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The role of prototyping and co-creation in circular economy-oriented innovation: A longitudinal case study in the kitchen industry

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ABSTRACT

To bridge the gap between the conceptualisation and implementation of circular value propositions, recent research efforts have focused on linking design-driven approaches with circular-oriented innovation. Such approaches can facilitate iterative processes that emphasise co-creation, prototyping, and real-life experimentation, ultimately promoting practical implementation. Still, there is a lack of understanding how companies go through the process of circular-oriented innovation, and how prototyping and co-creation support this process. This article presents a longitudinal case study of a four-year research project in which two academic teams, from Sweden and the Netherlands, collaborated with industrial partners to explore the potential of circular economy principles within the kitchen industry and develop a market-ready circular kitchen. The results indicate that prototyping plays a supportive role in the circular-oriented innovation process by making the concept of a circular economy tangible for stakeholders, facilitating knowledge exchange, and supporting overall developments towards collaborative circular supply chains. However, prototyping too early in the process linked to project deliverables carries a risk for 'prototype fixation', fragmented solutions, and missed opportunities for shared value creation. Co-creation was found particularly impactful during the early stages of circular-oriented innovation where it helped guide the project, enabled shared learning, built confidence and commitment amongst stakeholders, and supported the development of solutions tailored to demands of parties involved. The case study provides deeper insights on the role of prototyping and co-creation through diverse stages of the circular-oriented innovation process and extracts several lessons that might aid researchers and practitioners to navigate future circular-oriented innovation endeavours.

1. Introduction

In recent years, circular economy (CE) has gained widespread traction in business, academia, and politics. The CE is an industrial system based on cyclical flows of resources so that products, components, and materials are maintained at their highest utility and value, and the notion of waste is eliminated (Murray et al., 2017). Product-service systems (PSS) and circular business models (CBMs) support the economic viability of such a system, as these enable companies to benefit from the recovery and continuous utilisation of resources, thus incentivising resource efficiency and lowered environmental impacts (Tukker, 2015).

The CE is frequently seen as a driver for sustainable development that will reduce environmental pressure resulting from the construction and product manufacturing industry, while ensuring economic and social prosperity (European Commission, 2014, 2020). With a growing interest in the CE amongst consumers and producers, small- and medium-sized enterprises (SMEs) are increasingly exploring how they can integrate CE principles into their organisation and offering (Demirel and Danisman, 2019).

In the context of products, circularity can be seen as the property of a system which is based on (1) the circular design of products in line with the principles of slowing and closing of resource loops (Bocken et al., 2016), (2) business models that incentivise and capture value of product lifetime extension and resource recovery, and (3) supply chains and stakeholder networks that actively collaborate to enable the continuous

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utilisation and circulation of resources, and maximise shared value creation. Thus, a particular challenge for companies operating at a micro-level (products, components) is that concurrent efforts are needed towards a circular product, business model, and supply chain. Such efforts require companies to increasingly think outside of organisational boundaries and adopt a circular ecosystem perspective (Konietzko et al., 2020). To address such challenges, there is a need for circular oriented innovation (COI) (Blomsma et al., 2019a), which can be described as the process of integrating CE goals, principles, and strategies in the innovation process.

Recently, scholars have investigated the potential of linking sustainable design theory and design thinking frameworks with circular business model innovation (CBMI) (Baldassarre et al., 2020a; Geissdoerfer et al., 2016; Guldmann et al., 2019; Santa-Maria et al., 2022). Design thinking frameworks facilitate co-creative design processes, shared knowledge building, and real-life experimentation and prototyping which can help bridge the gap between the conceptualisation and the implementation of CBMs (Baldassarre et al., 2020b). To support COI, scholars have advocated for holistic approaches, stakeholder collaboration, and shared visions in COI (Blomsma et al., 2019b; Bocken et al., 2016; Brown et al., 2021). Yet, extant research seldom sheds light on how such conditions are fostered within COI processes in practice which typically include a multitude of stakeholders with diverse (aligned or conflicting) perspectives. Considering that COI is an iterative process performed over various distinct stages in time, there are few case studies that distinguish different stages of the innovation process and highlight the dynamics of stakeholder interactions, challenges, and success factors faced in practice.

This study responds to a call for longitudinal case studies that investigate COI and the implementation of CBMs in practice (Baldassarre et al., 2020b; Bocken et al., 2021; Brown et al., 2021; Pieroni et al., 2019). To date, there have been few case studies that provide insights into the process dimension of COI, distinguish the different stages in the innovation process, and investigate how prototyping and co-creation support the different stages of the COI process. Therefore, the aim of this article is to provide a longitudinal perspective on the process of COI and further the understanding of how prototyping and co-creation supports the different stages of the COI process.

A longitudinal case study of a four-year research project, 'the Circular Kitchen' (CIK), is presented in which academic teams from two universities (in Sweden and the Netherlands) collaborated with stakeholders in the kitchen industry to develop a kitchen solution based on CE principles. The case study builds on an earlier study by Wouterszoon Jansen et al. (2022a) which examined stakeholder choices in the Dutch trajectory. This article covers both the Dutch and Swedish trajectory and focuses particularly on the role of prototyping and co-creation throughout the project. In addition, based upon the case study several lessons regarding the role of prototyping and co-creation in COI are outlined.

The project adopted a design-driven approach with a focus on stakeholder co-creation and prototyping to develop kitchen solutions based on CE principles suitable for market implementation. The analysis of the longitudinal case study is aided by a timeline of events and semi-structured interviews with participating companies. Finally, findings are discussed in relation to the extant literature on COI and roles of prototyping and co-creation.

2. Literature review

The following section provides a brief overview of key concepts and earlier research relevant to the scope of this study. The section is divided in four parts, elaborating on the concept of COI, processes of prototyping, collaboration, and co-creation in the context of a CE, and an overview of existing case studies related to COI.

2.1. Circular design and innovation for a circular economy

Circular design aims to integrate CE principles throughout the design process and requires dedicated competences (Sumter et al., 2021), design methods (den Hollander, 2018), and design and business model strategies (Bocken et al., 2016). The novelty of the CE lies in the combination of the inter-connected ideas of a closed-loop economy with a 'restorative' design approach (Murray et al., 2017). Thus, a fundamental distinction of circular design is that it is an absolute approach (i.e. assuming a closed loop of materials) that strives to resolve issues related to waste generation and resource efficiency rather than to mitigate them, in contrary to relative approaches (e.g. eco-design) that are rooted in the notion of the current linear economy (den Hollander et al., 2017).

CBMI concerns the process of creating a circular start-up, transforming a business model into a circular one, and diversifying into and acquiring CBMs (Geissdoerfer et al., 2020). The transformation of a linear business model into a CBM requires radical changes to the value creation logic of a company. In a CBM, profit is not generated through the immediate selling of products but through their continued utilisation, and the utilisation of the economic value that is retained in products after use in the realisation of new offerings (Linder and Williander, 2017).

To date, most research efforts concerning CBMI have been of a theoretical and conceptual nature and have failed to address the 'design-implementation gap'. This refers to the gap between the conceptualisation and implementation of new business models, and to CBMI efforts that fail to leave impact in practice (Baldassarre et al., 2020a). Synthesising design thinking frameworks and CBMI can ensure iterative processes that focus on co-creation, prototyping, testing, and practical implementation (Santa-Maria et al., 2022). The framing of COI is useful as it encapsulates the combination of product design, business model innovation, and value network configurations to investigate the operationalisation of CE strategies (Blomsma et al., 2019a; Brown et al., 2021). Value network configurations need to be developed so that actors (e.g., suppliers, manufacturers, consumers) interact and collaborate in a way to enable, and benefit, from the extended utilisation and circulation of products and resources. Through COI, and applying circular business model strategies, companies can maximise value creation (in terms of economic, societal, and environmental value) of slowing and closing resource loops (Bocken et al., 2016; Geissdoerfer et al., 2020).

Still, there is a lack of understanding how companies go through the process of COI, particularly from a product design perspective, and how prototyping and co-creation contributes to COI.

2.2. Role of prototyping in a circular economy

Prototyping is a process that involves the development of tangible and intangible artifacts to explore, evaluate, and demonstrate the usability, function, and form of products (Houde and Hill, 1997). Prototypes, as outputs of prototyping processes, embody technical knowledge and can be critical to social interactions (e.g., to convey a value proposition to various stakeholders) (Lauff et al., 2020).

Within product development involving diverse stakeholders, prototypes can also function as boundary objects (Star and Griesemer, 1989) that make sense for each stakeholder from their own perspective, and create a common knowledge base amongst stakeholders and across boundaries. Prototypes thus serve a knowledge-brokering role and enable a shared space which allows people to work together without consensus (Kleinsmann and Ten Bhömer, 2020).

Baldassarre et al. (2020b) explain how piloting prototypes from an early-stage forces organisations to simultaneously consider the desirability, feasibility, viability, and sustainability of a new business model.

