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Article

Comparing Circular Kitchens: A Study of the Dutch Housing Sector

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Abstract: The built environment can become more sustainable by gradually replacing building components with circular ones. Kitchens are a logical component to be made circular, given their relatively short lifespan, product-based nature, and affordable prototypes. Since various designs for circular kitchens can be developed, understanding the feasibility of these designs is crucial for their successful implementation. This knowledge, however, remains limited. Therefore, this article aimed to determine which types of circular kitchens are feasible. Circular kitchens available or announced in the Dutch housing sector within the past five years were compared using an adapted version of the CBC generator, a comprehensive design framework for circular building components. The comparison included the Circular Kitchen (CIK), developed as part of an international research project. Data were sourced from manufacturers' websites and online publications supplemented by interviews with two outliers to verify the results. The analysis encompassed seven circular kitchens, with two developed by established manufacturers and five by start-ups. The manufacturers mostly communicated about their kitchen's physical design. The established manufacturers' circular kitchens were found to be more similar to their non-circular kitchens, while start-ups applied more radical innovations. Furthermore, the kitchens that had a frame structure using technical materials or a panel-based structure using biological materials were more likely to be feasible. These findings can facilitate future circular kitchen development by improving these kitchens' feasibility, thus aiding the transition to a more circular built environment. Furthermore, this research contributes scientifically by adapting a comprehensive design framework (the CBC generator) to compare circular designs.

Keywords: circular economy; circular design; building components; kitchen; circular kitchen; kitchen design; design comparison

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1. Introduction

The built environment is responsible for a substantial part of all human-induced emissions, resource use, and waste globally [1]. The Dutch housing sector will contribute significantly to these environmental impacts, as it is stands on the verge of a renovation wave to reduce operational energy use, and faces a crisis related to availability. Consequentially, 3.5 million homes are planned to be insulated and 1.5 million are set to transition to gas-free installations [2]. While these renovations will decrease operational carbon emissions, they can significantly increase embodied impacts [1,3–5]. To solve the housing crisis, one million homes are scheduled to be built in the next decade [6], further contributing to embodied impacts in the built environment. Hence, regulations on the environmental impact of new buildings will become stricter in the coming years [7], and the government states that the applied renovation solutions should align with the principles of the circular economy (CE) [2].

The CE is "a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops" according to Geissdoerfer et al. [8]. Narrowing loops aims to reduce resource use or achieve resource efficiency up front, slowing loops aims to use resources longer, and closing loops aims to (re)cycle end-of-life materials back to production [9]. Slowing and closing loops can be performed through value-retention processes (VRPs) such as reuse, repair, refurbishment, and recycling [10,11]. To realize VRPs, components, parts, and materials should be considered from a systems perspective, focusing not only on the physical design (or technical model), but also on the supply chain (or industrial model) and business model [12].

A gradual transition to a circular built environment can be achieved by replacing building components with circular components during renovation, maintenance, or construction. Kitchens are logical components to be made circular [13]; they have a relatively short lifespan (±20 years in the Netherlands) [14] and are produced as a standardized product. Furthermore, developing prototypes is seen as beneficial for the development of circular components [15], which is relatively affordable for kitchens due to the low investment costs compared to a building façade, for example.

In line with the definition of the CE provided by Geissdoerfer et al., a circular kitchen can be defined as a kitchen that incorporates a technical model, industrial model, or business model that aims to narrow, slow, or close resource loops. Consequentially, kitchens can be made circular by applying many different CE strategies to their technical model, industrial model, and business model. For example, a kitchen can feature a modular design to facilitate reuse and updates, thereby slowing loops in the future. Alternatively, it can be constructed using biodegradable, renewable resources or lightweight materials, thereby narrowing loops in the present [14]. However, not all designs are feasible in practice.

Knowledge of which types of circular kitchens are feasible in practice can facilitate future circular kitchen development, thereby accelerating the transition to a circular built environment. Therefore, this article aimed to determine which types of circular kitchens are feasible in practice. The circular kitchens that were analyzed (1) have been developed in the last 5 years and (2) are currently available or will soon be available—assuming that adoption in practice serves as an indicator of feasibility. It should be noted that the feasibility of circular kitchen types is context-dependent, varying between different countries [16]. To ensure that the kitchens were compared equally, this research was limited to the Dutch housing sector.

2. Background

The number of articles published on the subject of CE has risen from under 20 publications in 2013 to over 100 in 2016 [8] and has since continued to rise. Without claiming to be comprehensive, an overview of the relevant literature from this growing field of research will be provided in this section.

Numerous methods, tools, and frameworks have been developed to aid in the decision-making process when selecting from among various types of circular design options. These aids can be defined as either generative or evaluative [17,18].

Generative aids support the integration of circular strategies or options during the design process [19]. Several authors have contributed to the development of design guidelines for a circular built environment, with an emphasis on achieving optimal environmental performance [19–23]. A similar focus on environmental performance is found in the study by Kręt-Grześkowiak et al. [24], who reviewed 70 articles that offer guidelines for design for disassembly and design for adaptability and proposed a design process framework. Mackenbach et al. [25], on the other hand, proposed guidelines for circular buildings to overcome specific barriers. Other authors have focused on developing tools and frameworks for achieving a circular built environment. For example, Gillott et al. [26] developed a CE design workflow tool that can be used in an early stage of the design process, while Minunno et al. [27] applied a CE framework to the prefabricated building sector. Eberhardt et al. [28] conducted a literature review to assess the applicability and readiness of strategies linked to the circular economy (CE) in the context of building construction. Additionally, some authors have developed or derived archetypes for CE business models [29–32]. However, most of these articles did not study circular building components. Van Stijn et al. [19,20], Eberhardt et al. [22], and Zaman et al. [23] did develop aids specifically for circular building components, and van Stijn and Gruis [12] reviewed 36 existing generative design aids and developed the "Circular Building Components Generator" (CBC generator), a generative tool for circular building components.

