

# The Influence of Guidelines for Sustainable Prototyping

**F. Julie Heij**

Eindhoven University of Technology  
Eindhoven, Netherlands  
f.j.heij@student.tue.nl

**Sanne. M. M. Houwers**

Eindhoven University of Technology  
Eindhoven, Netherlands  
s.m.m.houwers@student.tue.nl

**Joep C. N. van der Kamp**

Eindhoven University of Technology  
Eindhoven, Netherlands  
j.c.n.v.d.kamp@student.tue.nl

**Pim Visser**

Eindhoven University of Technology  
Eindhoven, Netherlands  
p.visser@student.tue.nl

## Abstract

Design students use techniques such as prototyping and sample making when learning about and exploring new concepts and ideas. Due to the restriction by the time, money and guidance they have, it can be challenging for them to work as sustainable as possible. Based on interviews with professional designers in the field of textiles and smart wearables, we propose a set of simple guidelines aimed to support a more sustainable prototyping practice. The guidelines include practices like making more sustainable choices when selecting materials and techniques for more sustainable prototyping. They were refined through a first-person perspective and evaluated by students who applied them into their projects. A thematic analysis was used to analyze the interviews with the participants. We found that while the guidelines are generally easy to apply by the participants, and the effects of them can have a small positive effect on the creative process, the format in which they were presented needs improvement. This paper contributes with a set of guidelines which supports students in sustainable prototyping and insights into the influence of these guidelines on the prototyping practices of design students. Based on the results, the paper ends with a suggestion for a format of how the guidelines could be best presented to the students.

## Keywords

Sustainability; Prototyping; Guidelines; Garments; Electronics

## Introduction

Sustainability and minimizing waste, have been hot topics in research the past decades. Extensive research on large scale production of electronics and textiles has been done [8]. This paper focusses on a smaller scale, namely the prototyping phase of designers. This is the first stage where ideas and designs become physical items. Although this smaller scale is not the biggest contributor to waste and pollution, this is the stage in which designers can adopt a sustainability-oriented mindset. If this mindset becomes more generally adopted, it could bring about change in the larger industry.

Sustainability during the prototyping phase of a design process has been addressed in past studies. Within these studies, multiple approaches and techniques have been investigated to find opportunities to reduce the environmental impact of the prototyping process. The prototyping/design stage is a good stage to realize and test and significantly less research has been done here [6].

A way of reducing waste in prototyping is disassembling prototypes and garments so that materials can be reused. Devendorf and Wu [5] explore how garments can be designed with reuse in mind and how electronic and textile components can be disassembled and reused. Methods of unravelling knitted and woven garments are researched, weaving being the more challenging design space for disassembly.

3D software is used to augment garment design aiming to create zero-waste in fashion design [6]. This technique is used in the design process instead of physical material prototyping and is already being implemented in the

fashion industry.

Furthermore, Vasquez et al. studies the use of mycelium-composite in prototyping. Mycelium-composite is an “environmentally sustainable biocomposite” [5] that is mostly used as a construction material. It is noticeable that a significant percentage of designers involved in their study were willing to use the material in their first iterations, but this number decreased in iterations that got closer to a high-fidelity prototype [3].

The papers mentioned above address methods that can be used to prototype more sustainably. However, these papers do not discuss the effects that applying the methods they present have on the process of their users.

Vasquez et al came up with a Sustainable Prototyping Life Cycle for Digital Fabrication which is a method that assesses the sustainability of prototyping. This method also stimulates designers to be more aware of the environmental impact of their design practices. In this research, participants were studied in a workshop setting, where the participants had to consider environmental impacts in their prototyping practices [3]. This approach is similar to the way this paper aims to involve participants and served as an inspirational source.

The paper above does describe the experience of the participants when applying the methods. Yet, by limiting the participant study to only applying one technique, the study misses out on finding out how designers choose which methods work for them when they are offered different methods and choices. This paper investigates how and why participants choose certain guidelines and how they apply these to their own practices.

The authors propose a set of guidelines for design students to prototype in a more sustainable way. The proposed guidelines include ways for re-using materials, using sustainable materials, technique specific guidelines. The guidelines were set up by

interviewing multiple experts in the field of textile design. These guidelines were then refined through a pressure cooker in which each author conducted a small design project to experience the guidelines first-hand; and are evaluated by design students who implemented them in their own ongoing projects. Interviews with the participants were conducted and analysed with a thematic analysis.