Ultimately, products cannot be designed intrinsically circular, they can only be designed with the potential for circularity. The actual lifespan of a product is always dependent on socio-economic factors related to consumer behaviour and the business model the product is embedded in den Hollander (2018). Therefore, in the context of a CE, it is vital to develop prototypes and utilize them to execute small-scale pilots, to holistically assess the potential of a circular product design strategy alongside a CBM and a particular supply chain configuration. Pilots can be defined as semi-controlled launches and tests of business concepts and prototypes with the target market within small-scale and easy to analyse settings (Geissdoerfer et al., 2022).

The role of prototyping and pilots in relation to the CE has been investigated to some extent. In urban settings, prototyping was used for knowledge brokering, to explore "alternative futures co-defined by agents who do not interact with one another normally" (p.5) (Nogueira et al., 2020). A design thinking framework for CBMI developed by Guldmann et al. (2019) proposes a prototyping and testing phase to examine CBM ideas and undertake pilot experiments. Although these studies support the framing and understanding of prototyping in the CE context, there is a need for more knowledge of how prototyping supports different phases of the COI process.

2.3. Role of collaboration and co-creation in a circular economy

The CE challenges organisations to collaborate across the entire supply chain to enable continuous utilisation and circulation of resources, from upstream suppliers (e.g., for the recovery of materials) to downstream distributors (e.g., for reverse logistics of products). Scholars widely agree that stakeholder collaboration is a crucial factor to realise a CE (Blomsma et al., 2019b; Brown et al., 2021; Konietzko et al., 2020; Leising et al., 2018) and the lack of willingness to collaborate is a major barrier for a CE in the EU (Kirchherr et al., 2018).

A main challenge with collaboration in the context of COI, as pointed out by Brown et al. (2020), is the traditional mindset to maximise individual benefits over exploring potential value from a whole-system perspective. Brown et al. (2020, 2021) provided a process perspective on collaborative COI and presented four challenges related to it, emphasising the importance of aligning actors on shared circular propositions (and the role of scientific bodies in the external facilitation of this process), developing CE-oriented governance and decision-making, and enabling a suitable context for iterative experimentation.

COI typically involves a multitude of stakeholders with diverse (aligned or conflicting) agendas, interests, and perspectives. Participatory design approaches including co-creation and co-design are relevant as they enable creative collaboration in multi-stakeholder settings and provide a political and democratic function in large systemic transformations where neither agency nor power is evenly distributed amongst stakeholders (Gaziulusoy and Ryan, 2017). Although co-creation can refer to any act of collective creativity, co-design has its roots in design practice and more specifically involves collective creativity between designers and people who are not trained in design throughout design development processes (Sanders and Stappers, 2008). Furthermore, the term of value co-creation emerged from business and management literature, and more precisely addresses collaborative value creation within individual firms, in relationships between actors, and within a network of actors (Jaakkola and Hakanen, 2013).

Thus far, literature on co-creation and co-design provides limited guidance for development of CE value chains, particularly on how to select strategic partners, when to engage them, and to what capacity (Blomsma et al., 2019b). Apparently, co-creation and co-design approaches can contribute to COI, but limited empirical studies on COI exist that aim to better understand the role of co-creation and co-design throughout different stages of the COI process.

2.4. Case studies on circular-oriented innovation

A recent literature review (Bjørnbet et al., 2021) found that since 2015 the number of publications based on case studies in the context of CE in manufacturing companies has grown substantially, indicating a progress towards empirical research on CE adaptation in manufacturing companies. Case studies reporting success stories of CE implementation are plentiful (Diaz Lopez et al., 2019) though few empirical studies both report successes *and* extract lessons from failures (Bjørnbet et al., 2021). Many case studies take the perspective of manufacturing processes and technical aspects (Bjørnbet et al., 2021) or innovation in business models (Geissdoerfer et al., 2018; Guldmann and Huulgaard, 2020; Weissbrod and Bocken, 2017).

A longitudinal action research study based on a yearlong project by Linder and Williander (2017) examined causes for reluctance of CBM adoption in companies, providing insights into factors that contribute to the inherent uncertainties and financial risks experienced by companies. A longitudinal embedded case study by Hansen and Schmitt (2021) applied innovation community theory to provide deeper insights of how individual companies collaborate in the value chain to operationalise the CE.

There are few case studies that take a design perspective on CE innovation. A recent study by Meath et al. (2022) provided insights into the role and process of co-designing between industry and academia to develop a collaborative multi-level platform in the context of the infrastructure industry, revealing a set of critical factors (e.g., stakeholder alignment and relationships, shared vision building, value and risk mapping). Sumter et al. (2018) presented a longitudinal study on the role of product design in CBMI, highlighting crucial CE-related design challenges that appear once products are in use, and mapping the role and competences of designers in the creation of CBMs. A previous study carried out in relation to the CIK project examined stakeholder choices and extracted five lessons to develop feasible circular building components, relating to ambitions, aesthetics, design scale, participation, and focus (Wouterszoon Jansen et al., 2022b). Yet, this study examined the Dutch innovation trajectory only, and did not specifically focus on the role of prototyping and co-creation in COI.

Although retrospective case studies on circular innovations and CBMs are helpful by providing static 'snapshots', they provide limited insights into the dynamics of how companies or industries go through different phases of sustainable design (Baldassarre et al., 2020a). Longitudinal case studies based on action research are necessary to examine COI processes from ideation, conceptualisation, to implementation in practice, as practical implementation is what leads to transformation in organisations (Pieroni et al., 2019). To date, few case studies have examined the COI process longitudinally, distinguish the different stages in the innovation process, and investigate how prototyping and co-creation support the different stages of the COI process.

3. Material and methods

From 2018 to 2022, the research project CIK was conducted in which academic and industry partners collaborated to develop kitchen solutions based upon CE principles. The project provided the opportunity for a longitudinal case study of a design-driven COI process with a focus on prototyping and stakeholder co-creation.

3.1. Research context and approach

The CIK was a collaboration between two universities (from the Netherlands and Sweden) and stakeholders in the kitchen industry. The two research teams worked in parallel projects with national partners, pursuing a collaborative innovation trajectory in accordance with the cultural, regulatory, and market context in respective country. The researchers in the project acted as participatory action researchers (Reason and Bradbury, 2008) who engaged and involved diverse actors to co-create the intended CE solutions, facilitated the shared knowledge generation process, and actively participated in the innovation trajectory. This enabled them to investigate the COI approach comprehensively and to systematically document actions, views, and decisions.

In a four-year innovation project, it is likely that the perspectives of the involved actors are changing throughout the different phases of the

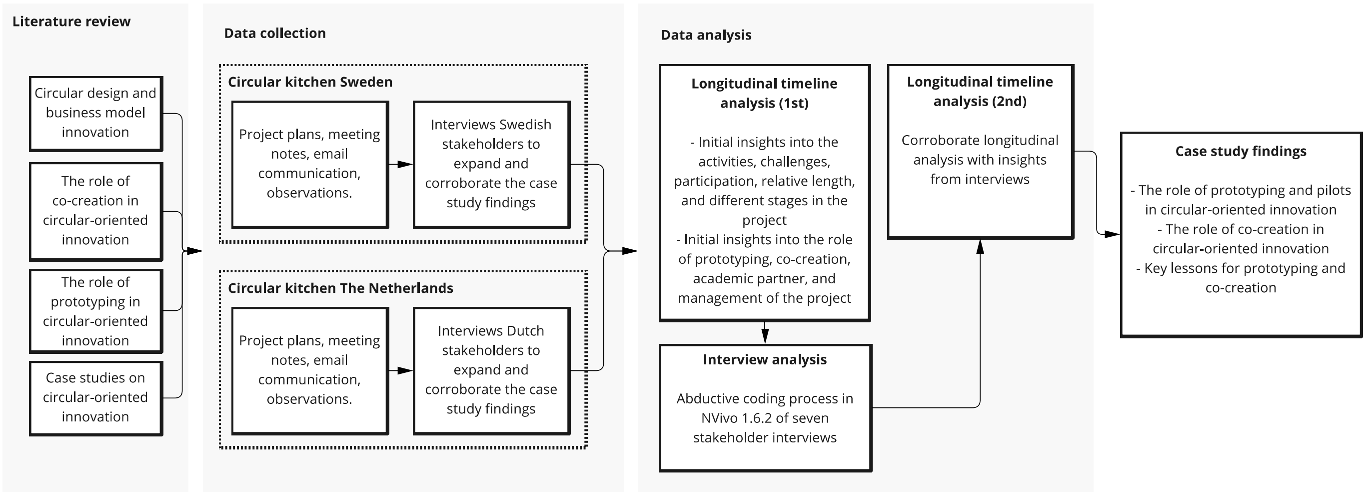


Fig. 1. Overview of the research approach in this study.

