Eco-Design-Sprint for Makers: How to make makers think about the sustainability of their products

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Abstract

Digital fabrication provides people with a range of opportunities to produce innovative products. These range from small to large, e.g. micro-controllers, drones, Internet-of-Things-devices, motorized vehicles, orthotics, machines and even houses. The possibilities seem to be unlimited and FabLabs, Maker-Spaces, or similar community places are promoting this development. However, not many of these makers completely consider the sustainability of their products. Quite often, questions of environmental friendly material, manufacturing procedures, or end-of-lifecycle questions are not of major relevance for the maker.

To create a new mindset of eco-friendly makers, we set up a so called Eco-Design-Sprint approach and applied this within our FabLab. This approach is based on the idea of Ecodesign (Tischner & Moser, 2015), which leads to solutions that, throughout the entire product lifecycle, optimize performance of desired benefits, minimize negative environmental impacts, or even positively impact the natural environment. In a continuous report-discuss-and-develop-practice, a set of ten of the most common issues that must be addressed in EcoDesign, known as the 'The 10 Golden Rules' (Luttropp & Lagerstedt, 2006), have been used as guidance to keep the discussion and development focused on the sustainability of the project.

In this paper, we present the design approach we applied during a study course at our university. The aim of the project was the fabrication of the FabHouse, which is an open source house based on the idea of WikiHouse (2018) but with a strong focus on sustainability. The application of the Eco-Design-Sprint shows advantages especially (but not solely) in teaching environments of multi-disciplinary teams. It helps to change the mindset of students from the beginning throughout the process.

Keywords

Eco-design, sustainability, making, fab lab, teaching, digital fabrication.

1 Background

Fab Labs or Maker-Spaces are community fabrication workshops in which people use lab equipment to create their own artefacts. The technical equipment ranges from conventional machine tools for wood,

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metal and plastic to digital fabrication tools such as laser cutters, 3D printers, CNC machines, etc. 'Personal fabrication' or 'making' is often coined as a social and collaborative activity in such a community space. The general aspiration of makers is shared knowledge, tools and cooperative design. *"Fab Labs share an identity, but each Lab is also free to determine its own activities, target user group and form of revenue depending on its own local conditions"* (Kohtala, 2017). Fab Labs regard themselves as being democratic, offering *"widespread access to the means for invention"* (Gershenfeld, 2005). Besides access to machines, there are also environmental and social benefits embedded in the ideology of Fab Labs. These benefits include the ability to disassemble and reassemble products, to explore sustainable solutions, to build products and to reproduce them in small volumes. This can be done locally and only according to the need (Gershenfeld, 2005; Kohtala, 2017; Lassiter, 2013). *"Making in Fab Labs is seen as a harbinger of a new paradigm: a "new revolution", in the words of network founder Gershenfeld"* (Kohtala, 2017).

1.1 Sustainability

There is an ongoing meaningful discussion about sustainability. It *"has become an urgent requirement for the future well-being of life on earth, considering the limits of resources and growth as well as the unequal distribution of wealth"* (Roeder et al., 2016). Although it is one of the major topics in political and economic debates worldwide, the concept is not understood by the majority of humans. Roeder concludes that a *"significant shift of paradigms towards sustainable consumption and production is not in sight."*

The maker movement with its concept of personal fabrication has the potential to support and strengthen local production and therewith, decrease mass production (Unterfrauner, et. al, 2017). The principle of personal fabrication has an influence on waste production and energy consumption (Kohtala, 2015; Kohtala & Hyysalo, 2015). As more people gain access to digital fabrication tools, the more opportunities they have to produce things on demand, *"meaning when and how they are needed"* (Kohtala, 2017). Unterfrauner, et. al (2017) see this also as an opportunity to draw back production into the regions where consumption occurs, which in turn can have significant *"economic, social and environmental benefits by decreasing traffic and transport of goods."*

Unterfrauner, et. al (2017) explored the environmental value of the maker movement tackling the most sustainable development goals, e.g. clean water and sanitation, affordable and clean energy, responsible consumption and production. There is an awareness of sustainability in the maker community, but its application is different and the level of environmentalism among them varies:

> *„Many concentrate on solving environmental problems and issues like waste production, others are aware of the need to use more sustainable materials or use environmentally friendly materials. [..] Some makers do not consciously choose environmentally friendly materials nor do they consider which waste is created due to their making activities. [...] Besides the repairing, recycling and upcycling approach of maker initiatives, environmental friendly (or unfriendly) materials play an important role when it comes to environmental and sustainability questions. The potential of possible impact need to be considered on a broader level. For many (but not all) makers the use of environmentally friendly materials is of high relevance. Probably the strongest environmental impact and also potential by the Maker community can be found in their creative ideas and products they develop and create to address environmentally relevant questions. Still, some makers do not (consciously) choose environmentally friendly materials nor do they consider which waste is created due to their making activities."* (Unterfrauner, et. al, 2017)

They concluded with an interesting question, which is, if the maker movement will emerge as one of the sources of providing solutions for sustainability and will build processes in the context of their creative activity. If this opportunity exists, it may require reshaping the current systems towards a distributed production by smaller entities, on the long run. In addition *"the shifting focus towards more individualised solutions for society, moving away from mass production will change also the value creation"* (Unterfrauner, et. al, 2017).

1.2 Eco-Design

In order to produce more sustainable products, environmental requirements must be considered during the design process. Best, during the early stages, where less costly changes are possible. The later changes are identified in the process, the more expensive it gets and the less likely it is, that these changes will be incorporated (Barton, 2001; Bovea & Wang, 2005). Typically, developers are frequently confronted with demands for improving efficiency in order to reduce the costs and time-to-market. As a consequence, environmental matters must be balanced against all other requirements, whereas those of functionality and economy will normally dominate (Luttropp & Lagerstedt, 2006). *"Without customers prepared to pay for the function and if companies cannot make a profit, there will be no market; no matter how well the environmental issues have been addressed"* (Luttropp & Ritze´n, 2001).

The challenge of eco-design is twofold: On the one hand, the product has to fulfill customer or user needs; at the same time, this benefit has to be achieved with the lowest negative environmental impact and least economical costs. Therefore, the consideration of sustainability must be implemented into the product development process, otherwise environmental demands will not be properly addressed (Lagerstedt, 2003).

1.2.1 Frameworks

To address this challenge, several eco-design frameworks exist. Smyth (2004) defines such a framework as *"a research tool to help to develop awareness and communication on environmental issues. It is hence a general structure composed of a set of concepts, meaning to be representative of the way of viewing eco-design practice and processes in a sustainability perspective."* Some of these frameworks aim to quantify and assess the environmental aspects or performance indicators of the process to create improvement for eco-design (DeWulf, 2003, Pigosso et al., 2013), while others *"involve considering the entire life cycle, raw material extraction, production, distribution, use, recycling and disposal from an environmental point of view"* (Tischner & Moser, 2015). Ecodesign is another such framework.

> *"Ecodesign (often used as a synonym for Green Design) primarily focuses on combining environmental and economic advantages through good design solutions. It uses a systematic approach that aims to integrate environmental aspects into the product planning, development and design process as early as possible. Along with classical product development criteria, factors such as cost effectiveness, safety, reliability, ergonomics, technical feasibility, and of course aesthetics also become requirements. The Ecodesign designation states that with the help of a sound design approach, ecology and economy can finally be united."* (Tischner & Moser, 2015)

EcoDesign leads to solutions that, throughout the entire product lifecycle, optimize performance of desired benefits, minimize negative environmental impacts, and even positively impact the natural environment. The approach includes several stages with focus on sustainability. *"Ecodesign projects typically involve more intense research activities than conventional product design, for example, on materials, technologies and target audiences. Collaborations are commonly formed with experts from other areas both inside and outside the contracting company"* (Tischner & Moser, 2015).

Such frameworks help to create a common ground. They create a common mindset and enable communication on an abstract level, without discussing details on the specific implementation.