When applying the guidelines to the prototyping process, designers described being restricted in some choices. Such “context specific constraints in the creative process leads to novel and original ways of solving problem” [5]. this paper builds on this knowledge by specifically looking at the effects on creativity in the prototyping process. By analysing the effects of these possible restrictions, this paper aims to contribute to knowledge about how guidelines can be best presented to students.

With the guidelines, we also hope to inspire other designers and challenge them to think about the choices they make while designing. As the guidelines are quite broad, everyone must be able to find some that are applicable to their project. Besides talking about responsible material choices, the guidelines presented in this paper give insight on how several different prototyping techniques can be performed in a more sustainable way.



## Current Practices

This paper describes the stages that were part of the research process. These stages are described to clearly communicate the way this research was structured. In total, the research consists of four essential stages.

### Study set-up

These stages are further described in the following sections.



#### 1. Expert interviews & guidelines

Description of how the expertise of ten experts in the field of textile and electronical design was collected as a base for the guidelines.



#### 2. Hand-out & pilot study

Description of how the experts' input was translated into the guidelines and how the hand-out was created and validated by the pilot-study.



#### 3. Participant study & interviews

Description of how the participants applied the guidelines and the setup of the interviews.



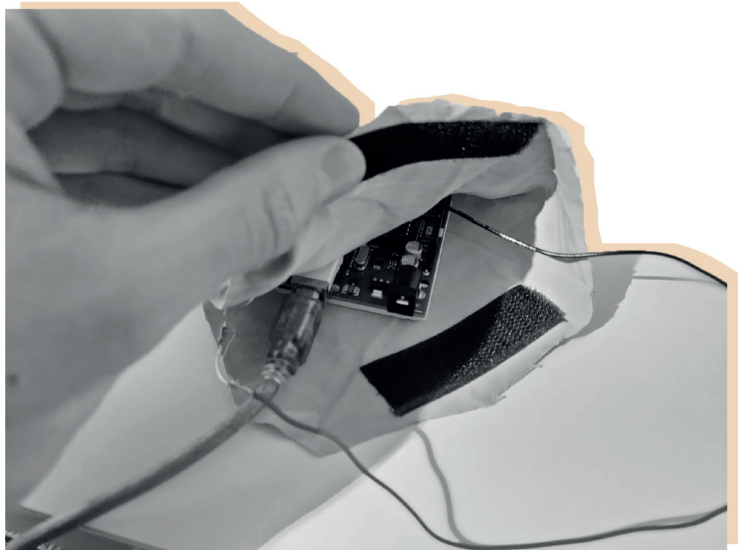
#### 4. Analysis

Description of how the input from the participant study and interviews was analyzed and presentation of the most interesting findings.

## Expert Interviews & Guidelines

Interviews with designers who are experts in the field of textiles, electronics design and 3D printing were the starting point of the development of the guidelines for sustainable prototyping. A total of ten experts were interviewed. During the interviews they were asked about the ways in which they try to make their prototyping sessions more sustainable and how they think students could improve the sustainability of their work.

Based on the results of the interviews in the previous section, a set of initial guidelines for prototyping were formed. The guidelines, shown on the right side of this page, were made using the following definition: The goal of the guidelines is to assist users during a process [4]. The list includes both general and specific guidelines. Not all guidelines are applicable in every project, they aim to increase the sustainability of the design process in different ways. The guidelines have been formulated and tweaked based on a paper about the usability of guidelines by Cronholm [1].



Electronics pocket in pilot study project

### Re-using materials

1. Use secondhand garments or leftover materials as the base material of your prototype. (This applies to both fabrics and electronics).
2. Save scraps for later projects.
3. When working with electronics and fabrics combined, one may shorten the lifespan of the other. If the electronics stop working the combination of both fail also the other way around. Making electronics removable can fix this issue. You can make your electronics removable by creating pockets for electronics for example. This way the garments and electronic components can be reused.

### Sustainable materials

4. Look at the environmental footprint of the materials and pick the right materials. For example, the effect on the environment of producing silver is a lot higher than when producing copper. So, take the time to do research in materials and don't just accept things intuitively, this could also be useful for your future projects.
5. If you cannot reuse material, it is best to use more sustainable fabrics. This means using natural materials like cotton, linen or polyester. Mixes are harder to recycle, although they can be more durable.