COI process. Therefore, a longitudinal analysis of the COI process was considered appropriate to capture the diverse activities, perceived challenges, and stakeholder interactions over time. The study primarily draws on longitudinal data collected by the researchers throughout the project, which was used to construct a timeline of events and extract insights.

Semi-structured interviews were carried out by the researchers to gather additional deep insights from the perspective of the involved stakeholders and corroborate the findings from the longitudinal analysis. Fig. 1 provides an overview of the overall research approach.

3.2. Data collection and analysis

A case study pursues analytic generalisation by comparing empirical results with previously developed theory (Yin, 2003). Longitudinal case studies require an extra step, namely a timeline of events or a sequence of changes in research variables across time, which are extracted from the data and serve as a basis for the case study narrative (Street and Ward, 2012).

Table 1 shows the data collection methods in this study. Documentation from various project activities was used to construct an initial longitudinal case study timeline in the online collaborative whiteboard tool Miro, which was reviewed and further complemented by the team of researchers. The aim of the timeline was to provide an overview of the different stages in the project, their relative length, and the shared events and activities between the researchers, partners, and supply chain actors in the project that featured extended interactions. Summarized versions of the timelines are presented in Ch. 4 to aid the description of the results.

At the end of the project (February to March 2022), seven semi-

Table 1
Overview of data collection methods included in this study.

Data collection type	Quantity	Notes
Semi-structured interviews with industrial stakeholders in the project	7 interviews	Sweden: - SE1 (Chief executive officer, kitchen manufacturer) - SE2 (Product assortment manager, kitchen manufacturer) - SE3 (Design engineer, kitchen manufacturer) - SE4 (Research & pre-development manager, kitchen appliance manufacturer) The Netherlands: - NL1 (Chief executive officer, kitchen manufacturer) - NL2 (Chief development officer, kitchen manufacturer) - NL3 (Innovation manager, kitchen appliance manufacturer)
Documented stakeholder interactions	139 activities	Sweden: - 32 meetings - 10 work sessions - 7 co-creation workshops The Netherlands: - 39 meetings - 24 work sessions - 20 co-creation workshops Sweden & The Netherlands: - 7 consortium workshops
Observed stakeholder interactions	56 events	Stakeholder interactions (observed by the first author).
Document analysis	–	- Analysis of project plans - Meeting minutes and email communication over 4 years (2018–2021) - Documents and visual outputs resulting from workshops and project activities

structured interviews were conducted with project partners, with focus on the stakeholders that have been involved during the whole process in both the Netherlands and Sweden (i.e., representing kitchen manufacturers and appliances). The aim of the interviews was to gather additional insights from the perspective of the stakeholders about the project and corroborate the timeline and initial findings. An interview guide (see appendix A) was developed with questions covering general experiences of the project, the role of collaboration and prototyping, and perspectives on the CE in the kitchen industry. Interviews were conducted face-to-face (n = 1) and digitally through Zoom (n = 6) in English, Swedish, and Dutch, and the audio was digitally recorded with permission of the participants. The interviews lasted between 52 and 92 min and were transcribed and then coded in NVivo (Release 1.7.1) (QRS international, 2022). At this stage, iterative discussions took place between the authors to define and cluster the findings from the interviews into themes.

3.3. Case study description: the circular kitchen

The following subsections provide background information to the case study, and a summarised description of the CIK project in the Netherlands and Sweden. The developed solutions are described as well as the process through which they were developed. A more detailed account of the Swedish case and Dutch case is included in the supplementary material, and Wouterszoon Jansen et al. (2022b), respectively.

3.3.1. Case study background

The innovation project CIK (2018–2021) was motivated by the pressing environmental concerns within the kitchen industry. Over recent decades kitchens have become increasingly central, multi-functional, and resource-intensive spaces within households. The kitchen furniture and appliances contribute substantially to the environmental impact of domestic buildings (Hoxha and Jusselme, 2017). Refurbishment of domestic kitchens can occur frequently over the lifetime of a building; often kitchen furniture and appliances are replaced far before they reach the end of their technical lifetime. In Sweden, premature replacements of kitchen furniture and appliances have been estimated to contribute 57 % to the overall climate impact of interior renovations in owner-occupied apartments (Femenías et al., 2016). In the EU, disposal of kitchen furniture accounts for approximately 25 % of the 10 million tonnes of furniture discarded on a yearly basis, of which 10 % is recycled and the majority incinerated or landfilled (Forrest et al., 2017).

In current linear business models of kitchen manufacturers, once kitchen furniture is sold and installed, there is typically no further engagement or value captured during the lifecycle (other than a limited warranty period on damaged furniture). Hence, opportunities exist to incorporate CE principles and capture value of lifetime extension and resource recovery, as well as providing services that enable refurbishment, recovery, reselling, and recycling of kitchen furniture (Ollár et al., 2020). To capture shared value of these opportunities, value co-creation was pursued with material suppliers, kitchen manufacturers, appliance manufacturers, customers, and service providers to enable the circulation and extended utilisation of resources.

The aim of the CIK project was to develop a market-ready kitchen solution based on CE principles with a potential for scalability exemplified through demonstration kitchens placed in the Netherlands and Sweden. The project adopted from the beginning a system perspective including a focus on (1) solutions including both kitchen furniture and appliances and (2) physical prototype developments and simultaneous work on a value network configuration and circular business model to shift towards a circular system. It should be noted that the innovation trajectory (and the focus of the case study) primarily focused on new product development, yet concurrent efforts were made to conceptualise and assess the potential of a circular business model and value network.

The approach with two parallel collaborative (academic and industrial) teams was adopted to support knowledge exchange and solutions with a wider international market potential. A design-driven approach emphasised co-creation, prototyping, experimentation, and practice-based research in real-life settings.

The Dutch project strongly focused on the social housing sector which provides affordable housing to low-income communities and is the most common type of rental housing in the Netherlands (represents around 30 % of the total housing stock) (CBS, 2021). Social housing associations are the owners (and main customers) of the kitchen furniture and appliances. Thus, the project team included various social housing associations, a property maintenance provider, a kitchen appliance manufacturer, and a kitchen furniture manufacturer that delivers kitchens primarily to the social housing sector (total production of around 55,000 kitchens per year).

The Swedish project team focused more on kitchens in condominiums (representing 42 % of the multi-residential housing stock in Sweden) (SCB, 2022), where the kitchen is 'resident-owned'. The project team included a kitchen furniture manufacturer (total production of 18,000 kitchens per year), a housing association, and a kitchen appliance manufacturer.

3.3.2. The circular kitchen in the Netherlands

A one-year pilot project (2017–2018) was conducted with industry partners to develop a proof of principle for a circular kitchen. The researchers deployed interviews, micro internships, and factory visits to understand current industry practices. Five circular kitchen variants were developed, and the resulting physical design for the kitchen applied a plug-and-play concept and featured a docking station and long-lasting frames (Fig. 2, image 1) to which functional models are connected (fronts, drawers, shelves), incorporating flexible connectors to enable future adaptability, repairs, and disassembly. The business model proposal consisted of a purchase with take-back model, in which the kitchen manufacturer takes a central role by offering docking stations and kitchen modules to landlords under the agreement that they are taken back after use for redistribution, refurbishment, or repurposing of parts and materials.

During the concept phase, the researchers developed various scenarios for CBMs, and discussions took place between the kitchen manufacturer and housing associations about financial contracts and the roles of each actor. The kitchen manufacturers CDO (Chief Development Officer) became involved in the project when an iterative phase with work sessions took place to elaborate on technical details regarding construction and materials of the kitchen, resulting in the use of plywood and flexible connectors. Environmental and economic assessment criteria were defined for the kitchen based on life-cycle assessment (LCA) and total costs of ownership (TCO).

The production of the first prototype (P-A in Fig. 2) was outsourced to a third party and the prototype was presented at a public event in January 2019. Due to time pressure, experimental materials and custom furniture connectors were not realisable, therefore the team incorporated conventional solutions. The prototype demonstrated the potential for repair, exchanges, and upgrades of components and allowed stakeholders to interact with the prototype and exchange spare parts. The researchers presented tentative positive TCO and LCA results of the circular kitchen compared to a business-as-usual kitchen (with a 20-year average lifespan). During 2019, 38 circular kitchen demonstrators were planned to be installed in dwellings of interested housing associations, offering potential for user testing and pilots. The Dutch kitchen manufacturer recruited a circular business developer to take over tasks in the project, coordinate product and business development, and coordinate the installation process of the demonstrators.

During the demonstrator phase, further technical development took place to prepare the kitchen design for market implementation. A demonstrator kitchen was placed in the kitchen manufacturers showroom for exposure to stakeholders. The Covid-19 pandemic had affected the project; meetings and workshops were conducted primarily online.

