications authenticate with Thingiverse using the OAuth2¹¹ workflow. It is visualized in Figure 3.4. By registering the application at Thingiverse for the first time, the developer receives a unique client ID and a client secret. When a user then visits the web application and wants to log in, he is redirected to the Thingiverse login page including the client ID as a parameter. With the help of this parameter Thingiverse identifies the application and asks the user if he really wants to access it; upon acceptance the user logs into his usual Thingiverse account (or creates a new one). In the next step, Thingiverse redirects a temporary code to the web application. It answers this code with its client ID and secret. This step ensures the web application's identity. Thingiverse then generates an access token for the user and the session and sends it to the application. With this token, the application can safely communicate with the Thingiverse server and access the user's data without knowing his sensitive login data. The user is then successfully logged in.

The OAuth2 authentication process is used.

All communications with Thingiverse happen through the REST API via HTTP requests. The FabFAQ backend utilizes the PHP cURL library for this process. All data is sent and received as JSON. This is an exemplary request for the user's data:

```
$tvurl = $tvurl.$accesstoken;
$curl = curl_init();
curl_setopt($curl, CURLOPT_URL, $tvurl);
curl_setopt($curl, CURLOPT_RETURNTRANSFER,
1);
$me = curl_exec($curl);
curl_close($curl);
$_SESSION['`me`] = json_decode($me, true);
```

Communication with Thingiverse is done via cURL requests.

First, the requested URL has the access token appended. Then cURL is initialized, the parameters "URL" and "RETURNTRANSFER" are set. The cURL request is executed and the result is stored in the variable "me", which finally becomes decoded from JSON into an array stored in the

¹¹<http://oauth.net/2/>

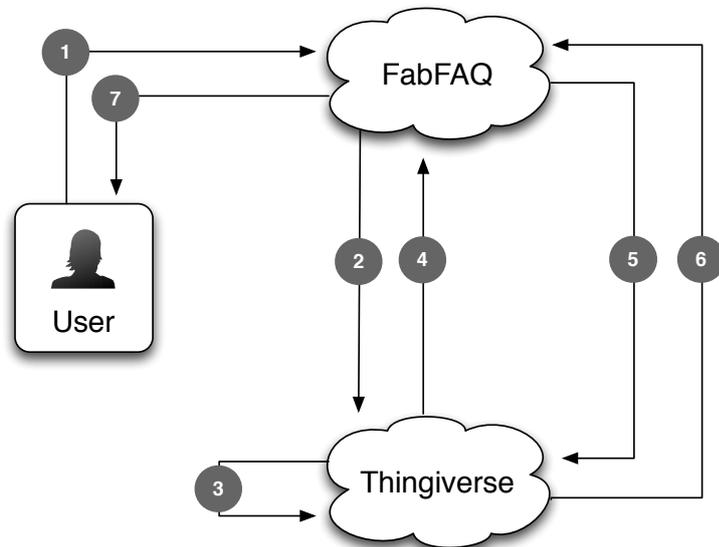


Figure 3.4: Scheme of the OAuth2 web application authentication process: [1] The user wants to log in. [2] He is redirected to Thingiverse including the application's ID. [3] User logs in at Thingiverse. [4] Thingiverse sends out a temporary code [5] FabFAQ authenticates itself with its ID and secret. [6] FabFAQ receives the access token. [7] User is successfully logged in.

session variable. All requests with Thingiverse are handled in that way.

Database Structure

To access, manipulate and store the data from Thingiverse and the user created content, FabFAQ uses a MySQL database. It consists of seven tables with several attributes, which can be examined in Figure 3.5. For example, the user data is stored in the table "userdata". It consists of the user ID, an 11 digit long integer which simultaneously is the primary key. The username is stored in a 45 digit long string. There are also fields for the points a user has earned, the URL of the public user profile at Thingiverse, his thumbnail and an indicator if there are any notifications for the

The database runs
on MySQL.

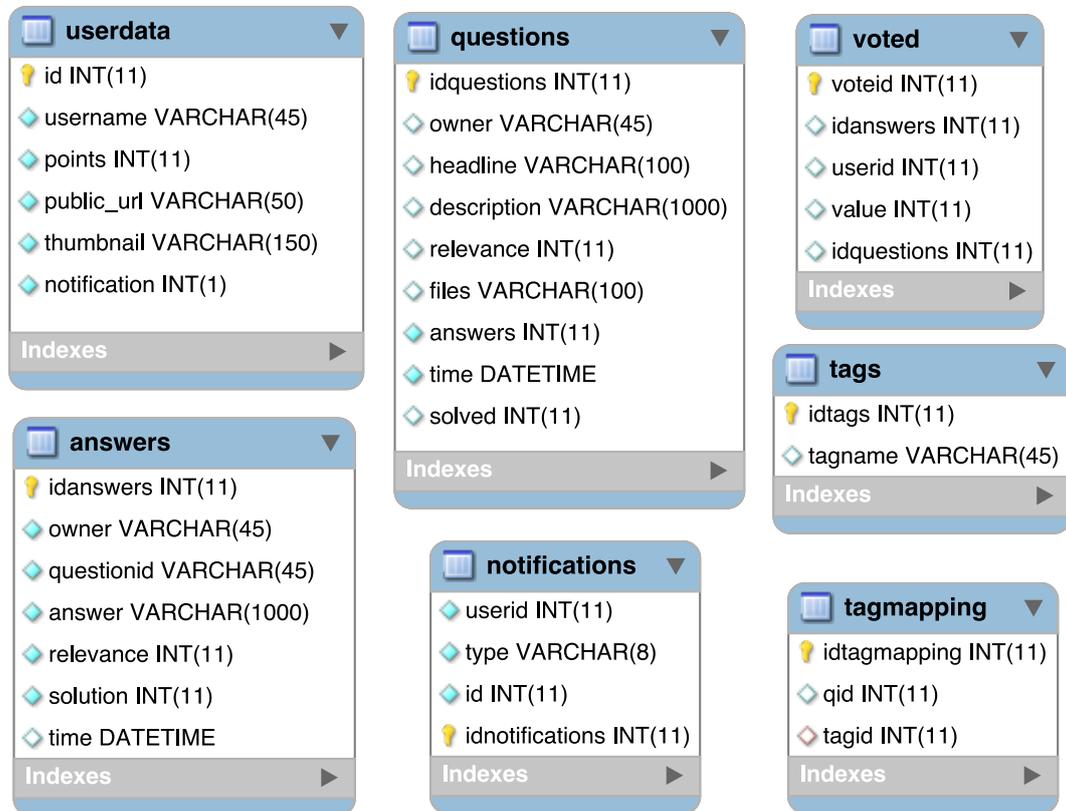


Figure 3.5: FabFAQ's database structure including all seven tables with their attributes and datatypes.

user. Every time a user logs in, the data is compared and updated if necessary.