### Durability

6. When you can't choose for recycled materials, choose the most durable material, so it will last for a long time.

### Technique specific

7. Think about the garments first and electronics later. This means that the garments should also look beautiful without the electronics.
8. When sewing, think of the most sustainable way to sew. Also think about the amount of energy that certain techniques use. For example, knitting uses a lot less energy than weaving. When 3D printing, print it in such a way that the least amount of support material is needed.
9. Print or build small so you use less materials. For first, lo-fi prototypes, use fast recyclable materials appropriate for the prototyping stage, until you are ready to create the final prototype.

### Other

10. Talk to experts around you and read about existing work to gain knowledge in finding the most sustainable and best techniques.

**Guidelines**  
**1,2**

During these interviews it was learned that using scraps, secondhand garments or leftover materials in prototypes and saving rest material for later projects can drastically decrease the waste of materials. During a visit to the Fashion Tech Farm, a makerspace located in the Eindhoven area, that specializes in using fabrics in original ways it was explained that they produce approximately 1m3 of waste every six months in a studio where over ten designers are working on projects [2]. They have optimized their waste prevention and produce significantly less waste than most student designers.

**Guidelines**  
**3,7**

An expert who specializes in e-textiles, the combination of textiles and electronics, explained that it is important to first focus on creating a garment that, even before adding electronics, looks visually appealing. The next step is to add the electronics and make them removable by using special pockets or pouches that hold them. This method prevents the entire design from become an obsolete object when the electronics stop working, which makes it harder to disassemble and replace certain parts.

Beginner designers often pick the cheapest, easiest to work with materials and techniques

**Guidelines**  
**6,8**

for their projects. Combining this with a prototyping phase which is often fast paced, designers make many hasty decisions. One expert mentioned that this decision-making process gives an opportunity for improvement. They mentioned the importance of taking time to make responsible choices when picking your materials. The benefits for the environment in the prototyping scale are small, however it will become useful if the prototype is later produced in large numbers. It is important to keep this in mind during the prototype phase. Van der Velden et al. [7] explain a tool for material selection called LCA (Life Cycle Assessment) and the relevance of it. Another argument for this approach was given by a different expert; by adopting a sustainable way of prototyping, designers become more aware of the effects they have which can carry through in their professional career when they work on a larger scale.

When asking the question 'Where do you think there is a lot of potential to improve during prototyping?' an answer that often came up was that more sustainable fabrics need to be used.

For prototyping, natural materials like cotton, linen and polyester are a lot more environmentally friendly than mixes. For the first few iterations of a product and lo-fi prototypes the most sustainable material should always be picked.

**Guideline**  
**4**

**Guidelines**  
**5,9**



## Hand-out & pilot study

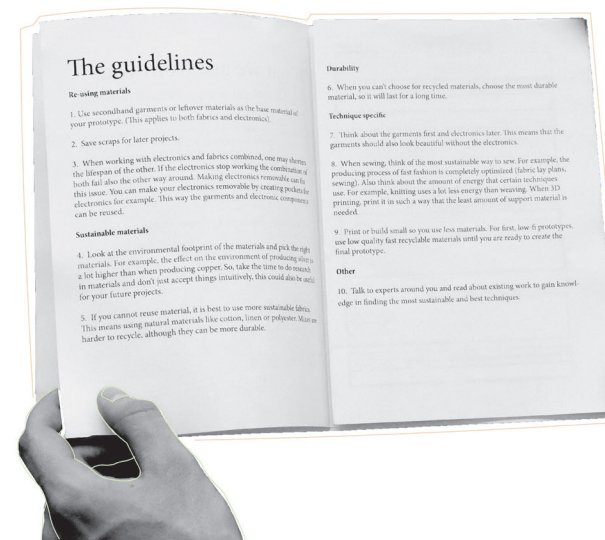
The guidelines were put in the format of a hand-out which included questions about how the process of applying the guidelines affected the work for later use during a participant study. The hand-out was tested during a pilot study in a first-person perspective. This gave insights in the changes that were needed to improve the hand-out before sending it out to the participants.