1.2.2 Tools

The implementation of such frameworks takes place at the tool-level, whereas these tools differ in complexity and structure. They can be simple as 'rules of thumb', or lists of recommendations, or they can be more complex, such as a book or online system. Another more complex tool is the Ecodesign Navigator, which can be seen as a roadmap and a reference for most eco-design purposes, as it lists most relevant tools (Simon et al., 1998). Luttropp & Lagerstedt (2006) created a useful overview by synthesizing existing knowledge and presented a 'selected best reading list' of literature relevant in eco-design. Some content focuses on a special kind of product, others concentrate on resources or dematerialization, and some tools have been designed with high ambitions to cover the whole process of design, while others can be used as inspiration for green design. In general, they say that there is a huge interest in sustainable product development. Many tools and guidelines exist but whether these tools are being used and have any real impact on the product development remains often unclear. Most of the tools are quite specific and consequently, they are never exactly right for the situation a developer may be facing.

For them, a tool was needed *"to facilitate the integration of reasonable environmental demands into the product development process"*. That's why they developed 'The 10 Golden Rules' (10GR); a 'lowest common denominator' of ten of the most common issues that must be addressed in eco-design (see Table 1).

The 10GR are generic and are not intended for direct use. They can be customized together with experts or according to the business constraints. It also may happen that certain advice in rules is contradictory. The rules are used to guide the developer *"to ask the right, general questions and to challenge them to seek answers to them by applying them with ''specifications'' to their particular product design challenges"* (Luttropp & Lagerstedt, 2006). The 10GR are the synthesis of environmental design guidelines that are used in companies and academia. They have been made as a foundation for teaching eco-design courses at KTH in Stockholm, Sweden and have been found to be a quick and easy introduction into eco-design and as a useful reminder during the design progress.

The authors took the idea of the 10GR and tested it in the context of their own study program. The context and the procedure will be described in the next clauses.

- *ONE Do not use toxic substances and utilize closed loops for necessary but toxic ones.*
- *TWO Minimize energy and resource consumption in the production phase and transport through improved housekeeping.*
- *THREE Use structural features and high quality materials to minimize weight ... in products ... if such choices do not interfere with necessary flexibility, impact strength or other functional priorities.*
- *FOUR Minimize energy and resource consumption in the usage phase, especially for products with the most significant aspects in the usage phase.*
- *FIVE Promote repair and upgrading, especially for system-dependent products. (e.g. cell phones, computers and CD players).*
- *SIX Promote long life, especially for products with significant environmental aspects outside of the usage phase.*
- *SEVEN Invest in better materials, surface treatments or structural arrangements to protect products from dirt, corrosion and wear, thereby ensuring reduced maintenance and longer product life.*
- *EIGHT Prearrange upgrading, repair and recycling through access ability, labelling, modules, breaking points and manuals.*
- *NINE Promote upgrading, repair and recycling by using few, simple, recycled, not blended materials and no alloys.*
- *TEN Use as few joining elements as possible and use screws, adhesives, welding, snap fits, geometric locking, etc. according to the life cycle scenario.*

Table 1: 'The 10 Golden Rules', representing a 'lowest common denominator' of ten of the most common issues that must be addressed in eco-design compiled by Luttropp & Lagerstedt (2006).

2 Context of the Cases Study: Interdisciplinary Course 'FabHouse'

The FabLab Kamp-Lintfort is an institution of the Faculty of Communication and Environment at Rhine-Waal University and the zdi-Zentrum Kamp-Lintfort. On 600 square metres it offers a unique environment for makers providing extensive, state-of-the-art professional hardware, software and tools. It serves as a drop-in centre for multidisciplinary collaboration, and the university's broad range of technical topics is an excellent basis for inspiration. Its mission is to manifest digital fabrication at all levels of education and training. Since its inception, we aim to integrate the FabLab as an integral part of almost all of our study programs. It is used as a shared work and teaching-place to bring students and industry together.