Evaluative aids help determine the "circularity" of a generated design, for which the environmental and economic performance is often assessed [14]—although some authors argue social performance should also be included [33,34]. Life cycle assessment (LCA) and material flow analysis (MFA) are often seen as suitable methods to evaluate environmental performance [4,34–36], while life cycle costing (LCC) is often seen as an appropriate method to evaluate economic performance [11,37]. However, these aids do not predict the feasibility of the practice of certain design options, as the complex context of the "real world" are simplified to measurable parameters or general design options.

Many authors have studied the feasibility of applying CE principles to this "real-world" by identifying barriers. Wouterszoon Jansen et al. [16] provided an overview of these studies and concluded that only Azcarate-Aguerre et al. [38,39] focused on the building component level (a façade). Many of the authors have opted for a literature study, interviews with one or multiple stakeholders (once), or case studies of completed cases. Some authors have also conducted case studies of circular buildings or building components without identifying barriers as a goal. For example, Mangialardo et al. [40] studied three cases of a building, while O'Grady et al. [41] provided a thorough analysis of a prefabricated building, which they analyzed using a new circular-economy-based index for the built environment, proposing that this index could be used in the design stage of buildings. Kyrö et al. [42] provided a case study of multiple relocatable buildings and detailed a framework to aid in the future development of such buildings. Leising et al. [29] studied three cases (a newly built project, a renovation project, and a demolition project) and developed a collaboration tool. Maerckx et al. [43] studied 14 cases of renovation or extension and derived multiple levers and obstacles, and Yan et al. [44] studied examples of both types of building components from various continents.

However, only a few authors have specifically studied circularity in the kitchen industry. For example, Ollar et al. [13] studied which aspects of stakeholders' value propositions might contribute to circular housing design, with a focus on the kitchen, and Dokter et al. [45] studied how co-creation can contribute to the implementation of a CE in the kitchen industry. For their Circular Kitchen (CIK) research project, Wouterszoon Jansen et al. [16] developed and reflected on the development of a single circular kitchen over four years, deriving lessons for the development processes of other circular components. However, these authors either studied the circumstances under which a circular kitchen could be developed best or were limited to (single) kitchens that were in the design or development stage, and therefore did not derive feasible types based on multiple real-world cases.

None of the studies mentioned above provided insight into examples from practice, or their similarities and differences. Arguably, the knowledge of which types of technical models, industrial models, and business models would be feasible in practice for circular kitchens remains limited.

2.1. Circular Building Approaches and Circular Kitchens in the Dutch Housing Market

The Dutch building practice includes examples that can be regarded as proto-circular. For example, the "open building" by Habraken [46] suggested separating buildings into layers (such as tissue, support, and infill), and standardized modules were introduced to allow for user customization and future upgrades. The industrial, flexible, and demountable building (IFD) [47,48] was built on the ideas of the open building and united flexibility with the industrialization of the building process. The "Slimbouwen" [49] is another example of separating the building into layers to improve the building process while allowing for future adaptations.

In more recent times, numerous instances of circular practices can be observed in the Dutch housing sector. These examples range from using "buildings as material banks" (for example, the "Circl" pavilion by ABN Amro [50]), to bio-based construction systems (for example Iewan [51], or "Kalkhennephuis" [52]), to flexible, movable container homes (for example, Finch modules [53]).

Furthermore, multiple circular building components have been developed in the Dutch housing sector in previous years. Some of these components were developed in an academic setting, as part of a research project, such as the 2nd Skin Façade Refurbishment system [54], the Façade Leasing Demonstrator [55], the Circular Skin [56], the Circular dwelling extension, the Circular Net-Zero-Energy-Building (NZEB) renovation concept [56], and the CIK [16]. Other components and products were developed independently of any academic research project. For example, The New Makers [57] and Obimex [58] developed circular interior partitioning walls, Phillips created a circular lighting solution called Signify [59], and Trebbe developed circular window frames [60].

In addition to the CIK, several other circular kitchens have been developed in the Netherlands. Six circular kitchens were identified that are either available or soon to be available in the Dutch market. These kitchens were found by making inquiries with relevant stakeholders and by using Google search engines between August 2021 and May 2022, searching for "circular kitchen" and the Dutch translation of these terms. The CIK was included in the comparison, since it was intended to be implemented in practice, but will be implemented in a simplified version, being an example of a circular kitchen that generated knowledge and experience but was eventually not seen as feasible in practice. Table 1 gives an overview of these circular kitchens. Of these kitchens, four are produced by companies whose core business is kitchen production, and three are produced by companies that offer products outside of the kitchen sector. Furthermore, two of the manufacturers can be considered as well-established within the Dutch sector and have been manufacturing kitchens for over 10 years, while for the others, their circular kitchen is the first kitchen product they have produced. All of the circular kitchens were announced in the last 4 years, with the first circular kitchen being offered in 2018 (No Waste Kitchen), and some of the kitchens are not yet offered.

Table 1. Overview of the circular kitchens offered or announced for the Dutch housing market in 2022.

Kitchen Name	Kitchen Manufacturer	Kitchens as Core Business?	New or Established in the Kitchen Sector?	Announced	Available from	Data Collection
Blue Kitchen	Blue Kitchen	Yes	New	Unknown	unknown	company website, publications
Chainable Kitchen	Chainable	Yes	New	2020	2020	company website, publications, interview
Coulisse Kitchen	Coulisse	No	New	Unknown	unknown	company website, publications
Green Kitchen	DKG	Yes	Established	2021	2023	company website, publications, interview
NeverEnding Kitchen	Triboo	Unknown	New	2019	2019	company website, publications
No Waste Kitchen	The New Makers	No	New	2018	2018	company website, publications
the Circular Kitchen (CIK)	Bribus	Yes	Established	2017	will not become available as developed in the research prototypes	data provided by the research project, as published in [16]

3. Materials and Methods

This research was conducted in five steps, as illustrated in Figure 1. In the first step, the existing circular kitchens that are either available or will soon be available to the Dutch housing market were identified by making inquiries with relevant stakeholders and using online search engines, for which the outcomes can be found in Section 2.1 and Table 1. Furthermore, the relevant literature was reviewed regarding evaluative and generative aids, circular building components and their feasibility, and circular kitchens. The evaluative aid that was utilized for gathering data and analyzing the selected circular kitchens was established in this step and is elaborated on in Section 3.1.