Pilot study prototypes

## Refining hand-out

During the pilot study, several issues with the hand-out were found. Some of the questions about the process resulted in similar answers or seemed to be relevant to the project yet turned out to give no useful input. These questions were adapted and some changes in layout were made to assure the most optimal visual communication before the hand-out was finalized and sent out to the participants of the user study. The final guidelines and questions in the hand-out can be found in the appendix.



## Participant study & interviews

In this study, five participants were asked to use the hand-out during their prototyping sessions. They were asked to document their process by filling out questions in the hand-out, to reflect on their prototyping session. The hand-out also contained a QR-code to a personal folder in OneDrive provided by the researchers to upload photos of their session. After two weeks of using the hand-out and uploading their results, the participants were asked to upload pictures of their filled-out hand-out. Next, thirty-minute interviews were scheduled with a participant and two researchers.

The interviews were recorded with consent from all parties. During the interview, one researcher took the role of asking the questions and engaging in the conversation with the participant, while the other researcher took the responsibility of recording the interview and taking notes on interesting points and the content of the interview.

The questions for these interviews were carefully composed by looking at both the context of the project of the participant, possible improvements of the guidelines and the influence of the guidelines. The interview questions and interview length were tested in pilot interviews regarding the pilot study.

### Processing interviews

After the interviews were conducted, they were transcribed with the help of online transcription software and were proof-read by the interviewers to assure accurate transcriptions were made. In the transcriptions, interesting points and main themes were highlighted as a preparation for the analysis.

# Participant Projects



Save scraps

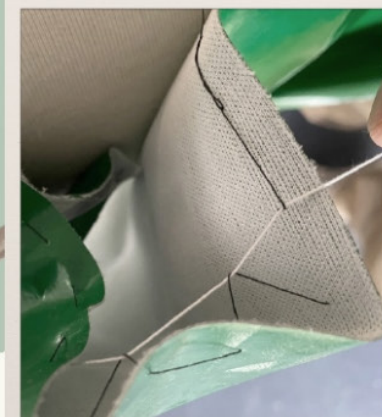


Use second hand materials



Choose durable fabrics

Make electronics removable by making pockets



Sew sustainably



# Analysis

As this study does not aim to verify previous research on how guidelines affect the target group, it is meant to generate new knowledge on this topic. Therefore, the reflexive, thematic analysis started without predefined categories. By clustering quotes and reoccurring themes from the qualitative research, categories were formed while analyzing the data.

This section first discusses which guidelines were applied most often and why these were preferred. Secondly, it explains the way the participants applied the guidelines. Next, the opinions of the participants on the guidelines and the way they affected them are described. The section is concluded with suggestions that were received from the participants on how the guidelines and hand-out could be improved.

## Difference in application frequencies

The participants worked on diverse projects. An immediate result of this was that not all guidelines were applicable to all participants work. One participant for instance was only working with electronics during the study and was therefore not able to apply some of the technique specific guidelines for prototyping with fabrics.

Besides the fact that not all guidelines were usable, some were applied significantly more often than others. The participants gave several reasons and motivations for why they chose certain guidelines and how they applied these. Technique specific guidelines, like 3D printing or sewing in a more sustainable way, were frequently applied. One participant explained that applying these guidelines was easy because it did not require them to adapt their project to be able to use them. The guidelines regarding sustainable materials were not used as often. One of the participants mentioned that they would need to do more research about this subject before being able to apply them: *"I'm still unsure about the sustainable materials, because I think I just have to do more research about them. So, I think I'm not ready to actually incorporate knowing which materials are sustainable, and how to choose those."* (Participant #1). Another participant mentioned that time

played a big role in choosing how to prototype. *"I don't really take it [sustainable but time-consuming methods] into consideration because I'm like, ok, I have little time. And maybe this is like the faster way."* and *"I barely ever have time to like, put a lot of like, time and effort into something."* (Participant #2).

## Approach of applying the guidelines

One of the participants took the approach of reflecting on the guidelines by checking the created prototype with the hand-out and trying to improve on the next iteration. For this participant, the guidelines functioned as a *"reality check"*. *"Am I actually like, being as sustainable as I think I am?"* (Participant #2). Other participants also mentioned that applying the guidelines will probably become easier over time. *"If you do it multiple times, I think it will work better."* (Participant # 3).

Another approach that was taken by a participant working in a group project was to carefully inspect the guidelines before determining exactly how they were going to create their prototype. This way, the group was able to determine which guidelines they could use when starting the final prototyping session.