2.1 Interdisciplinary Course

As part of the curriculum of each of our bachelor programs there is a course called "Interdisciplinary Projects" which takes place in the 5th semester. The content differs between projects, depending on the study program and the teaching staff's background. The interdisciplinary character of the project encourages students to discover new topics and gather practical experiences in different fields. Depending on students' knowledge, lectures and workshops concerning different topics will be included so that students can attend different lectures of other study programs.

Within the context of the FabLab we have already conducted several Interdisciplinary Projects (IP) that bridge the perspectives of the diverse disciplines, i.e. design, psychology, economics, electrical and mechanical engineering, biology, logistics and computer science (Nebe, 2017).

During winter term 2017/2018 we focused an IP on developing an open source house – the FabHouse – that can be reproduced in any of the Fab Labs worldwide and is deployed anywhere in the world. This vision is taken from the WikiHouse-Project (Wikihouse, 2018), which *"endeavours to democratise and simplify the construction of sustainable, resource-light dwellings"* (Wikipedia, 2018). With this project we not only wanted to challenge our digital fabrication skills in designing and building a house, but also to make it easy to reproduce, self-sufficient and sustainable by achieving integration between sustainable materials for a structure with innovative energy harvesting and management systems.

2.2 Eco-Design-Sprint Approach

Eco-design leads to solutions that, throughout the entire product lifecycle, optimize performance of desired benefits, minimize negative environmental impacts, or even positively impact the natural environment.

In short and on an abstract level, the activities always begin with an analytical phase in which the diverse requirements and constraints of the problem are studied and existing solutions are being evaluated. In eco-design more radical questions are being asked than in conventional projects and environmental issues are driving strategic decisions from the very beginning. Furthermore, the entire life cycle of the product is being considered; from raw material selection, to production, use and finally recycling or disposal. For this, an understanding of and cooperation with the entire value chain is important. Tools, such as the Sustainability-SWOT analysis or the Ecodesign checklist helped to examine the situation and existing products. The Life Cycle Assessment (as part of the framework) was not applied in the context of the course but is usually recommended to achieve in-depth details of the product characteristics and impacts at various lifecycle stages. Once the weaknesses and challenges of the situation have been identified, new ideas and concepts for improvement and detailed solutions can be developed. Following the iterative nature of the approach, evaluations take place to test the characteristics of the solutions. The involvement of experts from different fields creates a broader understanding and shorten the product-development time.

The Ecodesign toolbox includes also trend analysis and context research methods for *"enhancing creativity and Biomimicry, guidelines and general rules of thumb, software tools for environmental-economic assessments, scenario techniques and backcasting as well as a collection of inspiring examples and material databases"* (Tischner & Moser, 2015). Typically, eco-design projects involve intense research, more than conventional product design projects. This includes research about materials, technologies and target audiences. This can especially be confirmed for the context in which we applied the framework – a study course that aims to create a sustainable house, made in a fab lab.

Because of this context, we also had to tailor the general approach of Ecodesign. First, the course does not address the typical target audience of product designers (for which the framework was made) nor commercialization (including sales) of the product. Even though, costs are highly relevant to consider, of course.

The Eco-Design-Sprint consists of six stages which are based on the idea of the Ecodesign approach: Analyse existing products; 'Re-Think your product'; Identify potential for sustainability; Test the feasibility; Make it; Prove the sustainability (see Figure 1). The sprint is meant to be an iterative and incremental approach to build upon. At the beginning, it is about the development of (smaller) sub system whereas at the end, it is about the whole product. Even though the stages are numbered, they are not intended to be used as a strict linear sequence. Sometimes it is required to go back to any of the prior steps, sometimes one can jump forward.