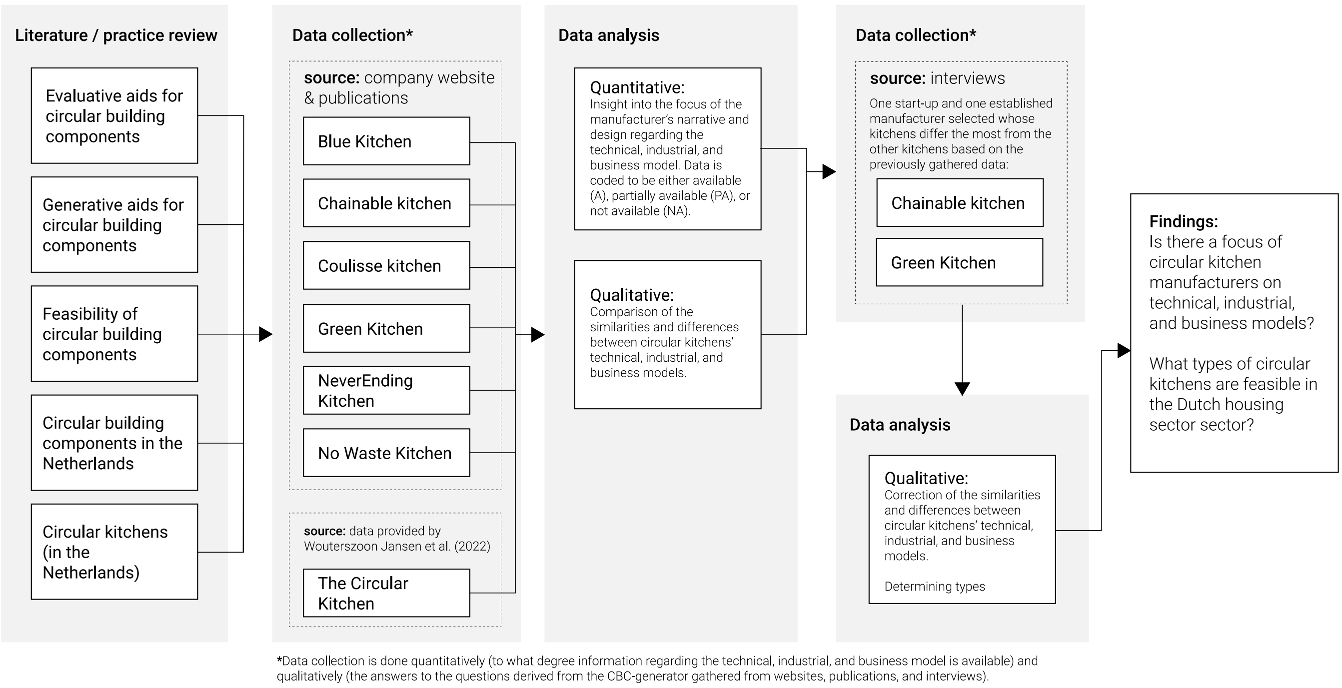


Figure 1. Flowchart of the research approach of this study. Data for the Circular Kitchen were sourced from Wouterszoon Jansen et al. [16].

In the second step, data were collected from the manufacturers' websites and publications about the kitchens. The data for the CIK were sourced from the existing research provided by Wouterszoon Jansen et al. [16]. Data collection (and analysis) was performed both quantitatively—to what degree information regarding the technical, industrial, and business model is available—and qualitatively—descriptions of the technical, industrial, and business model were gathered from websites, publications, and interviews.

In the third step, the data were analyzed. For the quantitative analysis, the data were coded according to three categories for availability and distinctness: available (A), partially available/unclear (PA), and not available (NA). The quantitative analysis provided insight into the focus of the manufacturer's narrative regarding their circular kitchen, which was assumed to be representative of the focus of the kitchen's design process, while simultaneously providing insight into the availability (and consequently, the representativeness) of the data utilized for this study. For the qualitative analysis, the similarities and differences between the circular kitchens were determined based on the design choices that were made for the technical, industrial, and business model.

In the fourth step, semi-structured interviews were conducted. Since not all manufacturers were available for interviews, a selection was made based on pre-existing data. Two of the six manufacturers (excluding the CIK) were selected based on two criteria: the type of manufacturer (one start-up and one established manufacturer were chosen) and the extent to which their kitchens demonstrated differences compared to the other kitchens, as determined through quantitative and qualitative analysis. The outliers were then selected.

The purpose of these interviews was to verify the accuracy and comprehensiveness of the qualitative data from the other sources and to correct the similarities and differences that were found based on these sources. An interview guide (see Supplementary Material S1) was developed based on the evaluative aid that was selected for data gathering and analysis. Both interviews (n = 2) were conducted digitally through Zoom in Dutch, and the audio was recorded with the permission of the participants. The interviews were transcribed and coded in Microsoft Excel (see Supplementary Material S2).

In the fifth step, the qualitative data were corrected, and typologies of feasible circular kitchens for the Dutch housing sector were derived based on the similarities and differences that were found.

3.1. The CBC Generator as An Evaluative Aid

To conduct a comparative analysis of circular kitchens, an evaluative aid is needed. However, the existing evaluative aids generally compare the (quantitative) circular performance of circular kitchens, and this study aimed to compare the designs for the circular kitchen's technical model, industrial model, and business model. Therefore, LCA, MFA, or LCC were not applied. Rather, an evaluative aid was needed that categorized the design options for the technical model, industrial model, and business model.

The CBC Generator [12] offers such a framework based on parameter option matrixes and design canvasses. The parameter option matrixes allow design teams to "mix and match" design options and create different variants for circular building components. This "mixing and matching" is performed by filling the design canvasses for the technical, industrial, and business models with the selected parameter options.