## Participants' opinions and perceived effects

When asking the participants how their process was affected by the guidelines, one responded with: *"Yeah, I think in a positive way. I think, I think that there are techniques, specific ones, that you just showed me definitely inspired me the most."* (Participant # 1). However, not only because they were inspiring but also because they offered this participant the opportunity to *"step outside my own shoes"* and to *"see what other people considered important. And then you can kind of empathize with that."* (Participant #1). This participant also mentioned that the guidelines helped them realize a broader understanding of designing for sustainability. *"I think I'm ready to incorporate, kind of, considering the kinds of lifestyles that your product promotes and how*

*sustainable those are, or not."*

### **Participants' suggestions for improvements**

Multiple suggestions for improving the guidelines and the way they are presented came up during the interviews. A participant mentioned that the paper format did not work very well as it felt very disconnected from their project, and thus would have liked it if the presentation of the guidelines was more intertwined with the prototyping process. *"If you say you want to use the guidelines for changing my behavior, I feel like only the words on the paper does not really be that enough for changing my behavior in sustainability for prototyping."* (Participant #4). Another participant also gave a suggestion to place these guidelines in maker spaces next to their respective machinery.

## **Limitations**

This section reflects on choices that might have had a significant impact on the results. Reflecting on this helps to understand the results better and to improve the scope for future research.

To begin, the participants that were recruited for the study were fellow students. Therefore, their motivation for participating can differ from when the guidelines were offered by, for example, the faculty. This difference can have an impact on how and why the guidelines were applied.

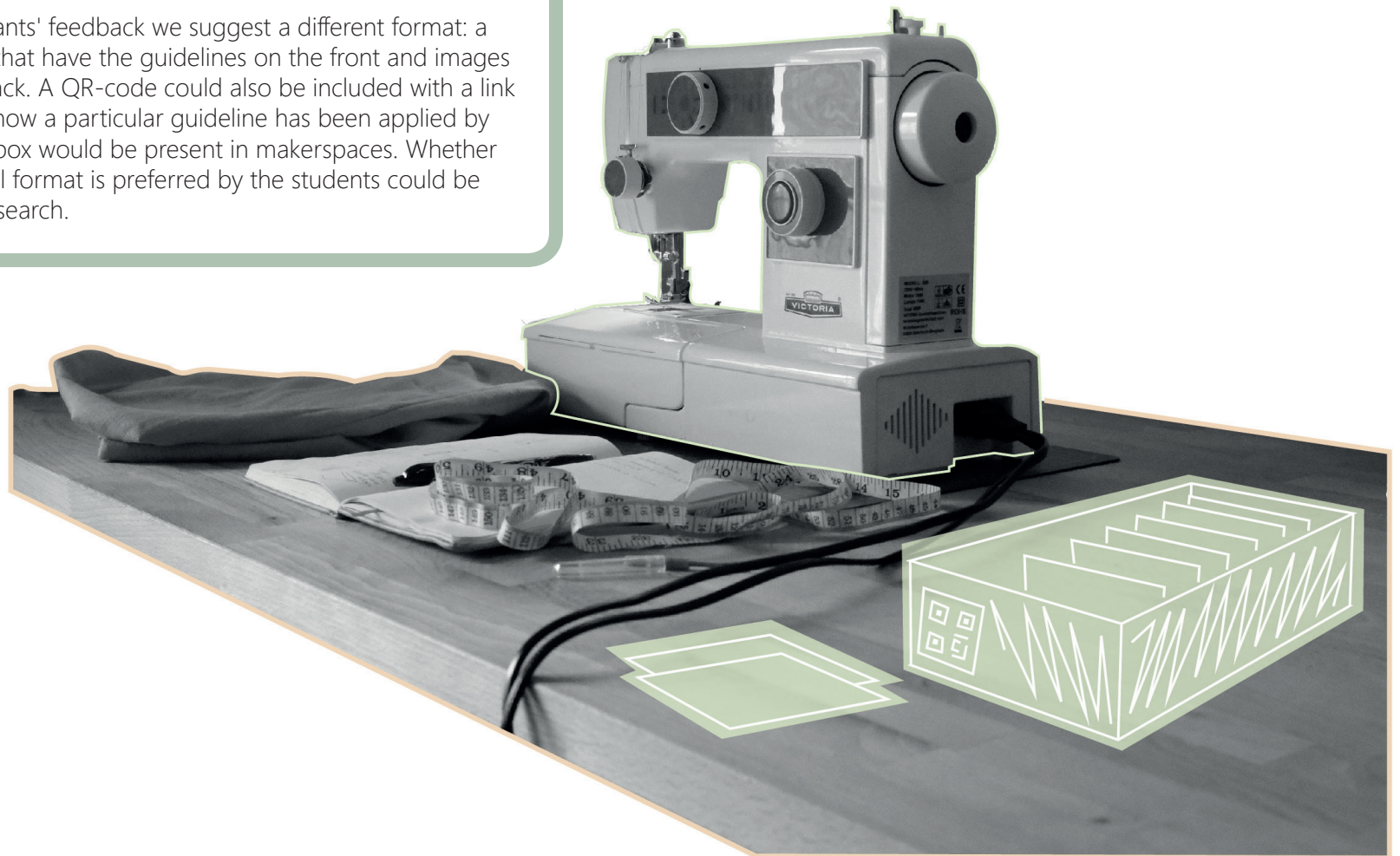
Secondly, several experts that were interviewed for this research mentioned that prototyping sustainably starts already at the beginning of a design process. The participants that were part of the study were only supplied with the guidelines during the prototyping phase. This could have led to more difficulty when applying the guidelines as some of them could be easier to apply earlier in the process. Also, some less sustainable design choices might have already been made while ideating or making lo-fi prototypes, which makes it harder to apply guidelines that go against the direction of the project. So, for future research, it would be interesting to have students work with the guidelines from the start of their design process.

