Supplementary material

Dokter, G., Boks, C., Wouterszoon Jansen, B., Hagejärd, S., Rahe, U. & Thuvander, L., (2022). The role of prototyping and co-creation in circular economy oriented innovation: A longitudinal case study in the kitchen industry. *Submitted to Journal of Sustainable Production and Consumption.*

S1 Interview guide

Table S.1. An overview of interview sample questions

General	**Can you describe your role in the project? Both as a company and individual.**
	What do you remember as things that went well in the project?
	What do you remember as the most significant challenges in the project?
Stakeholder collaboration	According to you, who were the most crucial parties or people that participated in the project?
	Did the project lead to any new relationships or partnerships with actors you did not collaborate with prior to the project?
	In projects like the circular kitchen, how important is it for you that other companies in the supply chain are involved? (e.g., suppliers, manufacturers)
	According to you, were there any parties or people missing in the project that would be essential to promote circularity within the kitchen industry?
	What activities or factors during the project supported the collaboration between the partners? And your willingness to collaborate?
Prototyping & co-creation	How do you see the role of the prototypes, and the process of developing the prototypes, during the project?
	How do you see the role of developing the business models (for the circular kitchen) during the project?
	How do you see the role of the international workshops between the Dutch and Swedish partners in the project?
	How do you see the role of the national workshops between the (Dutch/Swedish) partners in the project?
	Was there any other design and development work done within the context of the project that according to you has played an important role?
Circular economy	How are you currently working with the circular economy in your company? How has the project impacted the companies work with circularity?
	Do you see any benefits of a circular economy in the kitchen industry?
	What do you consider as the most important factors for increasing circular economy practices within the kitchen industry?
Project expectations and outcomes	What were your initial expectations of the project?
	What did you understand as the motivation for the project?
	According to you, what are the most valuable outcomes or lessons of the project?

S2 Detailed case study description

S2.1 The circular kitchen in Sweden

S2.1.1 Analysis phase (2018)

Introductory meetings took place between the research team and the project partners concerning potential directions for the project and helping the researchers to gain a better understanding of the current knowledge, challenges, and efforts in relation to sustainability and CE within the organizations. The project team identified an opportunity to investigate how kitchens can be designed in a flexible manner, to be able to adapt to changing circumstances (e.g., change of owner or tenant) and different preferences throughout lifecycles.

A consortium workshop took place (A1) including Chalmers, TU Delft, various stakeholders from the Dutch supply chain (e.g., kitchen manufacturer, appliance manufacturer, housing companies) and the Swedish kitchen manufacturer. Preliminary discussions took place for the design of circular business models and the kitchen within the Swedish context.

The project faced a couple of challenges. The assortment manager of the kitchen manufacturer (who was a driving force for the project and the internal sustainability agenda) left the company (E3), and the kitchen manufacturer raised concerns regarding available staff to assign to the project. The project proposal included a deliverable of a first physical prototype of a kitchen design based on circularity principles by the end of the first year, and during the rest of 2018 various meetings and three workshops (see table B.1.) were organized with the kitchen manufacturer (as the key partner to produce this prototype). The first workshop took place at the kitchen manufacturer and included a factory tour, a presentation of a market analysis carried out by the researchers, a stakeholder mapping workshop, and an innovation workshop that focused on kitchen design for different demographics. The second workshops featured a presentation by the research team of conceptual directions for a circular kitchen design, and a circular business model canvas workshop. During a third workshop, the researchers explained the circular economy concept in further detail, and facilitated a future vision workshop (for 2030 and 2050) on how CE principles could be integrated into the business, and a co-creative session took place with the purpose of conceptualizing a circular business model and service solutions. Through the workshops, the kitchen manufacturer particularly showed interest in two directions: (1) adopting durable materials with a higher potential for recirculation and (2) the development of a PSS and service-based revenue model that could enable maintenance and repairs and avoid the premature disposal of kitchen furniture.

The research team initiated user studies (focus groups, interviews) with households to investigate how contemporary kitchens are used (and changed throughout the lifetime) to adapt to preferences and demands of households.

Table S.2. Overview of co-creation workshops in analysis phase.

#	Date	Participants	Purpose	Activities	Outputs
1	2 Jul 2018	CEO (Owner) Product range manager Product coordinator Product manager Constructors (2) Concept marketeer Researchers (5)	Project introduction Relationship building Market analysis Stakeholder mapping Idea generation	Company presentation Factory tour SWOT analysis Stakeholder analysis Innovation workshop	Stakeholder map Company and market analysis Ideas for promoting circularity in kitchens

2	11 Sept 2018	CEO (Owner) Product coordinator Product manager Constructors (2) Researchers (5)	Evaluate concepts Identify circular business model opportunities Identify relevant stakeholders	Concept presentation Concept evaluation Circular business model canvas workshop Stakeholder mapping (continuation)	Concept evaluation and selection Ideas for circular business model
3	12 Oct 2018	CEO (Owner) Product coordinator Marketing manager IT manager Customer service manager Researchers (5)	Agree on circular goal/vision for project/company Further development of selected concept	Define circular vision project and company Discussion concept selection Evaluation opportunities/challenges for selected concept	Circular vision 2022/2030 Concept evaluation Prototype plan

S2.1.2 Prototyping phase (2018-2019)

The research team led the development of the prototype, the kitchen manufacturer was assigned with the fabrication of the prototype. Due to the limited time (approximately 3 months) and limited in-house prototyping capabilities at the kitchen manufacturer, a collective decision was made to produce a conventional kitchen but based on moveable kitchen modules on wheels. This enabled further investigation of how kitchens could adapt over time to changing preferences and demands (e.g., from different users), to avoid premature alterations and disposal of kitchens.