The other tables will not be described in detail here; we will refer to them when the corresponding function is described. The Figure 3.5 can be utilized to get an overview and better understanding of the structures underlying FabFAQ.

The "Questions" Tab

After successfully logging in, the user starts in the "Questions" view (Figure 3.6). Here, the user sees a list of the newest contributions. Every question consists of a headline and a short preview of the text underneath. In addition, the associated tags are displayed. There are two boxes on

Overview of all elements of the questions section.

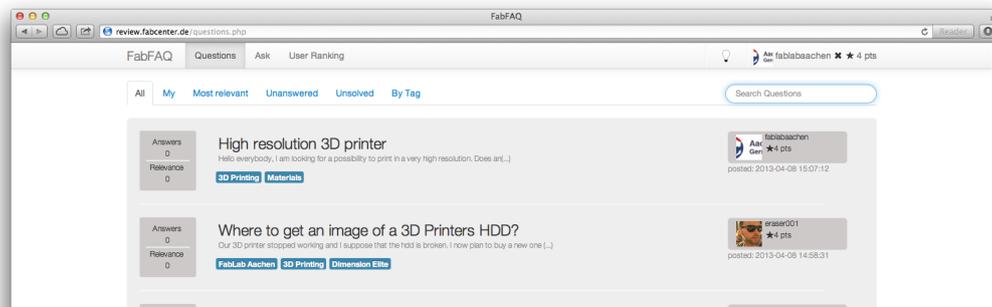


Figure 3.6: The Questions Screen.

each side; the left one shows the amount of answers and the relevance of this contribution. The relevance can be up and down voted by any user but the author and indicates the interest of the community regarding the topic. Important questions can gather a high relevance and, therefore, be answered with priority. The other box on the right hand side shows the author of the question, his reputation symbolized by the points and tags he earned and the date of the submission. By clicking on the user profile one is redirected to his Thingiverse profile. By clicking on the tags, all questions related to this tag are displayed.

FabFAQ provides possibilities to sort questions.

On top of the questions there are the navigation tabs. The standard view shows all contributions sorted by submission time. Through the other tabs the user is able to display only his questions, or can sort them by the relevance, the number of answers, or only display unsolved ones. On the right is a search bar, which allows a full-text search on the selected subset of questions. All search requests are performed via SQL requests to the questions table.

Tags assist in organizing the structure.

The last tab “By Tags” displays all available tags in the system. When it is selected, the search bar allows to search the tags instead of questions, which is indicated by its caption. Underneath the tags is a “Create New Tag” button (Figure 3.7). When using it, an input field appears, which allows to add new tags to the system that are instantly available. By clicking on a tag, all contributions related to it are displayed and can be searched by the search bar.

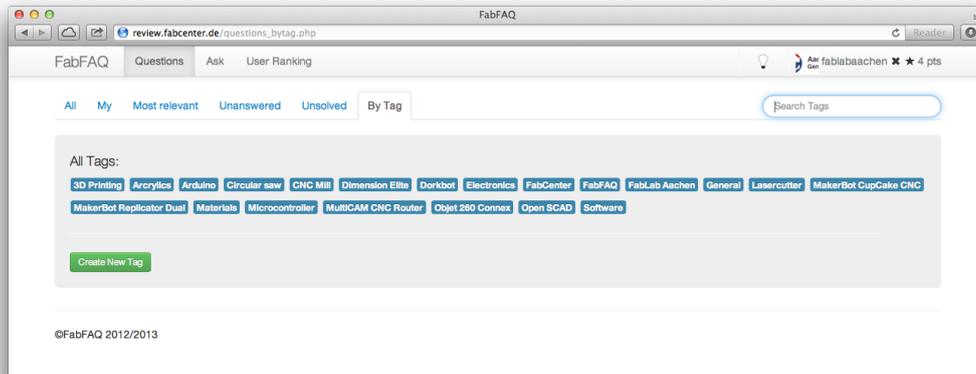


Figure 3.7: The Tag Screen.

After selecting a topic the user is interested in, he visits the detailed questions view by clicking on it. It consists of a detailed representation with all resources attached. For example, it is easy to attach a Thingiverse project to the question. Then the system automatically generates a picture and description of it and allows to expand a view with the instruction for the projects (Figure 3.8). It is also possible to include references to other resources. This will be described closer in 3.2.3. Here, the user can perform the actual up and down voting by pressing the green or red arrow. This is only one allowed in the detailed view, because the user is first intended to reflect on the content and then to vote. Only one vote per user is allowed on a question or answer.

Thingiverse
ressources can be
embedded.

Voting is supported.

To post an answer there is a “Write Answer” button at the bottom, which expands into an answer form. At the beginning, the form is hidden in order to lower the user’s cognitive load and allow him to focus on the content. When a question has received answers, the owner has the possibility to mark one answer as the solution (Figure 3.9). Once clicked, the question becomes marked as solved, and if there were more than one answers, the chosen answer gets moved to the top. The question does not appear anymore as unsolved. This function makes it easier for others to find the correct solution to a problem and differentiate between the answers’ quality.

Possibility to answer
a question.

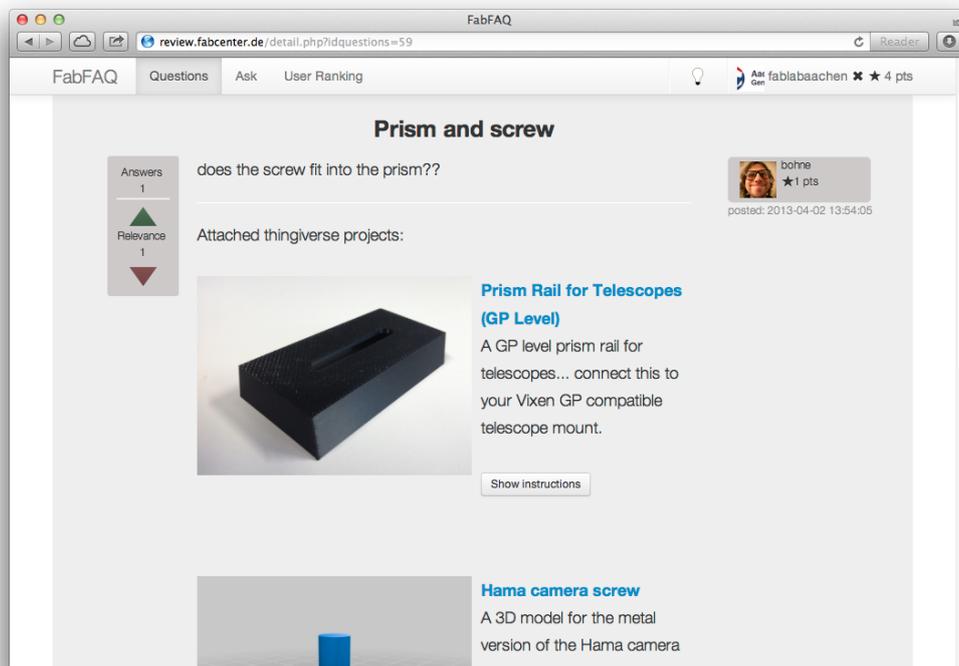


Figure 3.8: The detailed representation of a question.