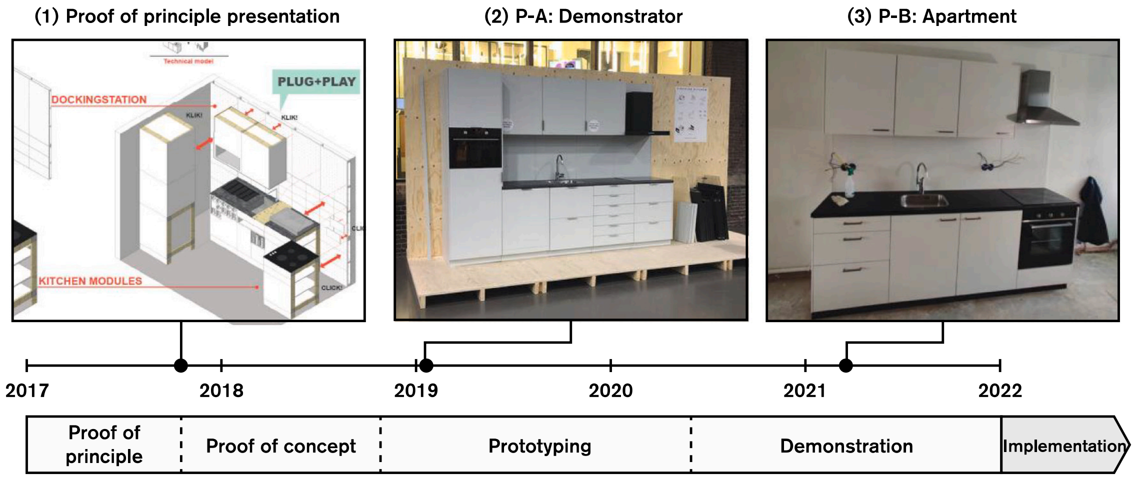


Fig. 2. Overview of design outputs during the Dutch project.

Simultaneously, the participation of some actors decreased during this period and their representatives shifted. Eventually, seven kitchen demonstrators were successfully installed in dwellings of one housing association (P-B in Fig. 2). Since then, the kitchen manufacturer has adapted the kitchen design to fit to the current manufacturing capabilities and business model, by reverting to chipboard and an alternative frame solution. After the end of 2021, research initiatives in relation the CIK discontinued, yet the kitchen manufacturer proceeds further development of the circular kitchen towards market implementation.

3.3.3. *The circular kitchen in Sweden*

During an initial analysis phase, introductory meetings with project partners enabled a better mutual understanding of current CE awareness, sustainability efforts, and directions for the project. The project plan included a deliverable for a full-scale kitchen prototype by the end of the first year, therefore various meetings and three workshops were organised on-site at the kitchen manufacturer (the key partner to produce the prototype). User studies (focus groups, interviews) were conducted with Swedish households to investigate contemporary kitchen preferences, use, and refurbishment practices (Hagejärd et al., 2020).

The project was faced with some challenges early on. The assortment manager of the Swedish kitchen manufacturer left the company and the company raised concerns regarding available staff for the project. Another challenge occurred as the Swedish appliance manufacturer was acquired by a larger consumer electronics concern, which reduced their participation in the project.

The researchers led the prototype development while the kitchen manufacturer was assigned with the fabrication. Research was conducted to identify alternative materials for kitchen furniture with higher potential for circularity than chipboard (e.g., solid wood and bio-composites). Yet, due to time pressure and the kitchen manufacturer's limited prototyping capacity, a conventional kitchen was developed based on moveable kitchen modules.

Eventually, the test kitchen (P-C in Fig. 3) was installed in a tenantless room of the living lab at the university campus. A consortium workshop was organised where the prototype was presented to the Swedish and Dutch partners and evaluated through a cooking session with professional cooks. P-C became a useful resource in user studies (e.g., to investigate spatial and functional preferences of different kitchen users) and student projects, which provided valuable insights and directions to the overall project.

In the proof of principle phase three key directions were identified: 1) integrating kitchen refurbishment services in the kitchen manufacturer's business model 2) develop a PSS to support a service-based revenue model, and 3) identifying alternative board materials with lower environmental and economic costs. To support these directions, ideas were developed for a modular kitchen construction to enable easier refurbishment of furniture components (e.g., fronts, shelves). The researchers requested the kitchen manufacturer to involve more supply chain actors in the project, whereafter four housing developers were contacted and individual meetings and a common workshop were arranged.

During the concept phase, an intensive collaborative phase with a subcontracted design consultant led to a concept kitchen design (Fig. 3,

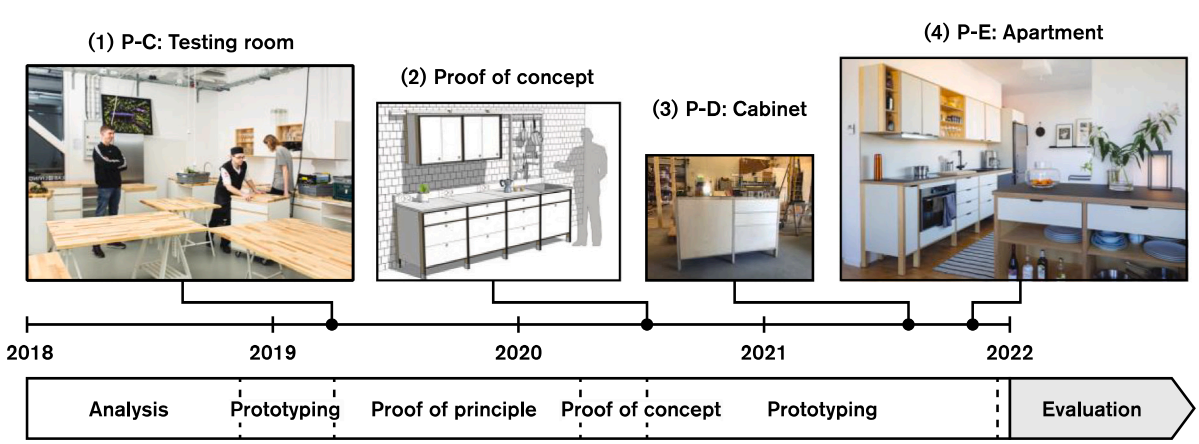


Fig. 3. Overview of design outputs during the Swedish project.

image 2) which was presented to the Swedish kitchen manufacturer. The kitchen manufacturer showed interest and assigned a design engineer to aid further development into a manufacturable prototype. Plans developed for a demonstrator prototype in a tenant-occupied apartment at the living lab, which offered a real-life setting for evaluation and testing. Yet, due to the Covid-19 pandemic the kitchen manufacturer could not support this prototype's production, and an external interior production company was subcontracted.

During the prototyping phase, technical details related to materials, dimensions, and components were elaborated by the kitchen manufacturer's design engineer and the researchers. The researchers arranged contact with a Finnish plywood manufacturer who provided lignin-based plywood panels for the prototype's plywood construction. An interested housing developer offered the opportunity to place two additional kitchen prototypes in apartments of an early-phase building project. Meetings were arranged with the Dutch appliance manufacturer to specify the integration of kitchen appliances in the prototype design. Several prototype cabinets were produced by the kitchen manufacturer to evaluate the design and construction (P-D in Fig. 3), which led to changes in details and dimensions.

Finally, the prototype was installed in the living lab (P-E in Fig. 3) where it is ongoingly evaluated by a researcher-tenant and through organised sessions with users. Insights regarding the construction, installation, and use of the kitchen were thoroughly documented and serve as input for a follow-up project running from 2021 to 2023, focusing on further development and market implementation.

4. Results

This section presents the results of the longitudinal case study combined with the analysis of the retrospective interviews conducted with project partners. The following subsections first address the role of prototyping in the CIK project and describe key lessons for prototyping in COI. Next, findings regarding the role of co-creation in the CIK project are revealed, alongside key lessons for co-creation in COI.

4.1. Roles of prototyping in circular kitchen project

Prototyping had a crucial role in supporting the innovation process and developing the proof of concept throughout the CIK project. Aside from the generic role of supporting the proof of concept, we identified three additional roles of how prototyping supported the COI process, which are summarized in Table 2. Different types of prototypes were produced (demonstrator, non-functional, functional, showcase) that served various purposes at different stages of the innovation process. In the following section, we refer to the different prototypes according to the labels given in Figs. 2 and 3.

The demonstrator circular kitchen (P-A) presented early 2019 at a public event hosted at the Dutch university provided positive momentum to the innovation trajectory. The present housing associations were invited to interact with the prototype and tentative results of the LCA and TCO analysis were presented. The prototype made the circularity principles tangible for the housing associations and enabled further communication and knowledge exchange about the circular value proposition. The event sparked further interest of the housing associations (e.g., prototypes were ordered for installation and testing in dwellings) which then stimulated further product and business development by the Dutch kitchen manufacturer, including investigations into large-scale production. P-E sparked further internal discussions at the kitchen manufacturer regarding how circular design strategies can be incorporated in the design of their kitchens. The prototype was, however, not publicly displayed through an event to engage the housing sector and other supply chain actors.

