Additive manufacturing for design in a circular economy

Research Through Design Case Study

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Abstract

In this thesis, we present the results of our explorations into how the use of additive manufacturing (AM) or 3D printing as a production method can contribute to design in a circular economy. The aim of design in a circular economy is to preserve the value of products and materials by keeping them in the economic system, either by lengthening their lifetime or through high value reuse and recovery. Design in a circular economy needs to account for both product integrity and material integrity, which represent the quality of products and materials to remain whole and complete over time. AM is an emerging technology and is viewed as a promising production process for the circular economy because of its unique additive and digital character. The papers and chapters making up this thesis answer the following two research questions:

1. How can additive manufacturing support product integrity in a circular economy?

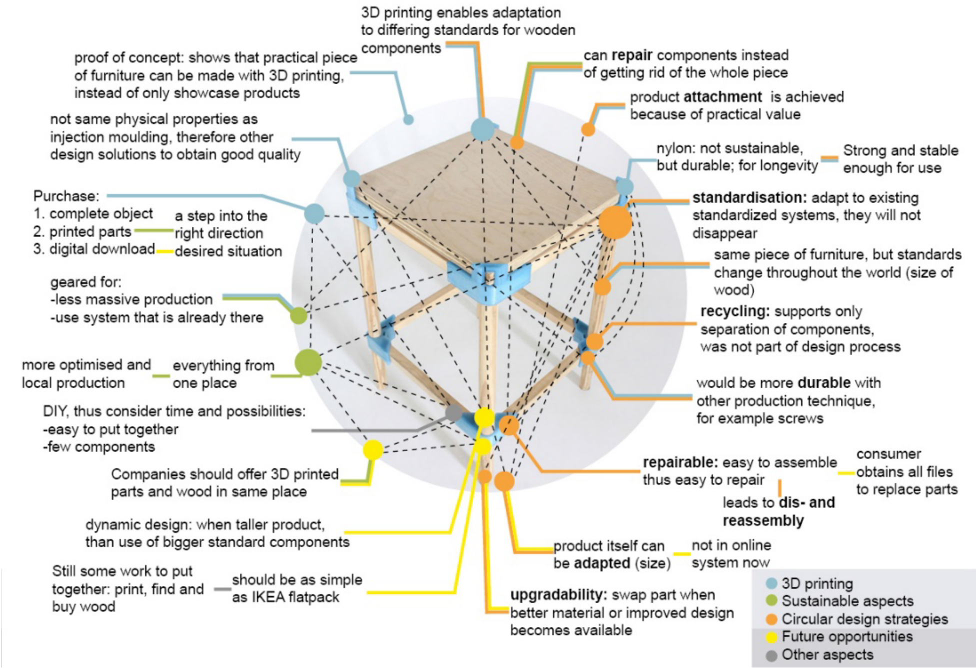
2. How can additive manufacturing support material integrity in a circular economy?

We addressed these questions by performing a literature and design review followed by experimental studies using "research through design" (RtD) as a research method. In RtD, design plays a formative role to generate knowledge by iteratively developing prototypes and framing, reflecting on, and communicating insights from these. We used the prototyping process to develop the emerging AM technology in

the new context of a circular economy. The main contributions can be summarised as following:

- We helped establish of a new research direction by exploring design approaches for product integrity and material integrity in a circular economy.
- We developed a circular AM process flow for product integrity. This is demonstrated by showing that the digital and additive character of AM can be harnessed to develop reversible connections that enable products to be disassembled and reassembled without loss of quality. We developed reversible joints and demonstrated these with a proof-of-concept of a lamp and vase (figure 5 and 6 in this document).
- We established a design approach for developing reprintable materials. This was demonstrated by producing reprintable materials from locally available bio-based resources, i.e. ground mussel shells with two different binders (sugar and alginate). We designed a lampshade and hairpin and 3D printed them using these materials (figure 2,3 and 4 in this document).

We contributed to the domain of 'research through design' by using the prototyping process for knowledge generation; a less common use. The design goal in the prototyping process was used to obtain relevant information (from other disciplines) for developing technology in a new context. This resulted in an iterative process between experimental prototyping processes and scientific knowledge generation.