During a workshop organized with the appliance manufacturer to discuss the role of kitchen appliances in the project and define a research agenda, it became apparent that the company had been acquired by a larger consumer electronics concern, and unclarity existed regarding their further participation in the project.

Material research efforts were conducted by the research team to explore and identify alternative materials for kitchen furniture. Conventional materials in the kitchen furniture industry (i.e., MDF, chipboard) were found to offer a relatively short lifespan and limited potential for recirculation, whereas materials like solid wood and bio-composites, respectively, were found to offer the potential of extended lifespans and improved recycling practices. The researchers initiated a meeting between a bio-composite producer and the kitchen manufacturer, revealing a significant potential of bio-composites for kitchen application but requiring radically different manufacturing capabilities and major investments from the kitchen manufacturer.

Through close collaboration with the kitchen manufacturer, the test kitchen based on standard components (prototype 0) was manufactured and installed in a tenantless testing room of a living lab at the university campus to enable testing and workshops with different types of users (e.g., cooking sessions, kitchen layout planning sessions). A consortium workshop took place where the prototype was presented to the Swedish and Dutch partners and evaluated through a cooking session with professional cooks (Figure B.1., left). During the workshop, the companies presented ongoing efforts and ambitions regarding circularity. Afterwards, a vision

workshop was organized to define a future vision on circularity in the kitchen industry and a back casting approach was used to translate the outcomes to concrete goals for the CIK project.

The research team conducted various user studies with the kitchen prototype to learn more about the spatial and functional preferences of kitchens according to different types of users (figure S.1., right).

Figure S.1. First prototype kitchen installed in the living lab on the university campus during consortium workshop with professional cooks (left) and user studies (right).

S2.1.3 Proof of principle (2019)

The prototype became a useful resource in work of students (e.g., thesis projects, course work) and the results provided valuable insights to the overall research project and directions for further research.

During a workshop organized with the kitchen manufacturer, preliminary research findings were presented by the researchers and circular design strategies were collectively ranked, resulting in three key principles: 1) integrating kitchen refurbishment services in the business model 2) undertaking a pre-study on developing a PSS that can enable a service-based revenue model, and 3) identifying alternative board materials with lower environmental impact and similar or lower economic costs than current standard board materials.

Efforts were made to engage relevant actors in the supply chain and three of the kitchen manufacturers clients (1 housing association, 2 construction companies) were contacted. Individual meetings took place with each company, the companies showed interest in the project and some already had an agenda for circularity. Afterwards, a common workshop (A3) was organized together with these actors, indicating that the costs associated with a circular kitchen design were a main concern. The workshop participants concluded that the next step would be to test a circular kitchen prototype in a real-life scenario (e.g., community room or guest apartment) where it would also be possible to evaluate the (dis)assembly procedure of a ‘flat-pack’ kitchen construction concept.

S2.1.4 Proof of concept (2020)

The researchers explored a modular kitchen construction to enable easier exchange of parts and components (e.g., doors, panels) that are prone to damage and likely exchanged during the lifecycle of the kitchen, thus facilitating maintenance, repair and exchange routines to extend kitchen furniture lifespans. Plans progressed for a second demonstrator prototype, a tenant-occupied apartment in the living lab was considered an ideal real-life setting for evaluation and testing. An external design consultant was subcontracted to further develop the concept into a manufacturable product together with the researchers.

Bi-weekly meetings took place with the design consultant to steer and co-develop the concept further. The consultant initiated contact with an aluminum manufacturer to evaluate the potential of using aluminum profiles as the material for the kitchens base frame. Due to environmental and technical concerns regarding this material, plywood was identified as an alternative material for the frame solution, offering a relatively high durability and lower environmental impact.

Because of the ongoing Covid-19 pandemic, the kitchen manufacturer announced that they were not able to produce the next prototype and an alternative partner had to be identified for the prototype production.

The final concept developed by the design consultant and research team was presented to the kitchen manufacturer (See figure S.2.). The kitchen manufacturer responded positively and showed interest in the further development of the concept into a prototype and made the decision to assign an engineer to the project to support further development.

Figure S.2. Proof of concept presentation featuring modular cabinet construction (left) and kitchen scenario (right).

S2.1.5 Prototyping phase (2020-2021)

Bi-weekly work sessions took place between the engineer and the research team to enable progress in-between the sessions and collaboratively elaborate and decide on technical details of the design such as materials, dimensions, and components.