Prototyping provided a common ground for co-creative collaboration between existing partners who previously had stricter customer-supplier relationships. Furthermore, it enabled project partners to have concrete discussions about (potential) business models, financial contracts between the parties involved, and the roles and activities for each partner in relation to the developed prototypes.

The process of prototyping also ensured a pro-active approach in contacting and collaborating with new material and component suppliers, as materials and components were identified throughout the project that could enable a circular kitchen design. For example, in the Swedish project a manufacturer of sustainable plywood panels was contacted, which ultimately led to a collaboration in which the manufacturer provided plywood panels to be incorporated in P-D and P-E.

4.2. Key lessons related to the role of prototyping

The longitudinal analysis and interviews revealed key lessons regarding prototyping in COI, which are summarized below in Table 3. To assess the potential of the circular kitchen concept, fully functional

Table 2
Roles of prototyping throughout the circular-oriented innovation process, based upon the longitudinal analysis and consolidated by the interviews.

Relates to prototype	Role of prototyping in circular-oriented innovation	Findings from case data	Example quotes
P-A P-E	Make the concept of a circular economy tangible	• Circular design and business model strategies became understandable when materialized into a prototype	*"The more theoretical part became more practical; you could see that there is a product and there's a click-together kitchen. And maybe it's not the nicest one to look at. But it's there. Right?" (NL1)*
P-A P-E	Facilitate knowledge exchange between internal and external stakeholders	• Prototype enabled stakeholders in the project to convey the circular value proposition to other (external) stakeholders • Prototype supported internal discussions on circular design strategies	*"… when we launched the prototype, I heard the discussion about the cost, and not us [kitchen manufacturer], or our colleagues from the university had to explain. Now somebody from the social housing corporation who was in the project had stepped forward and explained what the cost structure was and why it was so important that they [housing corporations] shouldn't look only if it is more expensive or less expensive, but what it's doing to our environment" (NL1)* *"We have been able to look completely differently at all the challenges in the construction in a real way. Everything from weights to dimensions to durability and so on as so I am very pleased with the prototype as a starting point for further discussions." (SE2)*
P-A P-E	Foster stakeholder collaboration and circular supply chains	• Prototyping created common ground for new forms of collaboration between existing partners • Prototype enabled discussions on actor roles in circular business model • Prototyping initiated new collaborations with material and part suppliers	*"No, we would never have done that [build prototypes], then we would probably just have coffee with a customer and maybe discuss things like that. But not so interactive, I think that is more testing and estimating if something like this [the circular kitchen] could work. But not that you really interact with each other in a kind of focus group that thinks along and helps each other." (NL2)*

Table 3
Key lessons related to the role of prototyping throughout the project.

Relates to prototype	Lessons related to prototyping in circular-oriented innovation	Findings from case data	Example quote
P-B	Align expectations and purpose of prototypes between partners	• Different expectations regarding quality/ maturity of prototypes for pilots between stakeholders	*"We made agreements with customers that we really wanted to deliver [prototype kitchens]. Then I noticed that people's expectations were very different…that they really thought we had a final product that we could deliver 1000 of and worked out in great detail… then I got a bit nervous."(NL2)*
P-C	Prototypes as primary deliverables can hinder potential for collaboration and shared value creation	• Reduced willingness to involve additional stakeholders in project due to risk of not realizing prototype in time	*"It would have taken more time; we wouldn't have gotten to the prototype if we would have involved two or three actors more. But on the other side, maybe it would have taken more time, but it would have resulted in a different prototype, but then maybe we wouldn't have managed to finalise it within the projects timeframe." (SE1)*
P-A P-B P-C P-D P-E	Ensure capacity and facilities for prototyping and experimentation in circular-oriented innovation	• Property owners might not dare to take the risk to put prototypes in real dwellings • Lack of prototyping capabilities at kitchen manufacturers required additional subcontractors • Living labs as risk-free platforms for prototyping and experimentation	*"We had our subcontractors who did the first one [P-D] and they were very important to us there. We hadn't been able to do it with ours." (SE2)* *"It is a prototype, so that entails potential problems for a landlord."(NL2)*

circular kitchen demonstrators were installed in realistic household settings. Seven circular kitchen prototypes (P-B) were installed early 2021 in dwellings of Dutch housing associations and pilots were initiated with real tenants. This provided valuable feedback (from users, installers, housing associations). Yet, the interviews revealed the challenge of aligning expectations of the prototypes between stakeholders, as different expectations towards the quality of prototypes created friction between the kitchen manufacturer and housing associations.

The results indicated that prototypes, linked to rigid deliverables and deadlines, can hinder the external collaborations and shared value creation necessary for COI and can lead to fragmented solutions. As the Swedish consortium was not part of the pilot project prior to 2018, an extended initial phase was needed to determine specific challenges and opportunities regarding circularity in the Swedish kitchen industry, educate the project stakeholders about CE, and initiate a collaborative stakeholder network. Yet, the prototype deliverable at the end of 2018 caused time pressure, leaving less time for the initial phase. The prototype deliverables were considered a primary objective and affected the willingness of the kitchen manufacturer to include more companies (e.g., potential clients, housing associations, contractors) as that might have impacted the project timeline.

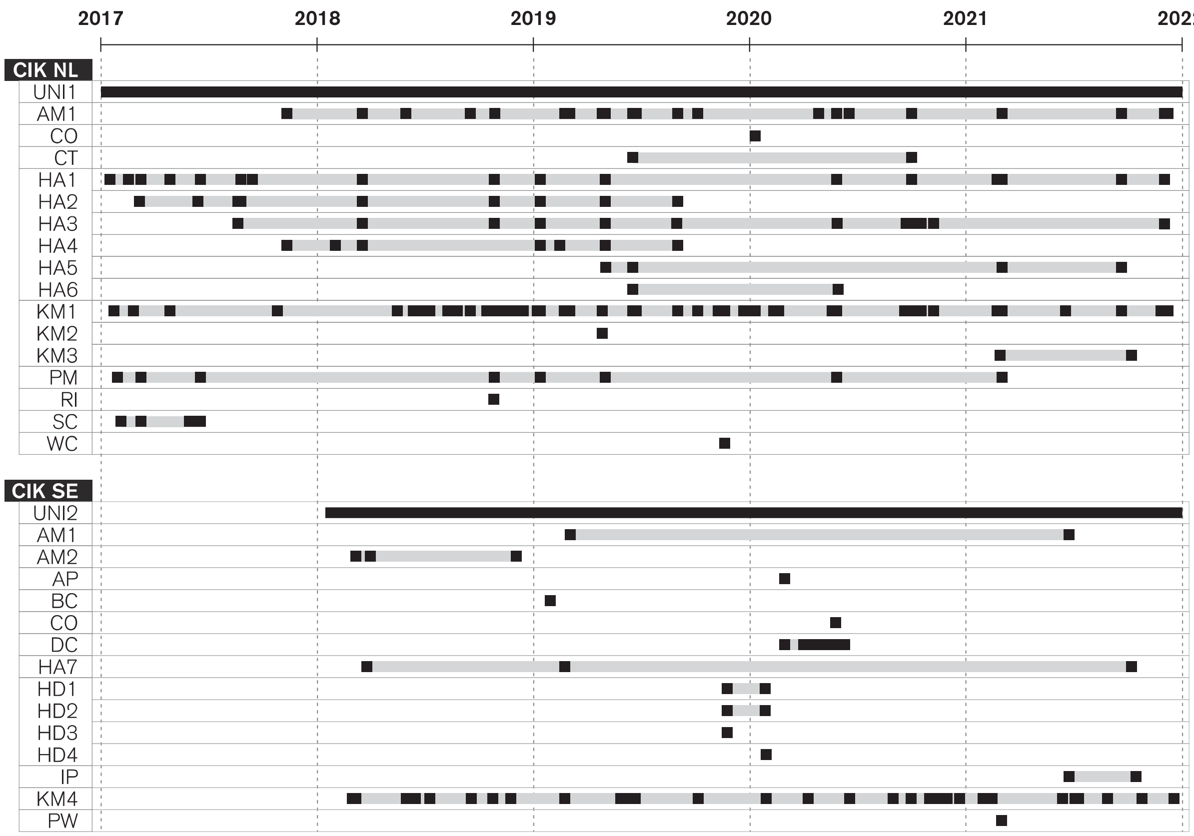
Throughout the project, identifying suitable facilities for testing prototypes was an important factor in the innovation process. In the Netherlands, the aim was to run pilots with prototypes alongside alternative business models (e.g., leasing services) in real dwellings, yet this was found difficult due to (1) some property owners not willing to take the risks (financial, safety risks) of placing prototypes in real dwellings and (2) current building laws and regulations consider kitchens part of the property and therefore restrict circular business models (e.g., leasing models where kitchen furniture ought to be returned after use). Overall, the project partners saw major challenges in moving from ideas for CBMs to experimentation and pilots with a business model in practice, which would rely on extensive collaboration.