Nonetheless, the CBC generator was originally designed as a generative tool, while this study required an evaluative framework. Consequently, the CBC generator was modified and repurposed to serve as an evaluative tool for this study; instead of selecting parameter design options to construct a technical model, industrial model, and business model, the existing designs for these models were analyzed and deconstructed into sub-parameters based on the qualitative data that were collected. For example, if text descriptions and images were gathered that illustrate how the wooden panels of a circular kitchen can be disassembled from the steel frame, then the parameter options to "separate parts at the material boundary", to "separate support and infill", and to "use separable connections" can be used to deduce that biological and technical materials were used. Furthermore, the availability of information regarding the sub-parameters for the technical model (27 sub-parameters in total), the industrial model (9 sub-parameters in total), and the business model (10 sub-parameters in total) constitutes the input for the quantitative analysis. Figure 2 illustrates the use of the CBC generator as a generative tool (as it was originally developed), and as an evaluative tool (as it was used in this study). The interview guide was based on the parameters and sub-parameters provided by the CBC generator as well (see Supplementary Material S1 for the relation between the CBC generator sub-parameters and the interview questions).

As the CIK was developed using the CBC generator, the process was merely reversed: it is known from the CIK research data which parameters were selected in the development of the technical, industrial, and business models.

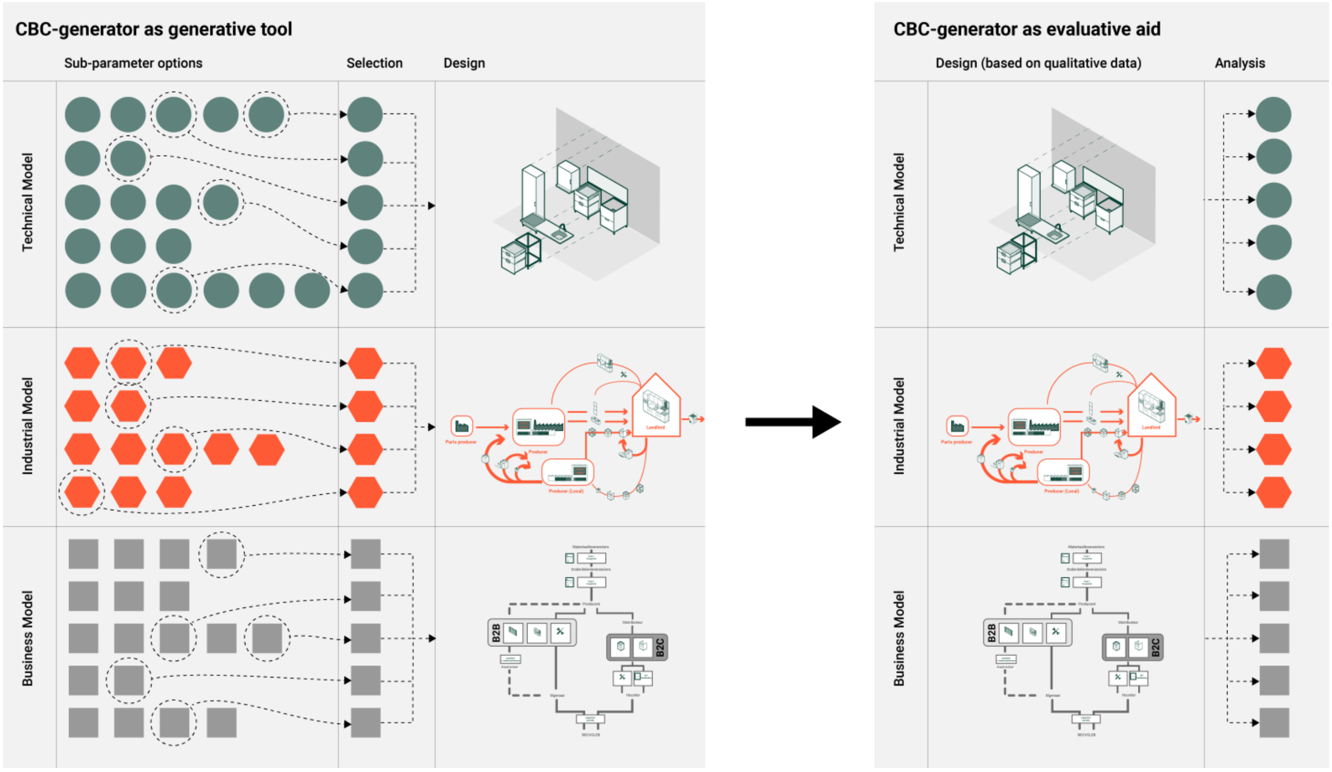


Figure 2. Original use of the CBC generator (**left**) and adapted use of the CBC generator (**right**) for this study.

4. Results

This article aimed to determine which types of circular kitchens are feasible in practice. To do so, circular kitchens that are available or will soon be available in practice were analyzed and compared to find differences and similarities.

The results are discussed in three parts. First, the quantitative analysis of data availability is discussed. The availability of the data gives insight into the narratives of manufacturers regarding their kitchens. This narrative is assumed to represent the focus of the kitchen's design process and gives insight into whether more focus on the technical model, industrial model, or business model is feasible. Second, the outcomes of the interviews are elaborated on. These interviews functioned to verify the accuracy and comprehensiveness of the qualitative data from the other sources and to correct the similarities and differences that were found based on these sources. Finally, the similarities and differences between circular kitchens are discussed, and which types of circular kitchens are feasible in the current Dutch practice is determined.

4.1. Availability of Data for Sub-Parameters on Manufacturers' Websites and Publications

Table 2 shows whether data regarding the sub-parameters in the CBC generator were either available (A), partially available (PA), or not available (NA) through the websites of the kitchen manufacturers and publications about their kitchens, and Figure 3 shows the relative number of sub-parameters for which data are A, PA, and NA.