The researchers set up contact with a Finnish plywood manufacturer offering plywood panels based on bio-based lignin adhesives instead of fossil-based phenols. The manufacturer showed interest in the project and decided to sponsor the project by providing plywood panels to produce the prototype.

Contact was initiated with a housing developer that is interested in the project and offered the opportunity to place additional two prototype kitchens in apartments of an early-phase building project targeted towards seniors. Floor plans were prepared for the installation of three prototype kitchens, one in an apartment in the living lab (figure S.3.), and two in apartments of the housing developer.

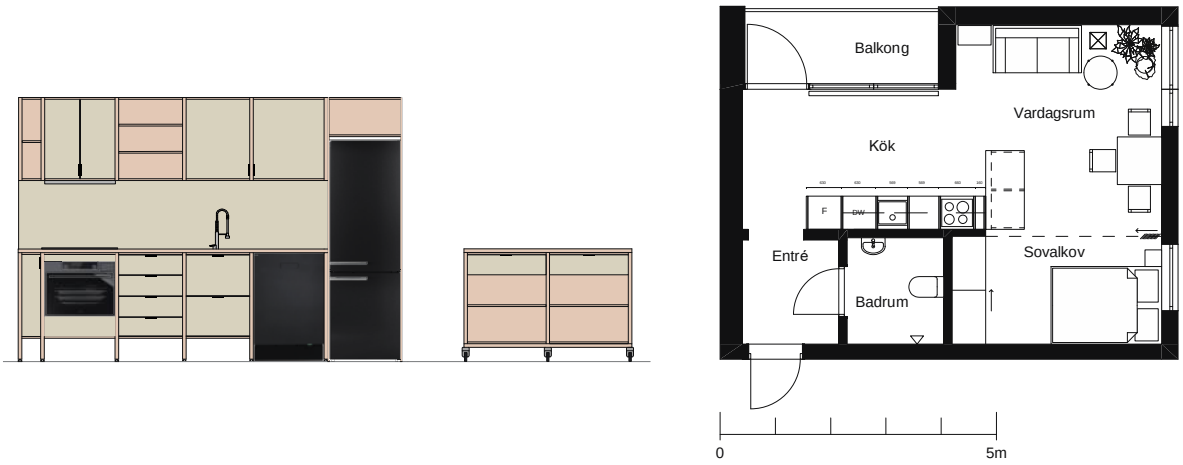

Figure S.3. Impression of prototype kitchen for installation in apartment living lab (left) and floorplan (right).

Meetings took place with the appliance manufacturer to discuss the upcoming prototypes and the integration of kitchen appliances in the kitchen prototype. Since the kitchen manufacturer lacked in-house prototyping capabilities, a carpenter was subcontracted to produce the prototypes. The kitchen manufacturer expressed confidentiality concerns regarding sharing the technical drawings of the kitchen concept with external parties and asked for signed NDA agreements.

Several prototype cabinets were produced by the kitchen manufacturer (through an external party) showcasing the plywood design construction (figure S.4.) and the prototypes were ocularly evaluated by a few members of the kitchen manufacturer and the research team. The potential of the kitchen design is displayed, several challenges are identified leading to changes in the dimensions of the plywood components of the kitchen. Another kitchen cabinet prototype is produced by the contracted carpenter and placed at the university for evaluation. Various technical challenges are identified relating to warping of plywood panels, the stability and weight of the cabinet components, and the connections between different components.

Figure S.4. Prototype cabinets showcasing the plywood construction based on flexible furniture connectors.

The kitchen prototype is installed in an apartment of the living lab (see figure S.5., picture to the right). The process of deconstructing the old kitchen and installing the new kitchen is carefully observed and documented by the research team to evaluate the overall construction and installation process. Further testing and evaluation of the prototype is continuously taking place with the researcher-tenant of the apartment. A final workshop took place to conclude the

project, evaluating the prototype, exchanging key learnings and experiences, and presentations of findings by the research team.

Figure S.5. Prototype kitchen installed in living lab, featuring a modular plywood construction and moveable kitchen island to adapt to changing social settings and functional demands.

S2.1.6 Evaluation phase (2021 onwards)

The kitchen prototype in the living lab is ongoingly tested and evaluated through daily use by the researcher-tenant, through organized kitchen sessions (i.e., cooking and eating) with diverse user groups, and through field visits (e.g., by professionals, researchers, students) where visitor responses are captured through observations and surveys. Through studying the daily use over several months (and potentially years), it will be possible to study the functionality of the kitchen over time, the wear and tear of the components, and potentially repairs and alterations. The insights gathered through the construction, installation, and use of the prototype were thoroughly documented and will serve as input for the further development of the kitchen design during a follow-up project running from 2021 to 2023, that will focus more on the further development from prototype to market implementation. During this project, the next iteration of prototypes will be installed (and tested) in two apartments of an early-phase building project targeted towards Seniors in the proximity of Göteborg, Sweden.