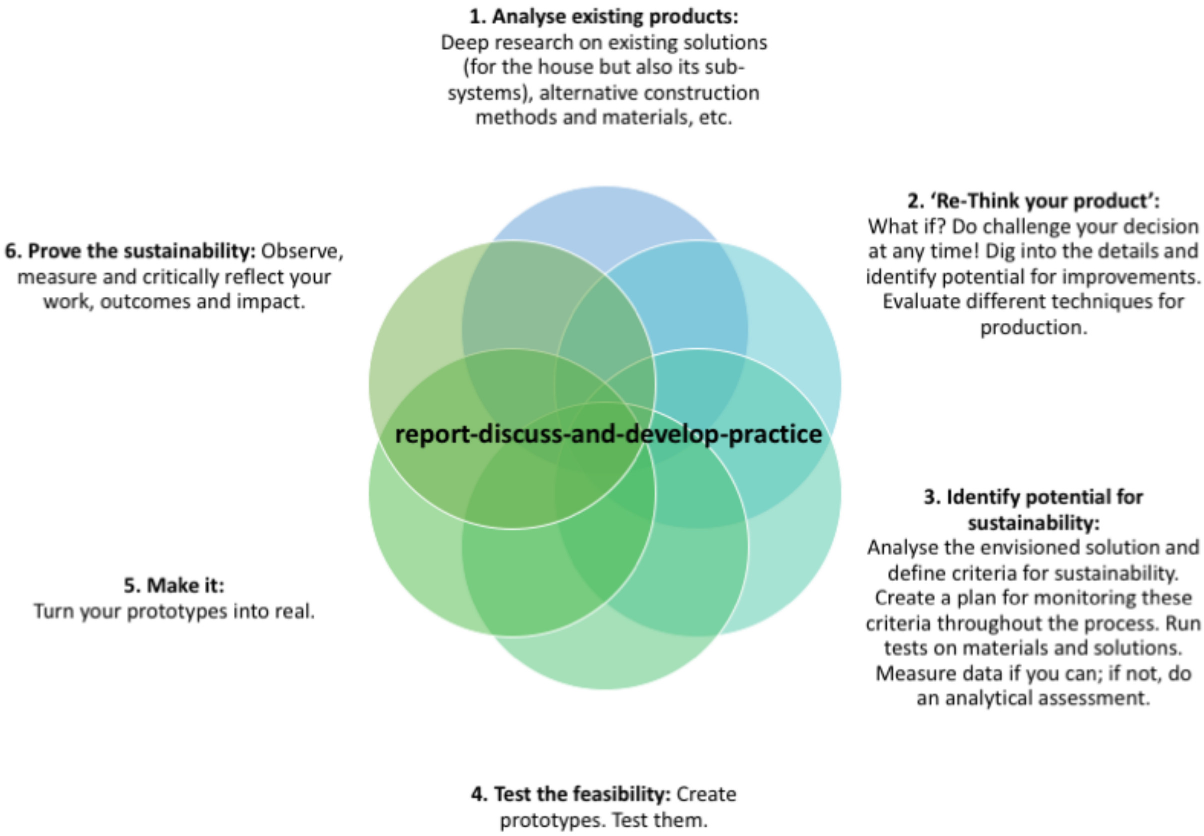

Figure 1: The six stages of Eco-Design-Sprint ('Re-Think your product'; Identify potential for sustainability; Test the feasibility; Make it; Prove the sustainability) with its core activity "report-discuss-and-develop-practice".

The word 'Sprint' refers to the speed in which we applied it. Due to the weekly meetings as part of the course, we established a report-discuss-and-develop-practice. At the beginning of each meeting (independently of the above stages), each student was requested to give a 5-10 minutes report of her past weeks activities, followed by a 10 minutes group discussion about sustainability. The discussion followed a structured approach in which we used 'The 10 Golden Rules' as a distinct basis (details will be given below). The reporter gathered feedback from her classmates and from experts being invited from time to time. After the report-discuss stage, the students turned the new ideas into practice and developed their work further. Of course, managerial and non-sustainability details as well as lectures and training have been treated, too.

This report-discuss-and-develop-practice turned out to be increasingly efficient due to the project the more we got used to it and to the 10GR. The 10GR helped to keep the discussion from drifting away and to stay focused on sustainable aspects, even though not all of the rules were followed all the time.

At the beginning, the tasks and reports were more specific to certain aspects of the FabHouse, such as identifying alternatives in material for the general construction, the roof or the insulation; or as about techniques and machines to be used. Over the course of the project, the discussion went from such specific aspects to more general aspects of the house, e.g. general architectural details of the house (shape, function), energy supply, water catchment, legal issues, etc.