In total, 26% (85 out of 322) of the data were available, 12% (39 out of 322) were partially available, and 61% (198 out of 322) were unavailable. Some information was available (either A or PA) for 39% (124 out of 322) of the data. Since the CIK was developed using the CBC generator, it provided the highest amount of data: 70% of the data were either A (32 out of 46) or PA (0 out of 46). In some cases, the data for the CIK indicated that the sub-parameter was not applied. This was not counted as A or PA, therefore 100% A or PA was not reached. The website and publications regarding Chainable and Blue Kitchen also provided data for more than 50% of the sub-parameters: 57% (37% A and 20% PA) and 54% (28% A and 26% PA), respectively. On the other end, the website and publications regarding the NeverEnding Kitchen provided data for only 22% of the sub-parameters (9% A and 13% PA), and Coulisse Kitchen only provided data for 19% of the sub-parameters (15% A and 4% PA). The lowest amount of data was found for the website and publications regarding the Green Kitchen, which only provided data for 2% of the sub-parameters (2% A and 0% PA).

Table 2. Availability of data for sub-parameters on manufacturers' websites and publications, categorized as available (A), partially available (PA), or not available (NA) per kitchen and in total.

	Blue Kitchen			Chainable Kitchen			Coulisse Kitchen			Green Kitchen			NeverEnding Kitchen			No Waste Kitchen			The Circular Kitchen			Total			
	A	PA	NA	A	PA	NA	A	PA	NA	A	PA	NA	A	PA	NA	A	PA	NA	A	PA	NA	A	PA	NA	A + PA
# available	13	12	21	17	9	20	7	2	37	1	0	45	4	6	36	11	10	25	32	0	14	85	39	198	124
% available	28%	26%	46%	37%	20%	43%	15%	4%	80%	2%	0%	98%	9%	13%	78%	24%	22%	54%	70%	0%	30%	26%	12%	61%	39%
Total #		46			46			46			46			46			46			46			322		

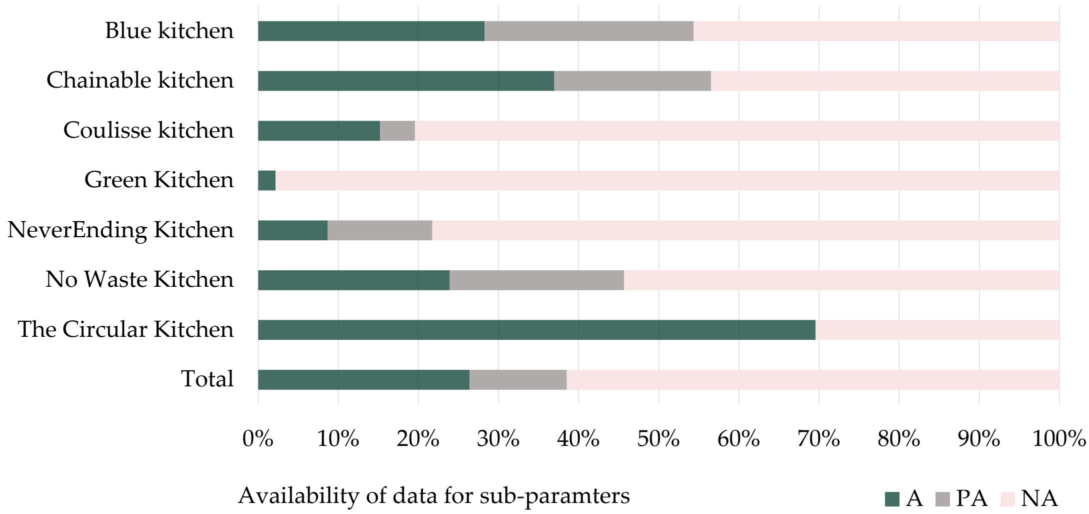


Figure 3. Percentage of the data for sub-parameters that are available (A), partially available (PA), or not available (NA) per kitchen, and in total.

The difference in these numbers could be explained by the extent to which circular kitchens are the core business of a company. Some companies only produce circular kitchens, and thus their company website is dedicated to circular kitchens (Blue Kitchen and Chainable), while others either have different products (No Waste Kitchen and Coulisse) or have non-circular kitchens as their core business (DKG), and therefore only have a small section of information about their circular kitchens.

Figure 4 shows the relative amount of data regarding the technical, industrial, and business models that were available, partially available, or not available on the companies' websites, or from publications about their circular kitchens. The relative amount is shown as a percentage of the total number of questions in that category; for example, 41% of the data regarding the technical model were available for Blue Kitchen.

On average, the highest relative amount of data was available regarding the technical model (33%), followed by data regarding the business model (21%), and the lowest relative amount of data was available for the industrial model (13%). Moreover, 45% of the data (be it available, or partially available) were provided regarding the technical model, 30% for the business model, and 29% for the industrial model.