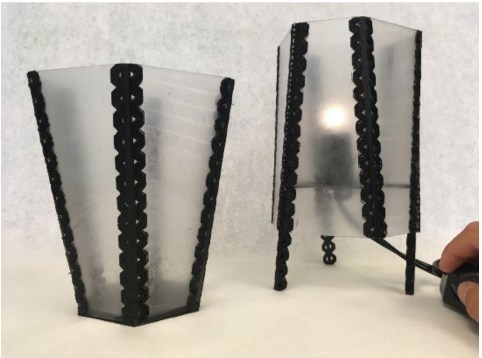


The thesis includes a number of published and submitted articles: chapters 2, 3 and 5 have been published, chapter 4 is under review, and chapter 6 is accepted for publication at the time of writing.

In chapter 2, the use of annotated portfolios was extended to analyse qualitative interview data. With this development, interview data can now be visually analysed, which is valuable when designers are interviewed about their design projects. The visual overview of images with annotations led to fruitful discussions and contributed to a deeper understanding of the subject. We applied this novel approach in chapter 3.

In chapter 3, we explored to what extent the opportunities that AM offers for sustainable design are also useful when designing in a circular economy. we performed a literature review and held qualitative interviews with five designers about their sustainable 3D printing projects. The interviews were analysed using the extended annotated portfolios. Our results present opportunities (adapting digital design files for changing needs and using complex structures for recycling) and challenges (complex geometries can hamper disassembly and reassembly, and designers request for renewable materials) for how AM can support design in a circular economy. Based on these findings, we defined two areas for exploration in our experimental studies: 'pursuing high value reuse with reversible connections for product integrity' (Chapter 4) and 'the development of reprintable materials from bio-based resources for material integrity' (Chapter 5 and 6).

In chapter 4, a theoretical framework is presented for a circular AM process flow that considers high value reuse by including both materials and physical parts directly in the digital production process. The process flow is demonstrated with a prototyping process resulting in prototypes with reversible 3D printed joints and laser cut panels that can be both disassembled and reassembled.



In chapter 5 and 6, we established a design approach for the development of reprintable materials. Reprintable materials can be reconstituted to their original properties in terms of printability and functionality. A full material life cycle is described for the development of these materials. In chapter 5, we explore this approach by using locally sourced bio-based waste streams. This resulted in a material for extrusion paste printing from ground mussel shells and sugar that can be dissolved in water after use to retain a printable paste. In chapter 6, we further elaborate on the design approach and developed a reprintable bio-based composite material from ground mussel shells and alginate. This new material can be recovered based on reversable ion cross-linking resulting in water-resistant materials.

In Chapter 7, we describe the insights gained about product integrity and material integrity with AM for design in a circular economy. Furthermore, we evaluate our research process with 'research through design' and present practical insights for design as well as share directions for future research.

We would like to conclude by nothing that, in spite of all the optimism about the way the use of AM can accelerate the transition to a circular economy, there are currently few AM applications that actually support and enable the circular economy. Our exploration shows that to successfully print for product integrity and material integrity, both in-depth knowledge and understanding of the AM production technique is required.

Summary of research through design activity

The following studies and activities were performed:

1. Interview study analysed with annotated portfolio

In this study qualitative interviews were held with designers about their 3D printed design projects. These were analysed with annotated portfolios, which is a new way of using this method. Annotated portfolios are used in RtD to support artefacts with text to make them topical for discussion. We developed this approach for interview analysis because designers were interviewed about their design projects and this provided the opportunity to visually analyse the data: When annotating interviews by relating data to the design objects, the information becomes visual and a means for discussion.

2. Design process to create reversible joints

In this study, the design process was used to explore a workflow for digital fabrication that considers high value reuse and recovery. To address the empirical evidence of this theoretical framework, we explored the practical details of the framework with prototyping. This resulted in a concrete example of products with reversible 3D printed joints and laser cut panels that can be disassembled and reassembled, and a demonstration of the developed workflow.