Lastly, the format in which the guidelines are offered to the participants can have an impact on how motivating it is to apply them and thus how many were applied and to what extent. For this study, the guidelines were summed up in a hand-out. Yet, from the participant interviews, it can be determined that this is not the ideal format. The participants explain that they prefer that the guidelines are more closely related to their projects. This requires that there are more guidelines. Also, examples of how the guidelines can be applied were lacking for most of the participants.

Besides the three points mentioned above, the conducted qualitative research gave a good insight into how and why the guidelines were applied, and how the students experienced this. Nevertheless, if future research were conducted, these discussion points are good to consider.

## Design Suggestion

Based on the participants' feedback we suggest a different format: a box containing cards that have the guidelines on the front and images of examples on the back. A QR-code could also be included with a link to more examples of how a particular guideline has been applied by other designers. This box would be present in makerspaces. Whether this physical and visual format is preferred by the students could be validated in further research.



## Conclusion

During this study, guidelines for sustainable prototyping were created with the help of ten experts. Their application and influence were tested in a first- and second-person perspective. Participants interviews were then conducted and analyzed using a thematic analysis. This resulted in four main categories, which gave insights into the way that the guidelines are used by design students and how it affected their prototyping process.

A few guidelines were used more frequently than others. These included making electronics removable, using secondhand garments, and saving scraps. These are the guidelines that are relatively easily applicable as they do not require a great amount of research and effort to apply. The nature of the guidelines makes it nearly impossible to apply all of them in one project.

Sometimes it is necessary to make a trade-off between using sustainable methods and materials and creating the best possible version of a project. Or certain guidelines are simply not applicable to a project. For example, one participant was working on a project where the patterns and flexibility of a certain material were researched. Therefore, it was not possible to choose a different material as their project was material specific.

Multiple participants considered the application of the guidelines as a learning process and said that trying out the guidelines multiple times led to better execution of applying the guidelines. The participants also stated that there were little restrictions caused by the guidelines during their prototyping sessions. As most participants had already chosen what to create, they were able to choose guidelines that fitted their project best. Therefore, they did not perceive their creativity to be limited. But an issue that multiple participants experienced was that the application of the guidelines slowed their prototyping process down at times.

To conclude, it can be difficult to stimulate designers to become pro-active in prototyping sustainably, as it can be at the cost of their project. Yet, this study has shown that the guidelines can positively influence the prototyping

process. The hand-out format provided in this paper was determined not to be the optimal format. Therefore, we provide a suggestion on how these guidelines could be presented in a different format, based on feedback from the participants.

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**Appendix**  
Participant hand-out

Sustainable prototyping  
study

Participant name(s):

Thank you for participating!