In the Swedish project, P-C and P-E were placed in the living lab at the Swedish university, which provided a relatively risk-free platform to evaluate the prototypes in realistic household settings without the risks associated with real dwellings. This allowed the researchers to simulate the use of the prototype and enabled careful documentation (e.g., of assembly, installation, usage), yet provided limited insights into contextual and socio-economic factors (related to the interaction with users and supply chain actors).

4.3. The impact of early co-creation on circular innovation trajectory

Stakeholder co-creation had a supportive role in the CIK project, particularly in the early stages of the innovation process and combined with the engagement of essential supply chain actors from the start. An overview of the different organisations in the project and their degree of participation in activities is shown in Fig. 4. As can be seen in the figure, the Dutch project included a combination of stakeholders in the pilot project between 2017 and 2018. The early co-creation workshops between the researchers, kitchen manufacturer, and social housing associations (as potential customers) enabled the consortium to co-develop the physical design of the kitchen, discuss concrete options for CBMs, and determine roles and activities of actors within the CBMs. This collaboration was crucial according to the kitchen manufacturer: *'Without the social housing associations in the project, there was no project… it gave us guidance, if we were on the right tracks, it gave us sometimes a very hard critic, critic on how we solve some things, right. They pointed out that some things we wanted were not feasible because of the regulations they are confronted with by the government.' (NL1).* Afterwards, workshops were consistently organised throughout the entire project and functioned as crucial feedback and evaluation moments, typically involving 4–5 stakeholders elaborating on details of the CBM and kitchen design. The co-creation workshops supported the COI trajectory as they (1) guided the direction of the project, (2) enabled shared CE learning and network building, (3) verified the market demand for a circular kitchen which gave confidence to the kitchen manufacturer to pursue further development, and (4) made it possible to develop solutions together tailored to the demands and wishes of the parties involved.

In the Swedish project, co-creation workshops took place primarily in the first half of the project between the researchers and the kitchen manufacturer and did not include other relevant stakeholders (e.g., housing associations, appliance manufacturer). This relied on several factors including: (1) limited participation and interest of the housing association and appliance manufacturer in the workshops, (2) time pressure to deliver a prototype in the first year of the project, and (3) limited willingness of the kitchen manufacturer to involve potential customers in the process prior to a developed prototype and circular value proposition. Although the workshops were found helpful in raising CE awareness and identifying opportunities for a circular kitchen design and CBM, it was found difficult to develop and convey a circular value proposition without the perspective and engagement of actors across the entire supply chain (production, installation, use, end-of-life). At the end of 2019, efforts were made to involve four housing developers more actively into the project, which led to fruitful discussions but no further structural collaboration in the project.



CIK NL

Label	Organizaton type	Value chain actor	Size
UNI1	University	NA	Large
AM1	Kitchen appliances	Product manufacturer	Large
CO	Connectors	Parts supplier	Micro
CT	Countertops	Parts supplier	Medium
HA1	Housing association	Service provider	Large
HA2	Housing association	Service provider	Medium
HA3	Housing association	Service provider	Large
HA4	Housing association	Service provider	Large
HA5	Housing association	Service provider	Large
HA6	Housing association	Service provider	Large
KM1	Kitchen furniture	Product manufacturer	Medium
KM2	Kitchen furniture	Product manufacturer	Small
KM3	Kitchen furniture	Product manufacturer	Small
PM	Property maintenance	Service provider	Small
RI	Real estate investor	NA	Large
SC	Surface coating	Material supplier	Large

CIK SE

Label	Organizaton type	Value chain actor	Size
UNI2	University	NA	Large
AM2	Kitchen appliances	Product manufacturer	Medium
AP	Aluminum profiles	Material supplier	Small
BC	Bio-composites	Material supplier	Large
DC	Design consultancy	Design	Micro
HA7	Housing association	Service provider	Large
HD1	Housing developer	Service provider	Medium
HD2	Housing developer	Service provider	Large
HD3	Housing developer	Service provider	Large
HD4	Housing developer	Service provider	Large
IP	Interior production	Construction	Small
KM4	Kitchen furniture	Product manufacturer	Medium
PW	Plywood producer	Material supplier	Medium

Fig. 4. Overview of stakeholders that participated throughout the Circular Kitchen (CIK) project in the Netherlands (NL) and Sweden (SE) and their degree of participation during the years between 2017 and 2022. Each black square represents a participation in a documented activity. The grey line represents the collaborative period from first to last activity. The research teams (UNI) in respective countries were continuously active and present at all activities, therefore marked by a black line. Company size (employees): Micro (1–9), Small (10–49), Medium (50–249) and Large (250 +).

4.4. *Effects of various co-creation activities in the circular kitchen project*

The timeline in Fig. 5 shows the key stages in the innovation process in both projects and the frequency and types of different activities. The longitudinal analysis combined with the interview findings provided insights into how various forms of co-creation supported COI.

Co-creation in the CIK project took place to a great extent in the form of workshops facilitated by the researchers. These had an important function as generative sessions in which companies and participants were provided with creative assignments (e.g., through printed workshop sheets) and were incentivized to exchange thoughts and ideas from different stakeholder perspectives and backgrounds. Co-creation

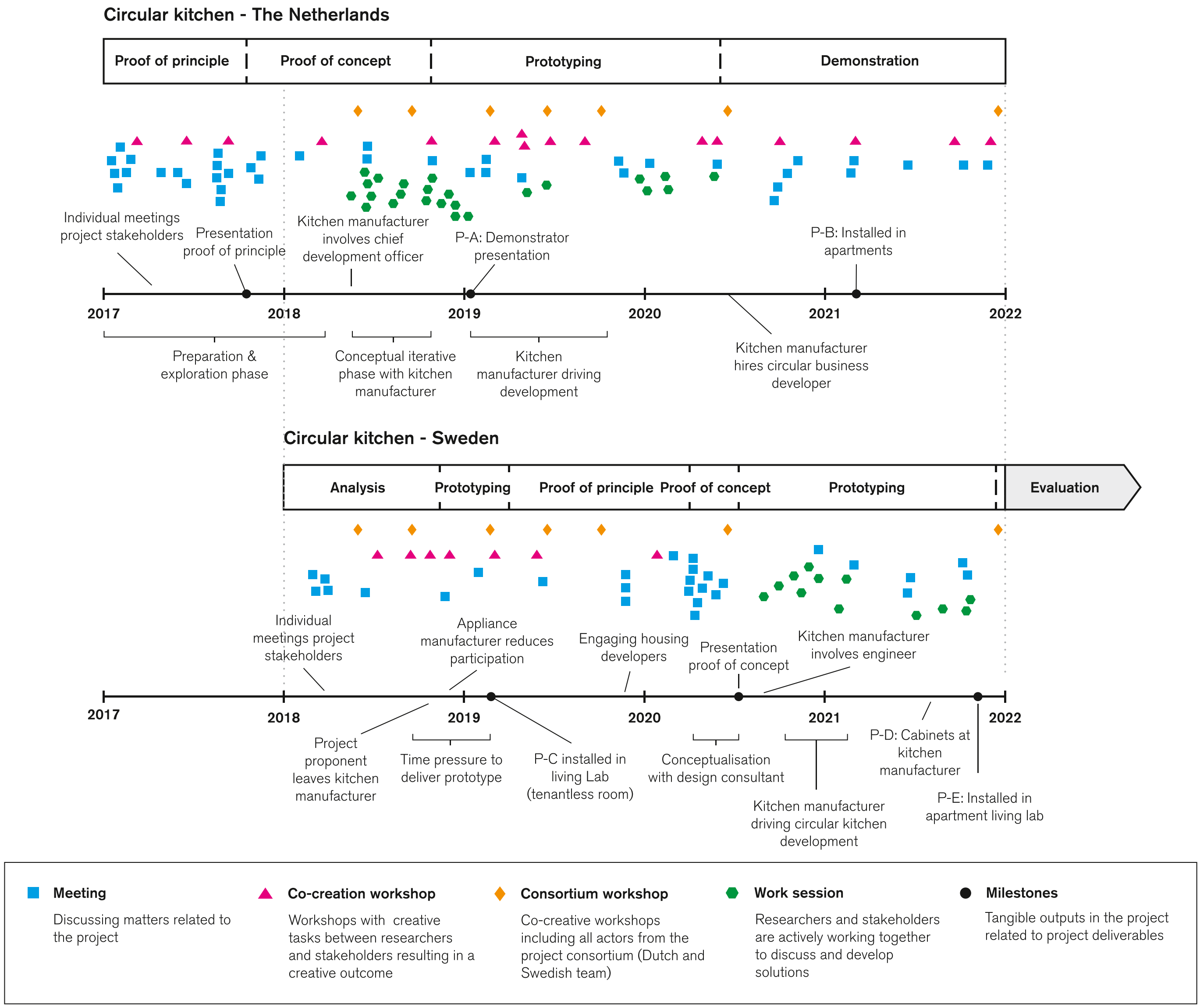


Fig. 5. Timeline of the project in the Netherlands and Sweden showing the relative length of key stages in the innovation process, and the frequency and types of activities.

workshops initially helped to develop the project vision, identify CE opportunities in the kitchen industry, and develop ideas for a circular kitchen design and business model based on identified strategies. The early workshops ensured a holistic focus on the products, business model, and kitchen industry by including several company representatives and top-level management (i.e., CEOs). Later in the project, the workshops focused on synthesis and had a supportive function in guiding the project and product development, ensuring stakeholder perspectives were ongoingly considered.