3. Material development and design process to create reprintable materials

In these studies, biobased and locally sourced waste streams were developed into 3D printable materials that can be reprinted to meet high value recovery in a circular economy. In this process, we developed and designed with these materials to test (re)printablity and possible applications. In this, way we developed a design approach for material development that includes the full material life cycle, and created proof-of-concepts with prototypes from the reprintable biobased materials. The supervision of two master thesis projects was part of this process.

Underpinning research, context and summary of methodology

This doctoral study started with a literature review from a design perspective by relating the literature to serval design projects. The designers of these projects have been interviewed and these interviews were analysed with annotated portfolios. Based on the outcomes experimental studies were performed in which the prototyping process was used to create insights and verify new approaches. We applied RtD to better understand the design implications of using an emerging technology (AM) in a future context (circular economy). The focus on prototyping processes for knowledge generation and technical development is not so common in RtD as most literature is related to user interaction. This work has therefore contributed to the development of RtD as a methodology. This doctoral study has resulted in several conference and journal publications, a doctoral thesis and tangible prototypes. The tangible prototypes have been exhibited at the Dutch Design Week and are still on display in museum Museon-Omniversum in The Hague.

The prototyping process occurred in two subsequent steps: the development stage and the design stage. These two stages are typical for our RtD approach; usually the prototyping process in RtD only entails a design stage. However, in our project, technical development was required before design objects could be made. We consider the development stage part of the RtD process as it serves a design goal and is prerequisite for establishing the requirements for the subsequent design stage.

During the design stage, we developed prototypes that demonstrate the current status and abilities of the newly developed 3D printing approach or material. They represent a proof-of-concept and the final outcome of an experimental study. Besides this, the prototypes revealed new challenges and they serve therefore also as a step towards further research.

To conclude, we consider prototyping processes for knowledge generation a valuable RtD approach for developing technology in a new context. The design goal in the prototyping process helped us to obtain relevant information from other disciplines and for technical development in a new context. Artefacts and prototypes, as well as a detailed process documentation, play an important role in the evaluation of the process of generating scientific knowledge.

References produced by researcher from/during doctoral research

Journal publications:

Sauerwein, M., & Doubrovski, E. L. (2018). Local and recyclable materials or additive manufacturing: 3D printing with mussel shells. Materials Today Communications, 15, 214–217. https://doi.org/10.1016/j.mtcomm.2018.02.028

Sauerwein, M., Doubrovski, E.L., Balkenende, A.R., & Bakker, C.A. (2019). Exploring the potential of additive manufacturing for product design in a circular economy. Journal of Cleaner Production, 226, 11381149. https://doi.org/10.1016/j.jclepro.2019.04.108

Sauerwein, M., Zlopasa, J., Doubrovski, E., Bakker, A.C., Balkenende, A.R. (2020). Reprintable paste-based materials for additive manufacturing in a circular economy. Sustainability.

Conference proceedings:

Sauerwein, M., Bakker, C. A., & Balkenende, A. R. (2017). Additive manufacturing for circular product design: a literature review from a design perspective. In C. A. Bakker & R. Mugge (Eds.), PLATE conference (pp. 358–364). https://doi.org/10.3233/978-1-61499-820-4-358

Sauerwein, M., Bakker, C. A., & Balkenende, A. R. (2018). Annotated portfolios as a method to analyse interviews. In C. Storni, K. Leahy, M. McMahon, P. Lloyd, & E. Bohemia (Eds.), Design Research Society 2018 (pp. 1148–1158). https://doi.org/10.21606/dma.2017.510)

Sauerwein, M. & Peek, N. (2019). Integrated Connections: Workflows for Hybrid Digital Fabrication, Poster proceeding at Symposium on Computational Fabrication (SCF), Pittsburgh, USA

Non-academic exposure:

Exhibition: Mussels in the 3D printer: a surprising look at recycling. Exhibition at Mind the Step, Dutch Design week 2018.

Online exhibition: Living Matters. Up close and personal. Research event at Design United, Dutch Design week 2020. https://2020.design-united.nl/day-3-living-matters/the-multiple-lives-of-3d-printed-designs-in-a-circular-economy/

Exhibition: One planet. Museon-Omiversum, The Hague. 2022-2024.

Website: https://materiom.org/recipe/599 and https://materiom.org/recipe/23

Online access

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