To illustrate how we went through the Eco-Design-Sprint we will give an example of the discussion and decision-making process for the roof of the FabHouse, using the 10GR.

2.3 Application of the 10 Golden Rules During the Eco-Design-Sprint

At the beginning of the project the students had to research sustainable roof solutions with focus on the material. Several alternatives were found, such as clay bricks, bamboo cane, roofing felt, metal, green roofs, etc. The 10GR helped the group to stay focused during the discussion. A moderator forced the students to get back when the focus shifted. Bamboo cane was proposed as eco-friendly because it is a grown material. However, with regards to rule TWO (*Minimize energy and resource consumption in the production phase and transport through improved housekeeping*) the logistic effort (environmental impact) for shipping the material in the required water-resistant quality were extremely high. A green roof but also clay bricks simply turned out to be too heavy for the construction plans. Roofing felt was excluded because bitumen is mostly produced from crude oil (Petroleum) and is not regarded as a sustainable material in building. The felt paper itself are made of lighter-weight fibre such as polyester or glass fibre. According to the 10 GR the discussion was led by rules ONE (*Do not use toxic substances and utilize closed loops for necessary but toxic ones*) and TWO.

In the context of the group discussion, the students came across the idea to make paper clay tiles as an alternative to purchasable materials and did some experiments with it (Figure 2, left). They made the material and tested it under usage conditions. At the end, it turned out to be too time-consuming to fabricate the material in such a scale. Similar exploration was undertaken for the insulation material (Figure 2, middle), where the students build a small testbed in which they were able to measure the efficiency of several materials.

Figure 2: Experimenting with paper clay (left); Setting up the water filtration system, and setting up the bio-gas reactor (middle); Model and assembly of the first life-size prototype (right).

The above example highlights the discussion for specific aspects of the house. However, the rules have also contributed to the general eco discussion about the implementation house's implementation, e.g. rule SIX (P*romote long life, especially for products with significant environmental aspects outside of the usage phase*) had an influenced the general architecture of the house. Following the idea, the house is composed of modules that provide up- and downgrading for changing personal living conditions. Modules (rectangular and caky modules (see Figure 2, right)) can be attached according to the needs, not just only during the construction phase, but also later on – the house can 'grow' and 'shrink'.

Table 2 shows some further examples of different levels of abstract influences or caused by the 10GR.

Golden Rules (selection of)	Impact of the Golden Rule
ONE Do not use toxic substances and utilize closed loops for necessary but toxic ones.	- Alternative materials were discussed and tested for the basic structure, outer layer and roof.
TWO Minimize energy and resource consumption in the production phase and transport through improved housekeeping.	- The plans and blueprints for production are open source (CC0 by CC) so that modifications, scaling and upgrading can be done according to special requirements and according to local materials.
FOUR Minimize energy and resource consumption in the usage phase, especially for products with the most significant aspects in the usage phase.	- Considered a proper (efficient but also sustainable) insulation (construction-wise) to avoid thermal loss in winter and overheating in summer. - Considered Reuse of rainwater. Developed a reservoir and filtration system for water treatment (raw water, not drink water).
SIX Promote long life, especially for products with significant environmental aspects outside of the usage phase.	- The general architecture of the house is composed of modules that provide up- and downgrading for changing personal living conditions. Modules (rectangular and caky modules) can be attached according to the needs not just only during the construction phase but also later on – the house can 'grow' and 'shrink'. - All used materials have been chosen with focus on recycling option. As an example, OSB was used instead of plywood, because of its composition and can be manufactured from lesser-quality trees and with less glue than plywood.
SEVEN Invest in better materials, surface treatments or structural arrangements to protect products from dirt, corrosion and wear, thereby ensuring reduced maintenance and longer product life.	- Oriented strand board (OSB) was used for the base-construction because it is comparably cheap, but larch wood was used for the outer layer because it is long lasting and does not need any paint coat. - The roof was made of thin corrugated zinc coated metal sheets which were higher priced than other materials but made to last and features better eco-balance than may other materials.
NINE Promote upgrading, repair and recycling by using few, simple, recycled, not blended materials and no alloys.	- A soda can solar heater was developed, tested and applied.
TEN Use as few joining elements as possible and use screws, adhesives, welding, snap fits, geometric locking, etc. according to the life cycle scenario.	- (Almost) Only wooden joints have been used for the connection of parts; screws have been avoided to the greatest possible extent.