The “Ask” Tab

BBCode is supported
to format
contributions.

When a user could not find a satisfying solution to his problem he can post his own question. This function can be accessed via “Ask” on the main navigation bar. The system offers a collection of forms (Figure 3.10), whereby the user can write the headline of his question in the first form. The second one offers the possibility for a detailed description of the question. This description can be written down without any formatting, but also offers the possibility to insert BBCode. There is a variety of symbols to assist in choosing the right tags. It offers the possibility to embed pictures (which the system scales if necessary), links, make lists, insert source code and much more. To guarantee a correct formatting, a preview can be enabled.

FabFAQ offers
attachable
thumbnails of
Thingiverse projects.

The next form shows all projects the user has in his Thingiverse account in form of a thumbnail list. It is possible to select or deselect them by simply clicking on the icon. As

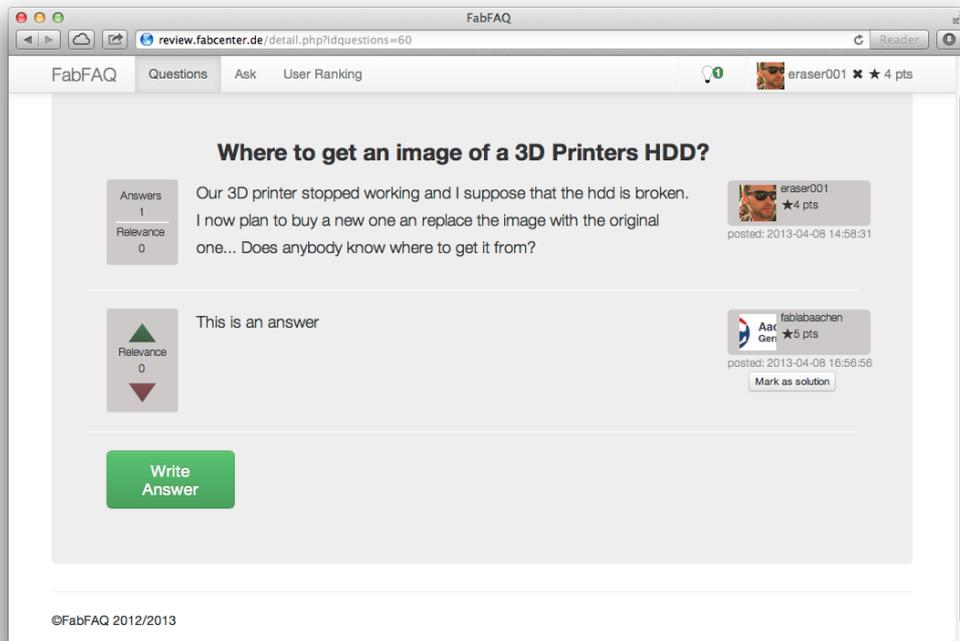


Figure 3.9: Possibility to mark an answer as solution.

mentioned before, the system auto-generates a picture with description according to the project. It also embeds a link to the corresponding project, if someone wants to examine it further.

The last form shows an alphabetically sorted list of all available tags in the system. The questions can be tagged, identical to the projects, by clicking on them. This helps to find relevant contributions to topics of interest later on.

Tags are being selected by clicking on them.

It is possible to hide the Thingiverse and tag overview to reduce the cognitive load and help the user to focus on his question.

After submitting the question, the code is checked and parsed into HTML and stored in the SQL database in the questions table. The user is redirected to the overview section, where he gets a notification that he successfully posted the question, and can directly view it.

Figure 3.10: Forms to assist the users in asking a question.

The “User Ranking” Tab

A ranking motivates users to participate.

The last main section is called “User Ranking”. Many actions the user can do generate points. When someone answers a question he earns a point. For every up or down vote on a user’s contribution, a point is added or subtracted. If an answer is marked as solution, the author gets two points. The points are openly displayed for everyone. On the one hand, the system allows to show the expertise of the users. Someone who has a lot of points is active and has contributed high quality content to the system. This can be seen by others and they can decide on how to weight his

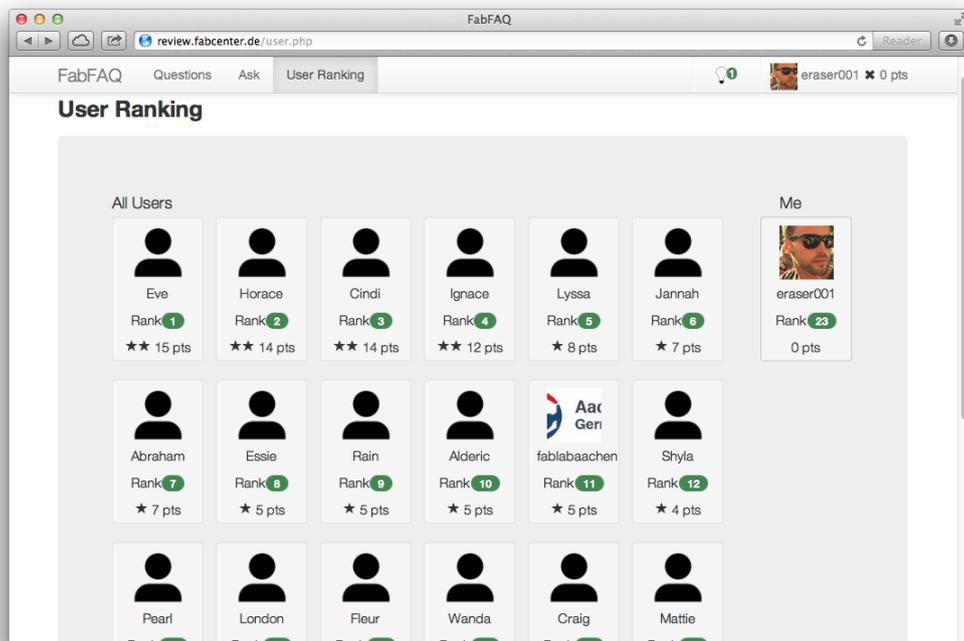


Figure 3.11: The User Ranking

answers on a topic in comparison to others. On the other hand, the users are motivated to participate in the system. They are rewarded for good contributions. Bad or destructive ones are down voted, which gives the originator a bad reputation. This is a self-regulation process, since it can easily be seen if a contributor or a contribution is useful without moderators actively interfering. After earning a certain number of points, the user receives badges in form of stars. The first one is earned after the first point, to encourage further participation and make the users familiar with the system.

This whole aspect of the system is visualized in the “User Ranking” (Figure 3.11). It is a list of the best users, sorted by their rank in comparison to the individual’s own rank. By clicking on a user, the Thingiverse profile is opened, showing more details of his work.