In the transition from concept to prototyping, iterative phases with work sessions between researchers and the kitchen manufacturers allowed for more focused development of specifically the circular concept into a manufacturable product. As can be seen in Fig. 5, both projects had similar phases in the innovation process, however the concept development and work sessions took place much later in the Swedish project. The yearlong pilot project by the Dutch consortium enabled an extensive explorative and preparatory phase based on co-creation that was crucial for joint CE learning and fostering stakeholder engagement and collaboration, prior to the CIK project (which focused more concretely on product development). Since the Swedish consortium was not part of the pilot project prior to 2018, the different context (marketwise, regulatory, culturally) imposed an extended initial phase and development of an own proof of principle. Afterwards, a co-creative phase with an external design consultant in 2020 rapidly led to a proof of concept which was positively received by the kitchen manufacturer. Consequently, the kitchen manufacturer assigned a design engineer to the project who helped develop the concept into a manufacturable prototype.

Consortium workshops were organised at least twice per year (either in the Netherlands or Sweden) until the start of the Covid-19 pandemic and invited all partners in the project. The seven international consortium workshops were appreciated as they enabled further exchange of knowledge and ideas between the projects through presentations and co-creative assignments. Additionally, it enabled some stakeholders (e.g., the CEOs of the Dutch and Swedish kitchen manufacturer) to exchange perspectives from respective markets and broaden their scope. Yet, some interviewees found it difficult to make progress in such large groups (between 15 and 20 people) and pointed out that the relevance and impact of these workshops were limited due to the different context and solutions in both projects.

4.5. Key lessons for co-creation in circular oriented innovation

The results indicate that the extent to which co-creation contributed to the COI process relied on a combination of factors identified in the longitudinal analysis: (1) aligned expectations, commitment, and project vision, (2) willingness to involve and collaborate with supply chain stakeholders, (3) the presence of a neutral platform and facilitator for co-creation.

4.5.1. Aligned expectations, commitment, and project vision

The project expectations, intentions, and commitment of the partners were diverse which influenced the collaboration in the project. Most interviewees expected a market-ready circular kitchen (furniture and appliances) by the end of the project, while some of the participants from the Swedish kitchen manufacturer did not have any concrete expectations or expected specific knowledge (e.g., about toolless assembly). Some interviewees indicated the project vision and goals were not made clear enough. Expectations about the roles of the companies in the project varied from a more passive-observer role: *"sitting along in those workshops, see and learn, and see what comes out of* it" (SE1) to a more active-participant role: *"think about how the circular kitchen of the future looks like as well as produce it"* (NL1). These varying expectations led to different levels of commitment to the project and its planned activities, and the participation of company representatives fluctuated or diminished entirely over the different stages in the process, which led to hindered progress. The kitchen manufacturer from the Dutch project explained that: *'Some customers were very much on sustainability and circularity, ..., and they stepped in. And they stepped out as easily as they stepped in. So, if I would do a project like this again, I would invite these stakeholders again, but I would ask for more commitment from them.' (NL1).*

4.5.2. Willingness to involve and collaborate with supply chain stakeholders

The willingness to collaborate with supply chain partners for COI was important for the co-creation and was diverse amongst the project partners. Some of the participants developed this willingness throughout the project as an increased CE awareness led to a perceived necessity to approach problems from a systemic and industry-wide perspective: *'This is one of the things I learned from the project, don't keep it to yourself… it's better to offer one system to the market so they [competitors] will adapt it earlier. And we bring in the sustainability and circularity much faster than if I will bring a [name of company] system and [name of competitor] or other companies will bring their system.' (NL1).* Other participants found it difficult to see how supply chain actors (e.g., housing developers) could be actively involved in the co-creation process and saw it as a potential hinder for progress: *'As an input to the project they [housing developers] are important, I think. But it's hard to see how they could be involved. I think they could be at the side…but not involved in the development process. It will be so many that are involved then, it will be more difficult to make progress.' (SE1).*

4.5.3. Presence of a neutral platform for collaboration and role of the facilitator

The interviewees revealed concerns about engaging in (external) collaborations, sharing knowledge and intellectual property, and their degree of transparency in sharing company information. Throughout the CIK project, the universities facilitated a neutral platform for collaboration that helped partners challenge their conventional supplier-client relationships and explore collaboration across the supply chain from a more systemic perspective. This is illustrated by the following quote of the Dutch kitchen manufacturer: *'There were a lot of relations, especially in the Dutch project, where there was a supplier-client relationship between us. I think that the university there also had a role as being a neutral partner in it. And it was very good for the cooperation.' (NL2).*

5. Discussion

The aim of this article was to provide a longitudinal perspective on the process of COI and create a better understanding of how prototyping and co-creation supports COI. Despite numerous case studies on CE implementation in recent literature, there have been few longitudinal studies that have examined the process dimension of COI and how companies go through the different stages of COI. Moreover, case studies often report success stories on CE implementation but more seldom extract lessons from failures (Bjørnbet et al., 2021). Therefore, we also outline several lessons learned regarding the role of prototyping and co-creation in COI. Overall, to our knowledge, there have been no longitudinal studies that have specifically examined the role of prototyping and co-creation in COI. In the following section, we discuss the theoretical and practical contributions of our research, limitations of the study and provide directions for future research.

5.1. The role of prototyping in circular-oriented innovation

We contribute to COI literature by providing case-based evidence of the role of prototyping through the longitudinal analysis of CIK, an example project of COI. We show that in the context of COI, prototyping has a supportive role by (1) making the concept of a CE tangible for stakeholders, (2) facilitating knowledge exchange between internal and external stakeholders, and (3) fostering stakeholder collaboration and circular supply chains.

In accordance with (Bogers and Horst, 2014), we also found that the process of prototyping provided a "platform for collaboration" (p. 757) between project partners and external stakeholders, which can be supportive when competitors or stakeholders with conflicting interests might need to collaborate to enable holistic circular solutions (Brown et al., 2021).

Some prototypes in the CIK project showed characteristics of boundary objects, such as the ability to support cross-disciplinary collaboration (Nicolini et al., 2012) and facilitate communication and knowledge exchange between diverse perspectives (Star and Griesemer, 1989). Moultrie (2015) described how demonstrators (seen as technological prototypes close to market implementation) can have multiple purposes simultaneously, such as demonstrating technical and commercial feasibility, and convincing funders and investors. Similarly, we found multiple and different purposes of prototypes at different stages of the COI process. For instance, prototype P-A embodied important technical knowledge, and by exhibiting it publicly at an organised event relatively early in the project, the circular value proposition was further conveyed to and between relevant stakeholders in the housing sector. In line with (Lauff et al., 2020), it is therefore important to be aware how prototypes are (and can be) leveraged in social situations between stakeholders to enable various actions (e.g., as a persuasive tool to gain buy-in). Furthermore, particularly for the process of COI, we found that prototypes can be utilised to involve new value chain partners, align on a shared circular purpose, and identify possibilities for shared value creation (Blomsma et al., 2019a, 2019b; Brown et al., 2021).

Despite the positive effects of prototyping, we also identified that linking prototypes to rigid project deliverables and funding agreements can hinder potential for external collaborations and shared value creation. When seen as a deliverable, there is a risk for 'prototype fixation' and prototypes being seen as a goal rather than a means to assess the potential of a circular value proposition. When planning prototyping in COI, it is thus recommended to define and align on the purpose of different prototypes between stakeholders, be aware of potential risks and ensure sufficient facilities and capacity for prototyping in the process.

Although the project focused mostly on product-level innovation, promising CBM concepts were also developed. Unfortunately, the project period was not sufficient to move these concepts into a prototyping and experimentation phase. Running CBM pilots (with users) was seen by project partners as a crucial challenge, but would also require a tighter connection to external actors (Geissdoerfer et al., 2022).

Apart from the limited possibilities to pilot prototypes alongside

CBM concepts, we also found that current building laws and regulations somewhat restricts CBMs (for kitchens). As already pointed out by Prendeville et al. (2018), we underline the relevance of experimental facilities such as living labs as they can provide a relatively risk-free platform for prototypes and CBM experiments in realistic household settings without the risks (financial, restrictions of building laws and regulations, potential image loss for housing associations) of placing prototype kitchens in real dwellings.