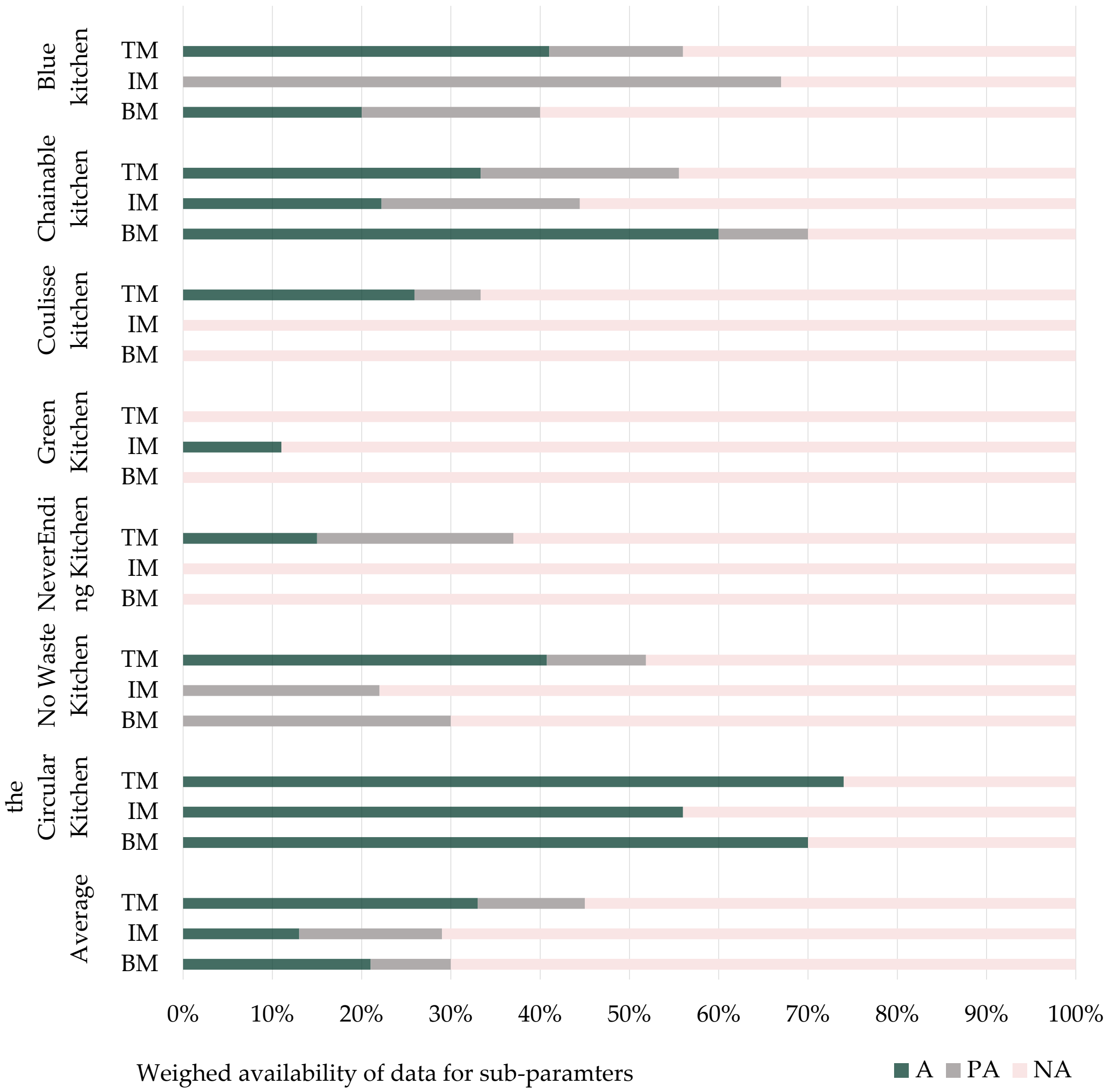


Figure 4. Percentages of the data for sub-parameters that are available (A), partially available (PA), or not available (NA) per kitchen and on average per category (technical model (TM), industrial model (IM), and business model (BM)), weighed according to the number of questions in the category.

Figure 4 shows that some kitchen producers deviate from the average. First, it can be seen that Green Kitchen only provides some data regarding the industrial model. Furthermore, Chainable is the only producer that provides the highest amount of data (relatively) regarding the business model. These two outliers were selected for the interviews to check whether the sourced data were correct. The interviews are discussed in the next section. As the CIK was developed using the CBC generator, the data from the CIK research provided the most complete answers to all of the categories.

4.2. Interviews

In addition to gathering data from the websites and publications related to circular kitchens, interviews were conducted. Since not all manufacturers were available for interviews, two outliers were selected based on pre-existing data: Chainable (a start-up), where we interviewed one of the founders, and DKG (an established kitchen producer), where we interviewed a product manager. The participants were asked the questions as described in the interview guide (see Supplementary Material S1) to verify the pre-existing data, clarify the data that were unclear, and gather data that were partially available or unavailable.

Table 3 shows the availability of data as a result of the interviews. Similar to the data for the CIK, answers that suggested that a sub-parameter was not applied were not counted as A or PA. The results show that both Chainable and DKG have considered significantly more aspects related to the technical, industrial, and business models than they have published. Notably, Chainable provided an answer to 89% of the questions related to the industrial model, while their website and publications did not provide any data for the industrial model. Similarly, DKG provided an answer for 85% and 80% of the questions regarding the technical model and business model, respectively, while their websites did not provide any data.

Table 3. Percentages of the data for sub-parameters that are available (A), partially available (PA), or not available (NA) for the Chainable Kitchen and Green Kitchen from the company's website and publications and the interviews, per category, weighed according to the number of questions in the category.

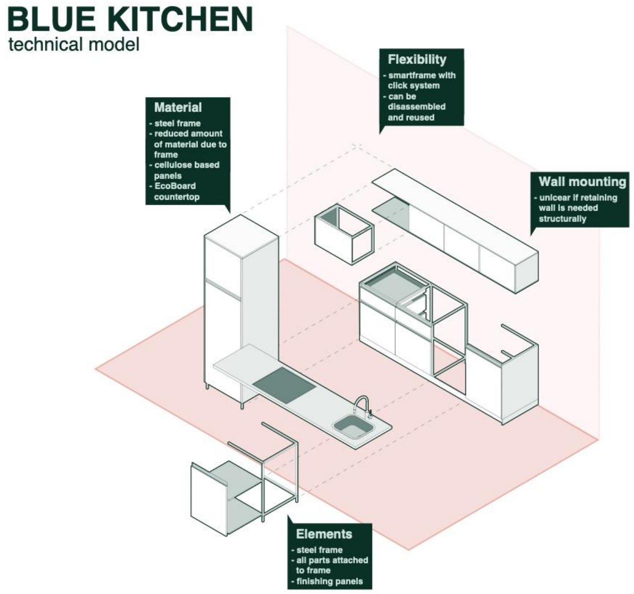
	Chainable Kitchen						Green Kitchen					
	Company Website, Publications			Interview			Company Website, Publications			Interview		
	A	PA	NA	A	PA	NA	A	PA	NA	A	PA	NA
Technical model	41%	15%	44%	89%	4%	7%	0%	0%	100%	85%	0%	15%
Industrial model	0%	67%	33%	89%	0%	11%	11%	0%	89%	78%	0%	22%
Business model	20%	20%	60%	90%	0%	10%	0%	0%	100%	80%	0%	20%

These additional data were used to refine the qualitative analysis of the technical, industrial, and business models of the kitchens. This was especially the case for DKG, who only mentioned the recovery of used kitchens on their website and answered most of the questions on their new concept during the interview. For the Chainable Kitchen, some data could be refined based on the interviews. For example, the expected lifespan of the kitchen's parts, where production of parts takes place, and which channels are used to sell the kitchen could be defined (see Supplementary Material S2).