The system provides a self-regulating process.

The Notification Center

Users are informed about new events through the notification symbol.

To notify a user of important personal events, there is the notification center in the navigation bar. It is symbolized by a lightbulb which can take two states. If there are no events, it is just off. When a new event has taken place, which the user has not noticed yet, it is burning. When the new event is noticed (through a click on the lightbulb symbol), the lightbulb is switched off again. Additionally, the number of notifications is displayed through a tiny badge. By clicking on the notification center, a list of events appears (Figure 3.12). By clicking on one, the user is redirected to the event (i.e. someone answered his question), and the event is removed from the notification center. The list of events also includes the option to delete all events in case the user does not want to visit them and wants to clean up the notification center.

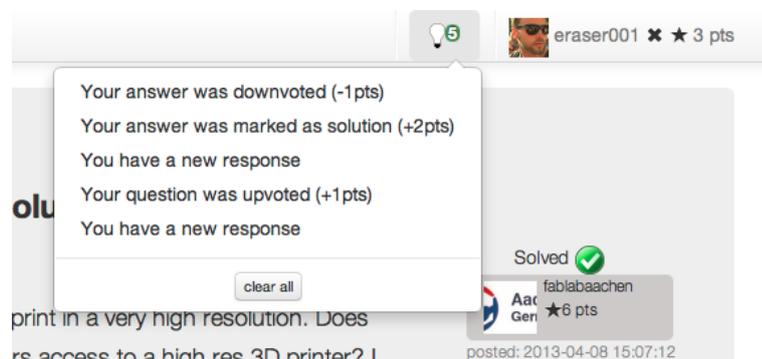


Figure 3.12: The notification center displaying several new events.

Possible notifications are up or down votes of answers and questions, when a contribution is marked as solution or when the user receives an answer. It also shows the points resulting from these actions.

Chapter 4

Evaluation

In this chapter, the final implementation will be evaluated. The evaluation consists of a qualitative user study in 4.1 in order to test the basic functionality of the system. In 4.2, the system's usability will be measured according to the System Usability Scale by Brooke [1996]. In 4.3, a heuristic evaluation of the system according to the demand-driven learning platform model (2.4.1) will be conducted, followed by a verification of the requirements in 4.4.

4.1 Qualitative User Study

The user test consisted of two tasks. The tasks, which represented the main functions of the system: The search and retrieval of information and the posture of a question including resources from the Thingiverse account. Afterwards, the participants received an answer and, hence, had the opportunity to become familiar with other functionalities, e.g. the notification center and the voting system. Twenty users participated. The complete questionnaire and evaluation form can be found in Appendix B. The participants were asked to fill out a five point Likert scale questionnaire regarding the tasks. A value of 1.0 means "strongly disagree", whereas 5.0 means "strongly agree". The results are discussed below, including references to the corresponding questions, their mean values and standard derivation in

The design of the user study.

brackets. We will use these conventions unless otherwise noted.

Task 1 tests the retrieval of information.

In the first, task the participants had to search for the settings of a laser cutter in order to cut 5mm strong acrylics. Every user succeeded in this task. Most of the participants used the search function for relevant terms, mostly “acrylics laser cutter”. The results are visualized in Figure 4.1.

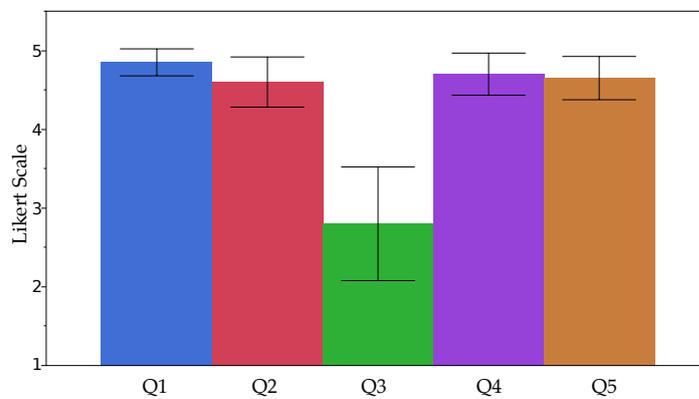


Figure 4.1: Evaluation of the first task. Overall, the testers agreed that they could fulfill this task easily. According to the Likert scale a score of 1.0 means “strongly disagree”, whereas 5.0 means the opposite. The error bars indicate the 95% confidence interval of the mean.

The task is very easy to perform.

The testers agreed that it was easy to navigate through the questions (Q1: $M = 4.85, SD = 0.37$) and found it very simple to find the solution (Q2: $M = 4.6, SD = 0.68$) in a short amount of time (Q4: $M = 4.7, SD = 0.57$). Even though the system provides indicators for the possible quality of the contribution (solved mark, relevance count and amount of author’s points) not all participants found it easy to determine the quality of the contribution (Q3: $M = 2.8, SD = 1.54$). Overall, all testers were satisfied with the way the system allowed them solve the problem (Q5: $M = 4.65, SD = 0.59$).

Task 2 lets the users post a question.

In the second task, the testers had to post a question regarding the best material for a 3D print of one of their projects. The project was already stored in their Thingiverse account

and they had direct access to it through the “Ask” section. After posting the question, the participants received a response, examined the notification center and had the opportunity to rate and mark it as solution. Again, all testers succeeded. Figure 4.2 shows the results of the questionnaire.

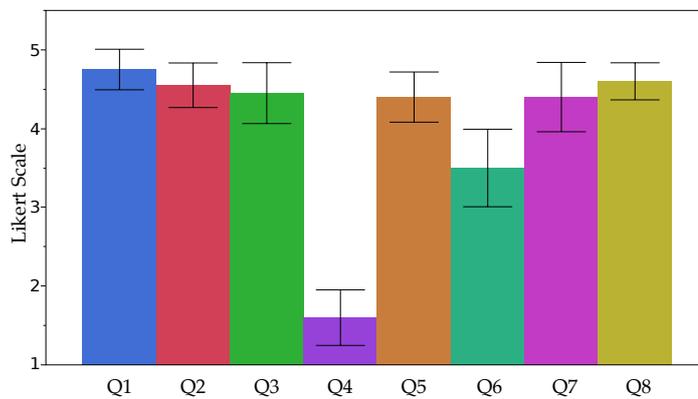


Figure 4.2: Evaluation of the second task. Overall, the testers could fulfill this task easily. According to the Likert scale a score of 1.0 means “strongly disagree”, whereas 5.0 means the opposite. The error bars indicate the 95% confidence interval of the mean.