Julie Heij, Pim Visser, Joep van der Kamp & Sanne Houwers

## About this study

We want to thank you for participating in this study and helping us with this project.

The importance of sustainability is becoming more recognized in the design and consumer worlds. For design students it can be difficult to implement a sustainable work ethic in their design process because it requires them to change their behavior. To find out what the effects of this adaptation are on the design process during the prototyping stage, we have contacted you.

We have created guidelines by interviewing experts about their work and finding out what they think are the best ways to make prototyping processes more sustainable. As design students, and thus the designers of the future, we ask you to use these guidelines to make your prototyping stage more sustainable.

## What we ask from you

For this two-week study, we ask you to document your prototyping sessions. Therefore, we created this booklet with a spread for each session. Please answer the questions after each prototyping session and make sure to make photos of your process. You can upload these photos by scanning the QR-code below, uploading might work best on your laptop. Be aware that you don't have to fill out all the spreads and you don't have to apply every guideline if this doesn't add anything to your project. Simply use this booklet whenever you are prototyping and see which guidelines fit best.

If you have any questions or experiencing troubles, feel free to contact Julie Heij.

E-mail: [f.j.heij@student.tue.nl](mailto:f.j.heij@student.tue.nl)

Tel.:



participant reference: group 4

# The guidelines

## Re-using materials

1. Use secondhand garments or leftover materials as the base material of your prototype. (This applies to both fabrics and electronics).
2. Save scraps for later projects.
3. When working with electronics and fabrics combined, one may shorten the lifespan of the other. If the electronics stop working the combination of both fail also the other way around. Making electronics removable can fix this issue. You can make your electronics removable by creating pockets for electronics for example. This way the garments and electronic components can be reused.

## Sustainable materials

4. Look at the environmental footprint of the materials and pick the right materials. For example, the effect on the environment of producing silver is a lot higher than when producing copper. So, take the time to do research in materials and don't just accept things intuitively, this could also be useful for your future projects.
5. If you cannot reuse material, it is best to use more sustainable fabrics. This means using natural materials like cotton, linen or polyester. Mixes are harder to recycle, although they can be more durable.

## Durability

6. When you can't choose for recycled materials, choose the most durable material, so it will last for a long time.

## Technique specific

7. Think about the garments first and electronics later. This means that the garments should also look beautiful without the electronics.
8. When sewing, think of the most sustainable way to sew. For example, the producing process of fast fashion is completely optimized (fabric lay plans, sewing). Also think about the amount of energy that certain techniques use. For example, knitting uses a lot less energy than weaving. When 3D printing, print it in such a way that the least amount of support material is needed.
9. Print or build small so you use less materials. For first, low-fi prototypes, use low quality fast recyclable materials until you are ready to create the final prototype.

## Other

10. Talk to experts around you and read about existing work to gain knowledge in finding the most sustainable and best techniques.

# Session one

How sustainable was this prototyping session in comparison to your usual prototyping sessions? (on a scale of 1 to 5)

What did you create?

What was the purpose of this prototyping session?

Which techniques and materials did you use?

Which guidelines did you apply? (write down the numbers)

How did you apply these guidelines?

How did this influence your process? (please explain why this is different from your usual approach)

Which of the guidelines would you use in the future and why?

Did you upload a photo through the QR code?

 Yes  No

Other comments and notes

# Session two

How sustainable was this prototyping session in comparison to your usual prototyping sessions? (on a scale of 1 to 5)

What did you create?

What was the purpose of this prototyping session?

Which techniques and materials did you use?

Which guidelines did you apply? (write down the numbers)

How did you apply these guidelines?

How did this influence your process? (please explain why this is different from your usual approach)

Which of the guidelines would you use in the future and why?

Did you upload a photo through the QR code?

 Yes  No

Other comments and notes



# Session three

How sustainable was this prototyping session in comparison to your usual prototyping sessions? (on a scale of 1 to 5)

What did you create?

What was the purpose of this prototyping session?

Which techniques and materials did you use?

Which guidelines did you apply? (write down the numbers)

How did you apply these guidelines?

How did this influence your process? (please explain why this is different from your usual approach)

Which of the guidelines would you use in the future and why?

Did you upload a photo through the QR code?

 Yes  No

Other comments and notes