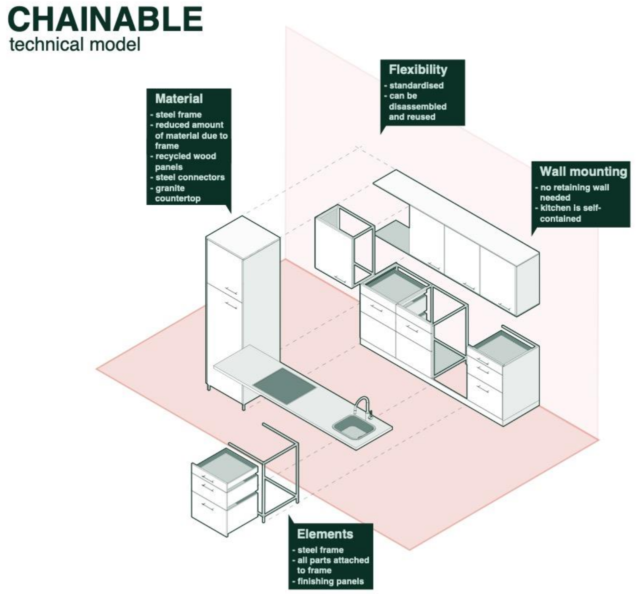
4.3. Similarities and Differences between Circular Kitchens

Through an in-depth comparison of the results, most kitchen producers were found either not to have considered a change in their supply chain and business model from the business-as-usual model of sale without take-back or not to have mentioned it. Two manufacturers were an exception: (1) the Circular Kitchen elaborates the proposed supply chain and business model; (2) Chainable mentions take-back and also offers kitchens as a service.

As most of the kitchen producers focused on the technical model, most of the similarities and differences can be found here. Figure 5a shows the technical model of the Blue Kitchen. Notably, the Blue Kitchen combines a stainless-steel frame with bio-based panels. All parts are attached to the steel frame and can be disassembled and reused. Figure 5b shows the technical model of the Chainable Kitchen. Like the Blue Kitchen, the Chainable Kitchen uses a steel frame, to which bio-based panels are attached. The steel frame is standardized and self-contained, thus wall-mounting is not needed. The countertop is made of granite. Figure 5c shows the technical model for the Coulisse Kitchen. Like the Chainable Kitchen and Blue Kitchen, the Coulisse Kitchen uses a steel frame and bio-based panels, and like the Chainable Kitchen, it is self-contained and does not need wall-mounting. The steel frame can also be disassembled; however, the Coulisse Kitchen is custom-made. Figure 5d shows the technical model of the Green Kitchen. The Green Kitchen is made from standardized bio-based panels but cannot be adapted after installation. The cabinets are directly mounted to the wall. Figure 5e shows the technical model for the NeverEnding Kitchen. It is made of bio-based panels that can be assembled and disassembled by its "plug-and-play" concept. The modular cabinets are mounted on a modular retaining wall, and all the parts can be recycled at the end of use. The NoWa Kitchen very closely resembles the NeverEnding Kitchen and is illustrated in Figure 5f. Figure 5g shows the technical model of the CIK. Like the NoWa Kitchen and the NeverEnding Kitchen, it applies a plug-and-play concept, uses a retaining wall, and is made of bio-based materials (although different bio-based materials). However, instead of using a panel-based structure, the CIK uses a wooden frame, to which infill elements such as drawers and finishing panels can be attached.



(a)



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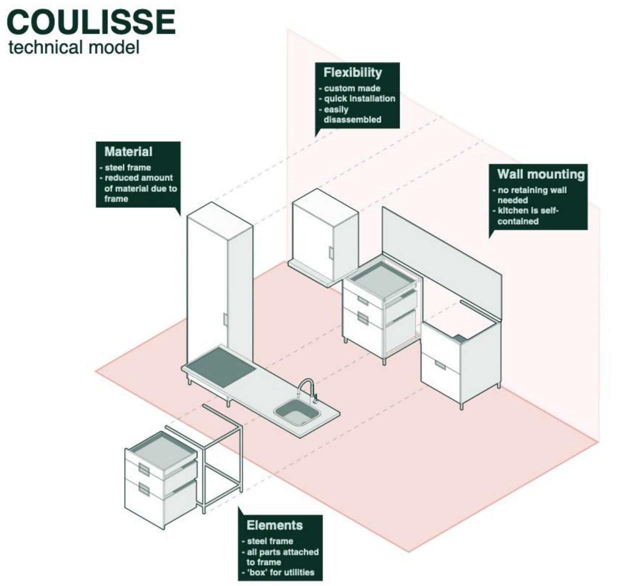
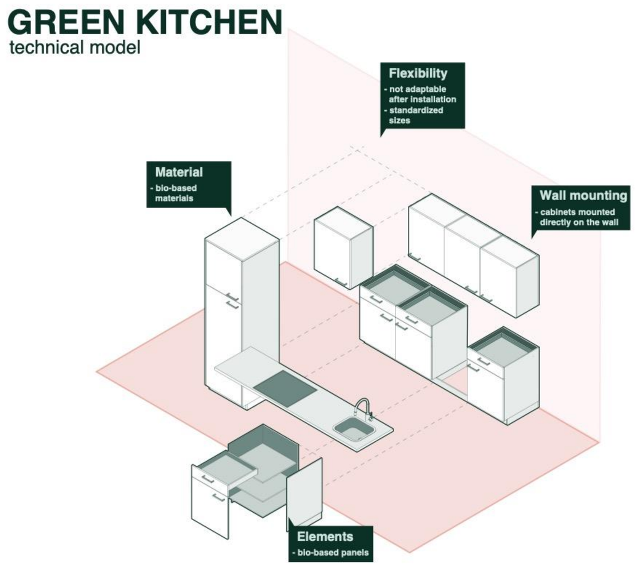
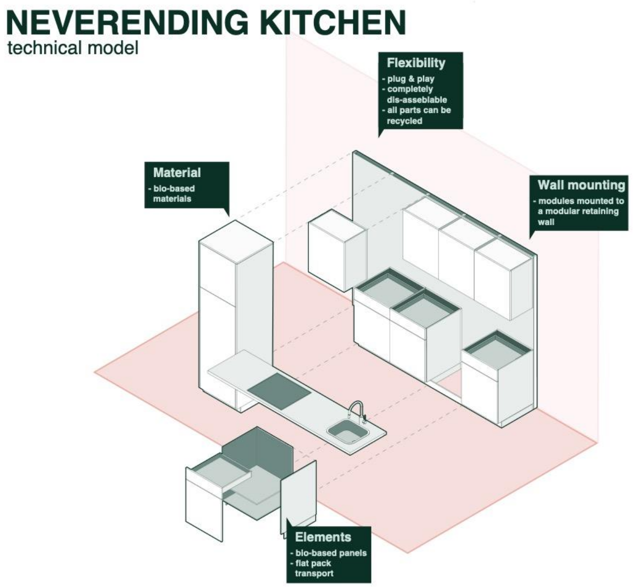