5.2. Leveraging co-creation in circular-oriented innovation

Our longitudinal case study illustrated how stakeholder co-creation can be leveraged in COI and showed how early co-creation in the form of workshops with essential supply chain actors can support the COI trajectory by (1) guiding the direction of the project, (2) enabling shared CE learning and network building, (3) verifying the market demand for the circular solution, and (4) making it possible to co-develop solutions together tailored to the demands and wishes of the parties involved. Co-creation can thus be useful in the context of the built environment, where silo thinking and a lack of collaborative approaches within the supply chain are key challenges (Adams et al., 2017).

Our case study findings align with Brown et al. (2019, 2021), who argued that the willingness to collaborate for COI depends on whether stakeholders see potential value from a whole-system perspective. Here, a careful selection of project partners and alignment on a shared vision is vital. The case study suggests that successful co-creation in COI depends on the alignment of expectations and project vision between stakeholders, and ultimately the willingness to collaborate. Although the case study indicated diverse levels of willingness for COI amongst project stakeholders, we found that some partners developed this willingness throughout the project. This, as they increasingly understood CE as a systemic and industry-wide challenge that requires comprehensive solutions (e.g., developed together with competitors). In accordance with Guldmann et al. (2019), we therefore underline the importance of extensive time in the initial stages of COI due to the necessary shift from a linear to a circular value creation logic and the way a CBM challenges existing organisational, technological, and industrial structures of companies.

Blomsma et al. (2019b) highlight that iterations towards a CE value chain may be required before the full set of stakeholders and possibilities for shared value creation are clear. Therefore, co-design processes in COI should allow, and welcome, the inclusion of new stakeholders to complement with necessary knowledge and capabilities. Our findings are consistent with these suggestions, but also indicate that a combination of essential supply chain actors from the start is preferable to enable joint learning, ensure an ecosystem perspective (Konietzko et al., 2020), and broaden the solution space. In the Dutch project, most of the partners that were involved from the beginning stayed actively involved until the end of the project, whilst it was found difficult to establish commitment amongst actors that were involved later in the project and create a sense of shared ownership and risk with them, in accordance with Blomsma et al. (2019b).

5.3. Towards implementation through iterative prototyping and co-creation

As pointed out by Guldmann and Huulgaard (2020), the findings of this study indicate that COI is indeed challenging as it requires 1) a radical shift for companies from a linear economy understanding and value creation logic to a circular one, 2) more stakeholders to be involved than in a traditional linear economy model to realise a CBM, and 3) a concurrent approach towards the development of a circular product, business model, and supply chain. While CBMI efforts often lead to promising CBM concepts, they are more seldom implemented in practice due to the design-implementation gap (Baldassarre et al., 2020b).

The iterative design-driven approach towards COI based on stakeholder co-creation and prototyping taken in the CIK project led to substantial impact in practice and resulted in solutions that are close to market implementation. Examples of the achieved impact are (1) the installation and testing of circular kitchen prototypes in real households and living-lab environments and initiation of small-scale pilots, (2) the dissemination of the project, gained knowledge, and developed solutions towards the market and a multitude of stakeholders in the kitchen industry, and (3) the development of awareness, (practical) knowledge, and capabilities amongst the consortium partners to drive the implementation of circularity further themselves (e.g., internal recruitment of circular business developers, adapted manufacturing capabilities).

Despite the project results being considered satisfactory, project partners need more time for the development and assessment of the circular kitchen design and small-scale pilots before reaching market implementation. Transdisciplinary projects such as the CIK are inherently inefficient and require learning and integration of knowledge (Gaziulusoy et al., 2016). Therefore, consecutive projects and a plan for how to maintain the larger arena and interest over time is recommended (Femenías and Thuvander, 2018).

For the academic partners it was vital to align (and educate) the project consortium on how circularity is defined and measured. They needed to ensure that 'the circular kitchen' concept is understood accordingly, contributing to the aims of sustainable development, and feasible in terms of environmental and economic costs measured over the entire lifespan without secondary rebound effects – a risk already pointed out by Pieroni et al. (2019). Related to this challenge, substantial LCA and LCC efforts were undertaken within the Dutch project consortium (e.g., see van Stijn et al., 2022; Wouterszoon Jansen et al., 2022a) while the Swedish consortium had only limited capacity and possibilities to address these questions.

5.4. Limitations

One limitation of the study relates to the risk of subjective bias, which is inherent to the nature of participatory action research and the retrospective analysis of the case study data. This was addressed by complementing the case study with interview data, securing project stakeholder perspectives. The participatory action research approach was greatly appreciated by stakeholders in the project as it added capacity and knowledge, but also means that the process and outcomes of the project are actively influenced by the researchers. Therefore, studies into COI processes over extended periods through participant observation are encouraged.

Although longitudinal case studies are time-consuming and have limitations regarding their generalizability, we provide rich and in-depth longitudinal insights of COI in companies, which address the current need for longitudinal data in COI literature. The issues of generalizability could be addressed through quantitative studies (e.g., surveys), which could provide more robust results of the role of prototyping and co-creation in COI and could corroborate the findings of this study. Yet, to account for the process perspective of COI and dynamics of experienced challenges and stakeholder perspectives, surveys at multiple stages would be recommended (e.g., before, during, after the COI trajectory).

Another limitation of the study was that no interviews were conducted with the housing associations. The participation of the Swedish housing associations was not considered sufficient to be able to reflect on the COI process, and attempts to arrange interviews with the Dutch housing associations were unsuccessful. The case was well-documented, yet interviews at various stages of the project would have been beneficial and are recommended to analyse developments and changes of stakeholder perspectives through the process.

6. Conclusion

Based upon a longitudinal case study of a four-year circular-oriented innovation trajectory within the kitchen industry, this research provides insights of how companies go through the process of circular-oriented innovation and how prototyping and stakeholder co-creation can be utilised to support the innovation process. To date, the role of prototyping and stakeholder co-creation throughout different stages of circular-oriented innovation is not well understood.

The results indicate that in the context of circular-oriented innovation, prototyping supports the process by making the concept of circularity tangible for the stakeholders, facilitating knowledge exchange between project partners and external stakeholders, and fostering stakeholder collaboration and circular supply chains. Furthermore, the longitudinal insights reveal how prototypes can be used for multiple purposes simultaneously at different stages of the innovation process. This research particularly highlights the supportive role of early co-creation workshops with project stakeholders for the circular-oriented innovation process by guiding the direction of the project, enabling shared circular economy learning and network building, verifying market demand for the circular solution and making it possible to co-develop solutions together tailored to the demands and wishes of the parties involved. The findings suggest that particularly the initial stages of the innovation process are crucial; the early involvement of the supply chain and dedicated time is needed to enable shared learning, network building, and a comprehensive project vision prior to the co-design of solutions and prototyping to ensure a viable circular value proposition.

This study outlines several practical lessons for prototyping and co-creation in circular-oriented innovation that might aid researchers and practitioners to navigate future efforts. Three key lessons for prototyping are highlighted, which emphasises that it is vital to align expectations and purpose of prototypes between project stakeholders, ensure sufficient prototyping and experimentation capabilities and facilities, and that linking prototypes to project deliverables carries a risk for 'prototype fixation', fragmented solutions, and missed opportunities for shared value creation. Furthermore, we extracted three lessons for co-creation in circular-oriented innovation, relating to the alignment of expectations and project vision between stakeholders, the willingness of stakeholders towards external collaboration, and the presence of a neutral collaboration platform and facilitator.

This research exemplified how a design-driven approach towards circular-oriented innovation based on prototyping and co-creation can ensure a focus on practical implementation and generate substantial impact in practice. This was indicated by the installation of demonstrator circular kitchens in real dwellings, upscaling pilots, public outreach to market and industry, and direct changes by the project partners to drive the implementation of circularity further themselves. Nevertheless, it is crucial that companies pursue a holistic approach towards circular-oriented innovation in which a product, business model, and supply chain are concurrently (re)designed in line with circular economy principles. The four-year project timeframe was not sufficient to drive all these parameters accordingly towards implementation. Approaching circular-oriented innovation through consecutive projects with the same consortium to gradually move from vision, conceptualisation, to implementation is therefore advisable.

The CIK project had a strong focus on product-level innovation and the developed solution displayed great potential for circularity. Yet, further research is needed to (longitudinally) assess the functional, environmental, and economic performance over entire lifecycles. This will require collaborative and coordinated efforts involving a wider network of stakeholders from the kitchen industry and researchers from more disciplinary backgrounds (engineers, environmental scientists, and economists).

Future research could focus on prescriptive frameworks and methods for COI which include how co-design processes and prototyping can be utilised to foster holistic circular solutions. By capturing the full potential of stakeholder co-creation and prototyping, the gap between the conceptualisation and implementation of circular value propositions can be further reduced, to ultimately support the transition to a circular economy.

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Declaration of competing interest

The authors declare that there are no conflicts of interest.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.spc.2023.05.012.

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