Table 2: Selection of 'The 10 Golden Rules' (Luttropp & Lagerstedt, 2006) applied in the context of this study, showcasing the impacts of their consideration for the FabHouse project at Fab-Lab Kamp-Lintfort.

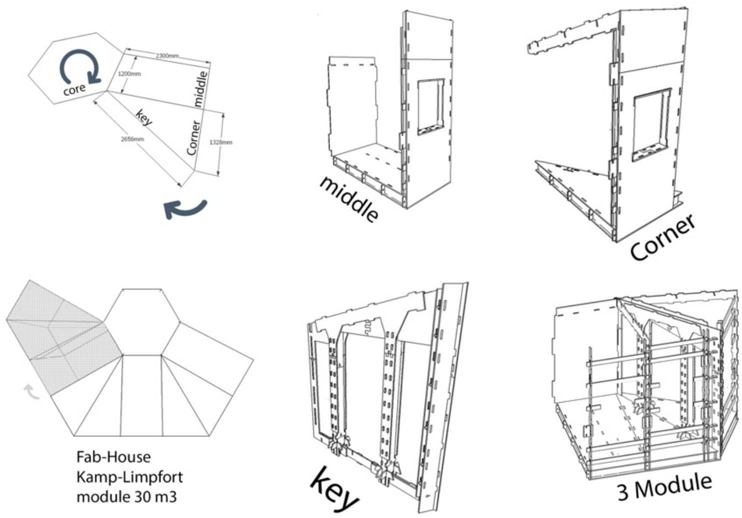

Figure 3: General construction of the FabHouse: dimensions, rectangular 'middle' pieces, 'caky' corner pieces, layout, key elements, setting of 3 modules (top-left to bottom-right)

3 Reflexion

Within the scope of the course we were faced with students of different backgrounds (computer science, environmental sciences, mobility and logistics, international business sciences). Just very few of the 12 students had prior experience in fabrication and handicrafts. Only two students knew about the concept of sustainability (due to their study program of environmental sciences). We wanted them to work together and to cooperatively come up with solutions to build a real house. The major focus was not just to make it, but to make it in the most sustainable way.

The Eco-Design-Sprint turned out to be an effective and efficient model to force the whole team to focus on the sustainability of the house. In each of the stages, the students had different tasks to do:

Analyse existing products: Deep research on existing solutions (for the house but also its sub-systems), alternative construction methods and materials, etc.

'Re-Think your product': What if? Do challenge your decision at any time! Dig into the details and identify potential for improvements. Evaluate different techniques for production.

Identify potential for sustainability: Analyse the envisioned solution and define criteria for sustainability. Create a plan for monitoring these criteria throughout the process. Run tests on materials and solutions. Measure data if you can; if not, do an analytical assessment.

Test the feasibility: Create prototypes. Test them.

Make it: Turn your prototypes into real.

Prove the sustainability: Observe, measure and critically reflect your work, outcomes and impact.

The report-discuss-and-develop-practice and the implementation of the 'The 10 Golden Rules' as a distinct basis for the discussion not only created a joint understanding and collaborative working atmosphere, it also ended up in an entire sustainable concept for the FabHouse in theory and practice. An impression of the final house is shown in Figure 4.

Figure 4: The FabHouse, located at Rhine-Waal University of Applied Sciences, Campus Kamp-Lintfort.