The participants found it very easy to post the question (Q1: $M = 4.75, SD = 0.55$). It was clear to them what each form meant (Q2: $M = 4.55, SD = 0.60$) and they disagreed that the amount of forms, especially the unusual Thingiverse projects and tags form, were distracting (Q4: $M = 1.6, SD = 0.75$). The testers had no problems in selecting the appropriate tags (Q3: $M = 4.45, SD = 0.83$) and found the tagging useful (Q5: $M = 4.4, SD = 0.68$). The participants were not completely satisfied with the way they were notified about important events (Q6: $M = 3.5, SD = 1.05$). Most of the users stated that the symbol was too inconspicuously placed. The testers liked the voting and marking system and would use it frequently to reward positive contributions (Q7: $M = 4.65, SD = 0.59$). Overall, the users were satisfied with how easy it was to use the system in this condition (Q8: $M = 4.6, SD = 0.50$).

This task also is very easy to perform.

In summary, one can state that the system's main functionality is well-integrated and easy to use. It is not fraught with obstacles and empowers even inexperienced users in successfully utilizing it. Nevertheless, the study showed also minor details which can be improved. This will be discussed in detail in chapter 5.

This user test evaluated only the main functions of the system with artificially inserted content. It would be very interesting to deploy the system and start a longer field study with users who generate natural content. The evaluation of the quality of the user generated content and the system's influence on the quality is beyond the scope of this work.

4.2 System Usability Scale

In addition to the qualitative user study the System Usability Scale proposed by Brooke [1996] was utilized. It is a tool to quickly determine a system's usability on a 0–100 scale. After getting familiar with a system, evaluators had to weight ten statements about the system with the help of a five item Likert scale. The statements were:

- SUS1: I think that I would like to use this system frequently.
- SUS2: I found the system unnecessarily complex.
- SUS3: I thought the system was easy to use.
- SUS4: I think that I would need the support of a technical person to be able to use this system.
- SUS5: I found the various functions in this system were well-integrated.
- SUS6: I thought there was too much inconsistency in this system.
- SUS7: I would imagine that most people would learn to use this system very quickly.
- SUS8: I found the system very cumbersome to use.

- SUS9: I felt very confident using the system.
- SUS10: I needed to learn a lot of things before I could get going with this system.

The results of FabFAQ are shown in Figure 4.3.

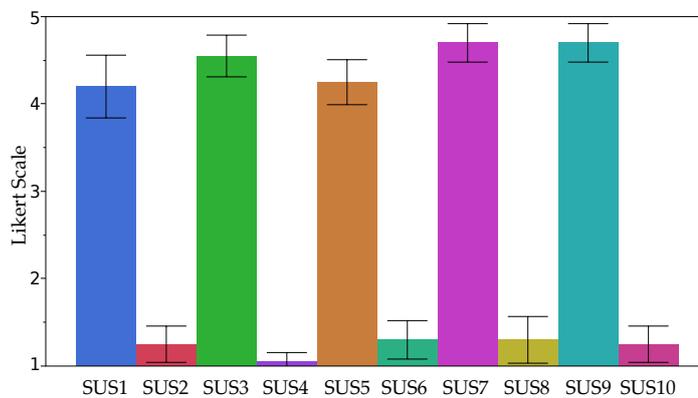


Figure 4.3: The results of the System Usability Scale test ($N = 20$). According to the Likert scale, a score of 1.0 means “strongly disagree”, whereas 5.0 means the opposite. The error bars indicate the 95% confidence interval of the mean.

FabFAQ has scored 90.63 points out of 100. Principally, this is a very satisfying result, but it is difficult to classify it, since there are no comparable systems from the personal fabrication sector. But even though the result has to be seen cautiously, it clearly indicates the good usability and learnability of the system.

The system achieved a high SUS score.

4.3 Heuristic Evaluation

In this section the demand-driven learning model (presented in 2.4.1) is the base for a heuristic evaluation. By meeting the requirements, FabFAQ can be considered as a well-functioning demand driven learning platform. First, the main principles were transformed into a sequence of statements, which are evaluated afterwards with the help

The demand-driven learning model needs are evaluated.

of a Likert scale. We firmly present the list of questions, followed by the part of the model it represents in brackets. Since the system has already proven to be usable, this particular point will not be further considered.

- HE1: The system satisfies my needs (Superior Structure).
- HE2: The system motivates me in participating (Superior Structure).
- HE3: The goals of the system are visible (Superior Structure).
- HE4: I can see a pedagogical strategy (Superior Structure).
- HE5: The content has an appropriate level of understanding (Content).
- HE6: I feel confident with the content's authenticity (Content).
- HE7: I am satisfied with the representation of the content (Content).
- HE8: The system is interactive (Delivery).
- HE9: The technology behind it does not distract me from my goals (Delivery).
- HE10: The resources the system can provide are sufficient for my needs (Service).
- HE11: The system is responsive (Service).
- HE12: I can access the system easily from everywhere (Service).

The heuristic evaluation was conducted by twenty reviewers, who were familiar with the system. The results for HE1-HE12 are visualized in Figure 4.4

The results show that most of the aspects of the demand driven learning platform were successfully met. Except for HE4 ($M = 3.4, SD = 1.1$), every statement lies in between

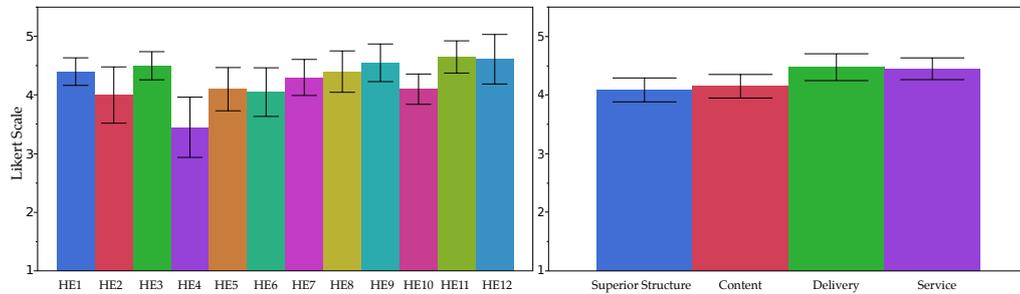


Figure 4.4: The results of the heuristic evaluation ($N = 20$). According to the Likert scale a score of 1.0 means “strongly disagree”, whereas 5.0 means the opposite. The error bars indicate the 95% confidence interval of the mean. On the left hand side are the results for HE1–12, on the right hand side the cumulated values for the main parts of the demand-driven learning model.

$M = 4$ (HE2 with $SD = 1.03$) and $M = 4.65$ (HE11 with $SD = 0.59$). The second part of Figure 4.4 shows the cumulated values for the model’s main parts, which all lie above the “agree” threshold. The system satisfies the model’s demands and, hence, is a low cost, superior learning platform with personal advantages for the learner. In addition, this evaluation also reveals further aspects which can be improved in the future (following the ongoing evaluation suggested by the model). This will be further pursued in chapter 5.

The model’s requirements are met.

4.4 Requirements Analysis

After evaluating the system, we can now show that all requirements are met by the implementation.