4 Summary, Discussion and Outlook

In this paper, the authors present an approach that has been used in teaching to raise the awareness of sustainability in a fab lab. The duty of the students in the context of an interdisciplinary project was to build an open source house – the FabHouse – that can be reproduced in any of the Fab Labs worldwide. This vision was taken from the WikiHouse-Project (Wikihouse, 2018). However, the focus of this course was to not to simply copy it but to 'Re-Think it', driven by the goal of making it as sustainable as possible. This included not only the construction of the house and materials used, but also energy harvesting and management systems. Finally, within a period of 5 months the students and supervisors built the house (Figure 3). Due to legal constraints it is a small version but sufficient to test the architecture and materials under life conditions. Besides the sustainability focus, one of the major differences lays in the construction of the FabHouse. The modular structure of rectangular and caky-pieces enable the house to grow and shrink, according to the users' needs. If more space is needed, even after the house has been finished, it can be extended at any time by just removing one of the outer walls and by attaching one of the preferred modules. Shrinking takes place in the reverse way. Self-sufficiency was also addressed by the students so that it is equipped with a rainwater-filtration system, a soda can solar heater to produce thermal heat through sunshine, and a test-installation has been made for a bio-gas-reactor.

Besides the challenge of building the house and its systems, we also tested a new methodology, which we called the Eco-Design-Sprint. The iterative process consists of six stages: Analyse existing products, 'Re-Think your product,' Identify potential for sustainability, Test the feasibility, Make it, and Prove the sustainability (see Figure 1). The sprint is meant to be an iterative and incremental approach to build upon. Depending on the stage, we made use of several tools provided by the Ecodesign framework (Tischner & Moser, 2015). As part of the Sprint, we established a report-discuss-and-develop-practice, in which ideas, research results and prototypes have been discussed every week. As a distinct basis for the discussion we used 'The 10 Golden Rules' (Luttropp & Lagerstedt, 2006). These are a 'lowest common denominator' of ten of the most common issues that must be addressed in eco-design.

At the beginning, the work and discussion were more specific to certain aspects of the FabHouse. Over the course of the project, the discussion went from such specific aspects to more general aspects of the house, e.g. general architectural details of the house, such as the shape (as mentioned above).

This practice turned out to be increasingly efficient. The 'The 10 Golden Rules' helped to keep the discussion from drifting away and to stay focused on sustainable aspects from the very beginning until the end, when the complexity of the project increased.

At the end we concluded that the project was a great success in many ways. The students gained new skills in fabrication and craftmanship and – even more interesting – developed a great sensibility for sustainability. This was supported by the structured Eco-Design-Sprint approach and 'The 10 Golden Rules'. Of course, there are some learnings from this. The tools selected from the repertoire of Ecodesign shall be interlinked with the 'The 10 Golden Rules' and the report-discuss-and-develop-practice. It is also recommended to present them as a chain of logical steps from the very beginning in liaison with the stages of the Eco-Design-Sprint. This would give the students a more comprehensive view on what to expect. Of course, the approach is not limited to the context of teaching. It can be further developed and tested to become a general approach for makers aiming for sustainability.

The authors planned to measure the impact of the teaching approach in order to justify an increased awareness of sustainability. But as most students left for their semester abroad or did their long-term internship we missed this. This can be confirmed based on subjective behaviour but will be done for the next project form the very beginning.

According to stage six of the Eco-Design-Sprint, the sustainability of the house will be tested. We plan to: put sensors for measurement (heat, humidity, etc) to analyse the comfort of living (not too warm in the summer, not too cold in the winter, etc.), and test the quality and resistance of the materials and the general construction (changing weather conditions). Based on the results, we plan to build a bigger version for the "Landesgartenschau 2020" (Landesgartenschau, 2018), which is a show of the federal state of North Rhine-Westphalia. It takes part in different cities every three years, and presents gardens and parks of an area. The FabHouse 2.0 will then be accessible to the public and can become a demonstrator to showcase the developments of personal fabrication, maker movement and sustainability.

The online portfolio of the FabHouse can be found at FabLab Kamp-Lintforts webpage (http://fablab.hochschule-rhein-waal.de/fabhouse/). The FabHouse is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License.

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