The three main requirements are met:

- M1 (usability): The main functions have proven to be very easy to conduct. The user tests indicated a very usable system without any major constraints. In addition, the system achieved a very high System Usability Scale score.
- M2 (lower barriers for personal fabrication): The system is usable and meets the requirements for

a well-functioning, demand-driven online learning platform. Hence, it generates a central database concerning all upcoming questions from the field and assist in the learning process. This lowers the barriers for all users.

- M3 (connection to fab labs): The connection can be easily made through tagging the contribution with the corresponding local fab lab tag. All results concerning the fab lab can then be separately displayed and accessed. It is instantly possible to see if the problem is solved or heavily discussed. The tagging system was very well accepted in the user tests.

The six important requirements R1-R6 are also met:

- R1: The system is a web application and, hence, supports nearly all platforms, either desktop or mobile.
- R2: The users' questions build the base of the system, the main focus lies on solving them and, through this, generating a knowledge database.
- R3: All actions, which help the users in achieving their goals, generate points which manifest in badges and reputation for the users. The study showed that this system is well-accepted.
- R4: Users can attach all their Thingiverse resources in the "post question" dialog with simply one click.
- R5: The appearance of the system is very well accepted by the users. The structure of the system is organized through participation and voting, and implicitly offers an auto purification.
- R6: The heuristic evaluation showed that all basic principles of the demand-driven learning model are met.

Chapter 5

Summary and Future Work

5.1 Summary and Contributions

In this work, the style of learning and working in the personal fabrication domain was examined. It crystalized that a lot of demand-driven peer learning and reviewing techniques were utilized. To better understand this phenomenon, the field of peer learning and reviewing in other domains was examined. From a variety of reviewing techniques and peer learning systems we extracted requirements for a system which aids the people in the personal fabrication domain in their creation and learning process and presented a model for successful peer learning web platforms.

The peer learning and reviewing field was examined.

On the basis of these requirements and the model, we described the design of FabFAQ, a demand-driven learning platform for the personal fabrication domain. We showed various design-implement-analyze cycles, from an early paper prototype over a refined mock up prototype to the final implementation of the system. All technology used was described in detail, along with all functions the system provides.

A learning platform for personal fabrication was presented.

User studies indicated the system's quality.

The final system was evaluated in three steps: A qualitative user study of the main functions was conducted, the System Usability Scale was determined, and a heuristic evaluation on meeting the model's requirements was conducted. The system proved to be usable and accepted by the users.

FabFAQ transports the learning process observed in fab labs into the ubiquitous web.

The main contribution of this work is the transfer of the observed demand-driven peer learning process of people from the personal fabrication domain into the ubiquitous internet, and, hence, allows them to solve the problems they encounter faster and contemporary. They do not need to wait for the next open fab lab day, but can directly search for an answer or ask the community in a central location. In addition, the system provides a connection to fab labs and can help the fab lab users and masters to assist each other in a faster and more comfortable way.

5.2 Future work

The user tests showed a few minor points which could be improved in the final system:

The notification center needs improvement.

Regarding the usability, a lot of users have initially not noticed the notification center. To solve the problem it could be moved from the right corner to the middle. In addition, the system could provide an overlay at the very first login, which shows the symbol and explains it. The notification center's behavior can additionally be improved: When a user visits a contribution for which he has several notifications, all should be removed automatically and not only the one the user has clicked. By navigating to an answer through the center, the system should automatically scroll to the respective position on the web page.

Editing capabilities need to be implemented.

The system does not yet offer any editing capabilities. The users should be able to edit their contributions after posting. In addition, we suggest a subtle comment function for each contribution, contrary to the heavyweight answer functionality. The votes should also be reversible to avoid accidental triggering.

The preview function should not only display the detailed description of the contribution, but show a preview of the final html representation with projects and tags attached.

The search by tag function should offer the possibility to select multiple tags and not only one, and the create new tag button should also appear in the “post question” dialog, to empower the user in creating new tags without leaving the current view.

Minor UI improvements are needed.

The question search bar and the forms should provide an intelligent autocompletion which directly shows existing and closely related contributions to avoid duplicate posts.

The connection to Thingiverse could be further improved, e.g. it could show the projects last visited and also allow to attach them to the contribution.

A long term study on the influence of the system on its content’s quality would be very interesting and could provide further insights.

Long time study on content’s quality.

The idea of brainstorming sessions, dropped early in the development process, has a high potential and could be investigated further. Especially the problem of motivating users to complete the sessions and the representation of the rounds are unresolved problems.

Brainstorming offers further potential.

More sophisticated pedagogical strategies than the reward system could be further investigated and adjusted to the system and could provide a more efficient learning experience.

Appendix A

The Fab Lab Charter



The Fab Charter

What is a fab lab?

Fab labs are a global network of local labs, enabling invention by providing access to tools for digital fabrication

What's in a fab lab?

Fab labs share an evolving inventory of core capabilities to make (almost) anything, allowing people and projects to be shared

What does the fab lab network provide?

Operational, educational, technical, financial, and logistical assistance beyond what's available within one lab

Who can use a fab lab?

Fab labs are available as a community resource, offering open access for individuals as well as scheduled access for programs

What are your responsibilities?

safety: not hurting people or machines

operations: assisting with cleaning, maintaining, and improving the lab

knowledge: contributing to documentation and instruction

Who owns fab lab inventions?

Designs and processes developed in fab labs can be protected and sold however an inventor chooses, but should remain available for individuals to use and learn from

How can businesses use a fab lab?

Commercial activities can be prototyped and incubated in a fab lab, but they must not conflict with other uses, 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

draft: October 20, 2012

Figure A.1: The fab lab charter^a

^a<http://fab.cba.mit.edu/about/charter/>

Appendix B

User Questionnaires

B.1 Initial User Study

Hardware Design Reviewing Survey

Thanks to the spread of digital fabrication labs (workshops where you have free access to computer aided production machines like 3D printer, CNC mills, laser cutter...) it is possible for everyone to produce his design ideas in a near industrial quality. Because of the open community character a broad variety of users, from absolute beginners to computer aided design experts, is addressed. This is amplified through the increasing appearance of easy-to-use tools.

Our research goal is to aid this widely spread group of people to exchange and review thoughts, designs, knowledge and skills in a fablab near social network environment.

Thank you for helping us by participating in this questionnaire.

Your answers may be published in anonymized form. Under no circumstances shall this data be published or be otherwise made available to a third party without prior removal of all personally identifiable data.

* Required

Demographical Questions

Age *

Gender *

- Female
 Male

Profession *

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Figure B.1: Initial user study page 1

Hardware Design Reviewing Survey

* Required

Designing and Personal Fabrication

Do you have any designing experience at all? *

- Yes.
 No.

Have you heard of personal fabrication before or worked in a fablab? *

- Yes.
 No.

Have you heard of peer reviewing before? *

- Yes.
 No.

Would you be principally interested in personal fabrication given there was no technical or handling barrier? *

- Yes.
 No.
 Don't know.

Would you share your designs with other people? *

Designs can be 3D models, pictures, ideas...

- Yes, with everyone.
 Yes, within groups (friends, colleagues...).
 No.
 Depends on the project.
 Don't know.
 Other:

Would you appreciate to get feedback of any form on your work/idea/design from the community? *

- Yes.
 No.
 Don't know.

Figure B.2: Initial user study page 2

Hardware Design Reviewing Survey

* Required

Feedback

Imagine you are using a social network like platform for sharing your designs. It is possible to search for others and comment on them. You can also allow other people to use your work, change it for their purposes and vice versa.

The design could be for example a 3D model of an object, a picture or a textual description of an idea.

Could you imagine to (at least eventually) let the other people use your designs? *

- Yes.
 No.
 I don't know.

Would you like to receive feedback in form of a one dimensional scale (like 5 stars, percentage, scale from 1 to 10...)? *

1 2 3 4 5
 strongly agree strongly disagree

Would you like to receive feedback in form of a multi dimensional scale (consists of a few scales for different aspects which cumulate into an overall scale)? *

1 2 3 4 5
 strongly agree strongly disagree

Would you like to receive feedback in form of a multi dimensional scale (as above but without a cumulated scale)? *

1 2 3 4 5
 strongly agree strongly disagree

Would you like to receive feedback in form of written reviews/hints/text? *

1 2 3 4 5
 strongly agree strongly disagree

I would like to use another rating strategy:

Figure B.3: Initial user study page 3

Would you rate/comment more designs if there was a reward system for reviewers? *

Yes.

No.

Don't know.

How could you imagine such a reward system to look like?

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Figure B.4: Initial user study page 4

Hardware Design Reviewing Survey

* Required

Brainstorming

Imagine you are trying to evolve a new idea for a project or solve a problem you have.

Would you like to start an online brainstorming session with other users? *

- Yes, with everyone who wants to attend.
- Yes, within invite-able groups.
- No.
- I don't know.

« Back

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Figure B.5: Initial user study page 5

Hardware Design Reviewing Survey

Comments

Do you have any suggestions or comments?

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Figure B.6: Initial user study page 6

B.2 Qualitative User Study

Participant ID: _____

FabFAQ – Qualitative Evaluation

Form of Consent

I agree that the data generated in this study will be stored and analyzed for research purposes within the FabFAQ project. I agree that this data may be published in anonymized form. Under no circumstances shall this data be published or be otherwise made available to a third party without prior removal of all personally identifiable data.

Aachen, _____
(Date) (Signature)

Initial Questionnaire

Gender: male female

Age: _____

Profession/field of study: _____

Please rate your familiarity with...

Personal Fabrication unknown very familiar

Thingiverse unknown very familiar

Figure B.7: The consent form of the qualitative user study.

Task 1

You want to use your new Laser-cutter for the first time. After reading the manual you are familiar with operating the machine.
To test it you want to cut 5mm strong acrylic. Unfortunately you do not know the settings for cutting it.

Search for the solution using FabFAQ.

Task 2

You have created a 3D model which is already stored in your Thingiverse account. You want to 3D print it soon, but you do not know which material is the best suited for it.

Post your question using FabFAQ and try to include the resources you need.

Figure B.8: The tasks of the qualitative user study.

Participant ID: _____

The system is responsive	strongly disagree	<input type="checkbox"/>	strongly agree				
I can access the system easily from everywhere	strongly disagree	<input type="checkbox"/>	strongly agree				
I think that I would like to use this system frequently	strongly disagree	<input type="checkbox"/>	strongly agree				
I found the system unnecessarily complex	strongly disagree	<input type="checkbox"/>	strongly agree				
I thought the system was easy to use	strongly disagree	<input type="checkbox"/>	strongly agree				
I think that I would need the support of a technical person to be able to use this system	strongly disagree	<input type="checkbox"/>	strongly agree				
I found the various functions in this system were well integrated	strongly disagree	<input type="checkbox"/>	strongly agree				
I thought there was too much inconsistency in this system	strongly disagree	<input type="checkbox"/>	strongly agree				
I would imagine that most people would learn to use this system very quickly	strongly disagree	<input type="checkbox"/>	strongly agree				
I found the system very cumbersome to use	strongly disagree	<input type="checkbox"/>	strongly agree				
I felt very confident using the system	strongly disagree	<input type="checkbox"/>	strongly agree				
I needed to learn a lot of things before I could get going with this system	strongly disagree	<input type="checkbox"/>	strongly agree				

Figure B.10: The evaluation form of the qualitative user study.

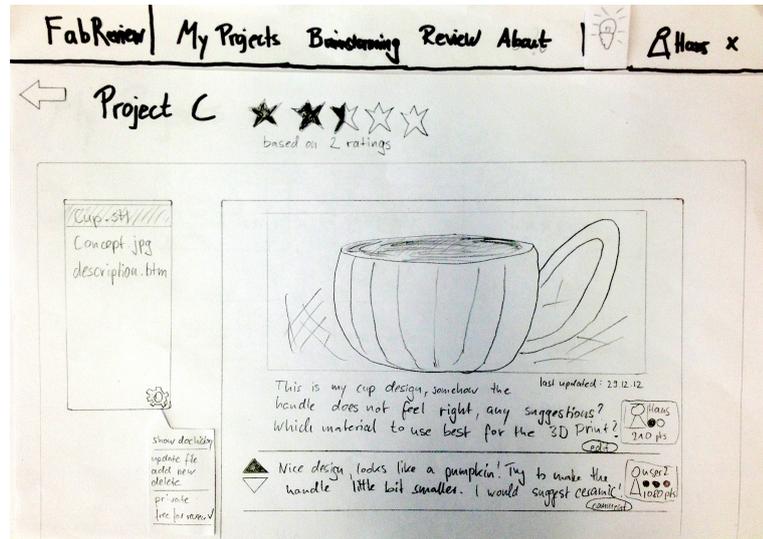


Figure C.2: A project in detail with the associated resource browser

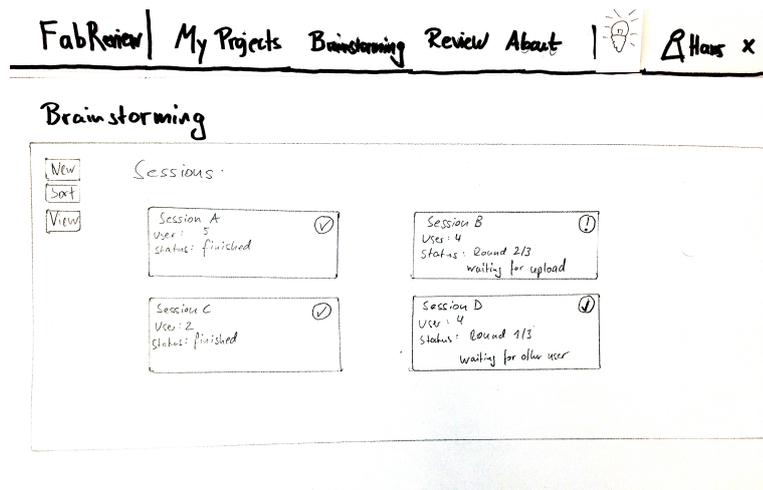


Figure C.3: The Brainstorming overview screen

FabReview | My Projects Brainstorming Review About | | Hours x

← Session B (active)

	Initial	Round 1	Round 2	Round 3
You	You uploaded	User 4 uploaded	User 2 uploaded	User 3
User 1	User 1 uploaded	User 2 uploaded	User 3 not yet uploaded	You
User 2	User 2 uploaded	User 3 uploaded	You have to upload Found File	User 4
User 3	User 3 uploaded	You <input type="checkbox"/> uploaded	User 1 not yet uploaded	User 2

Figure C.4: View of an active brainstorming session

C.2 Interactive Prototype

Images of the final interactive mock-up prototype:

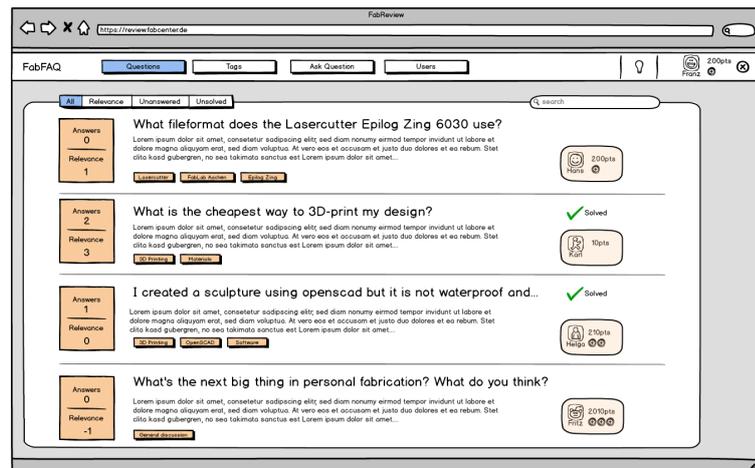


Figure C.5: The prototypes question screen

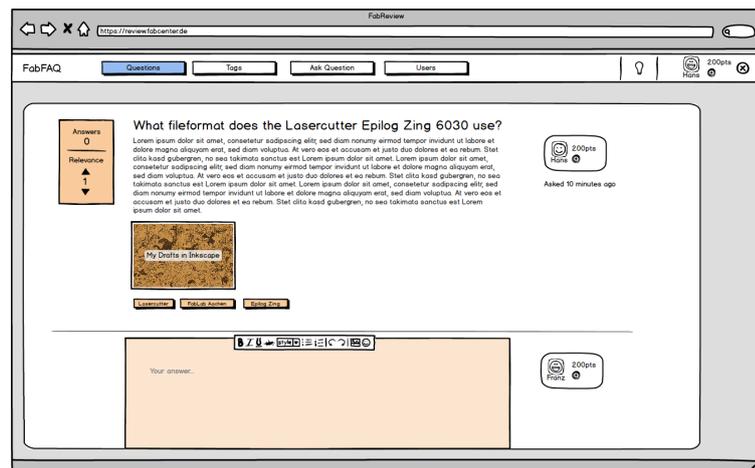


Figure C.6: A question in detailed view, including answer form.

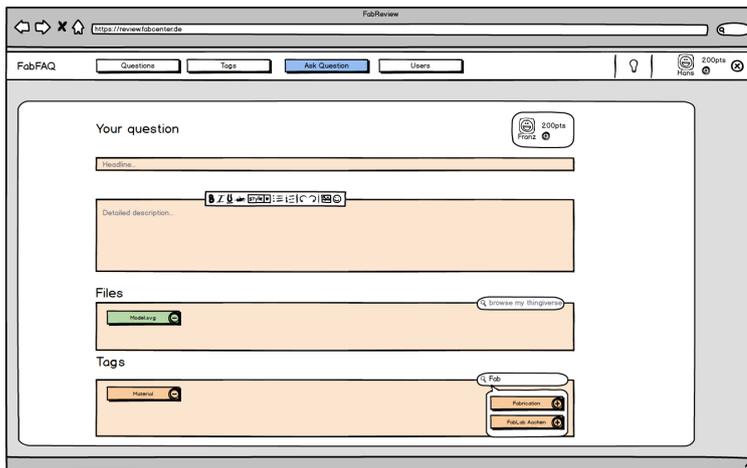


Figure C.7: The ask a question screen with resources and tags.

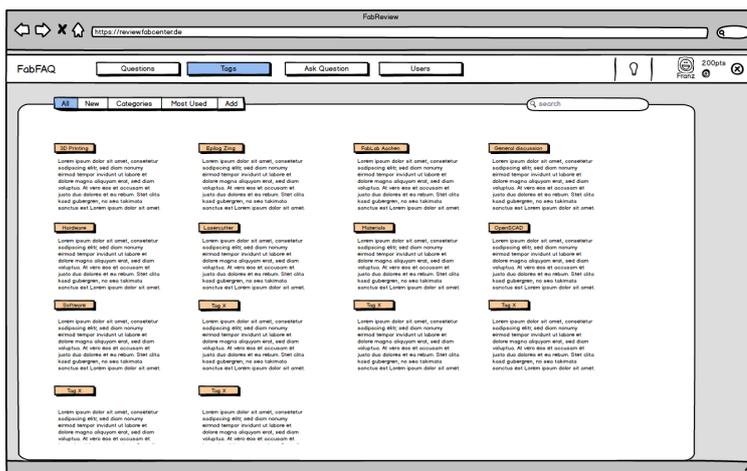


Figure C.8: Overview of the Tags

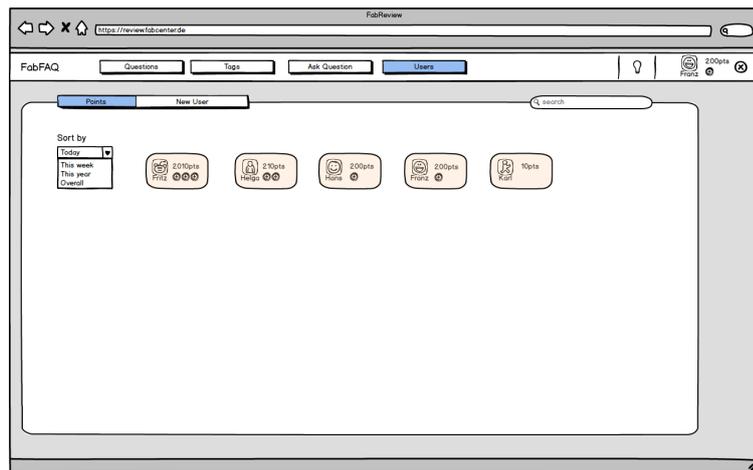


Figure C.9: Detailed view of own projects

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