(c)

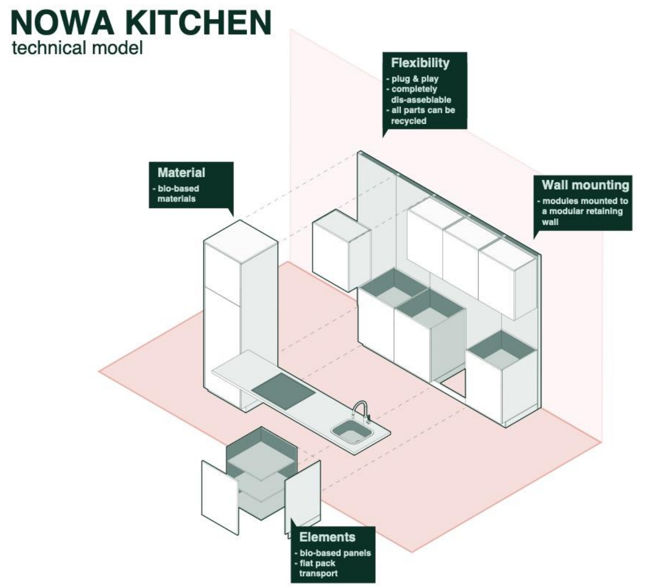


(d)

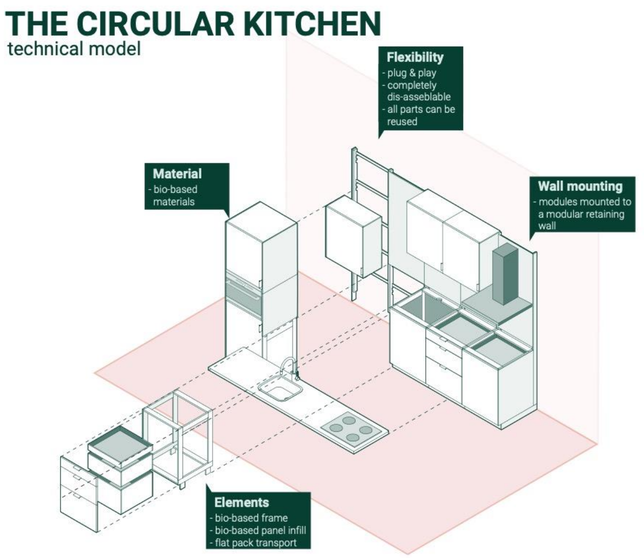
Figure 5. *Cont.*



(**e**)



(**f**)



(**g**)

Figure 5. Technical models of the (**a**) Blue Kitchen, (**b**) Chainable Kitchen, (**c**) Coulisse Kitchen, (**d**) Green Kitchen, (**e**) NeverEnding Kitchen, (**f**) NoWa Kitchen, and (**g**) CIK.

The circular kitchens that were studied were bifurcated based on the choice of materials for the structure: technical (Blue Kitchen, Chainable, and Coulisse) or biological materials (Green Kitchen, NeverEnding Kitchen, NoWa Kitchen, and CIK). Furthermore, the kitchens that have a structure made of technical materials all use a frame structure, while most of the kitchens that use bio-based materials for the structure use panels (Green Kitchen, NeverEnding Kitchen, and NoWa Kitchen). Only the CIK design uses a bio-based frame structure. However, Bribus has since redeveloped the CIK to remain closer to the technical model of their current (non-circular) kitchens. Instead of a frame, this kitchen uses a panel structure as well, without a retaining wall.

Furthermore, the start-ups deviate further from the current standard kitchens for housing kitchens, which are made with bio-based (melamine-coated chipboard) panels that are glued together. This deviation is either in the material choice, by introducing more technical materials to prolong the lifespan of the kitchen, or by using a retaining wall to increase the adaptability of the kitchen. The established kitchen manufacturers develop circular kitchens that are more similar to the current standard kitchens (after redevelopment in favor of feasibility in the case of the CIK), using bio-based panels for the structure, and not using a retaining wall.

Finally, all the circular kitchens have demountable parts, allowing for VRPs to take place, and prolonging the overall lifespan of the kitchen. Table 4 gives an overview of the circular kitchens that were studied, the materials of the structures if they use a retaining wall, and whether the parts are all demountable.

Table 4. Overview of the main types of circular kitchens. Whether a kitchen applies the design strategies is indicated with "•".

Kitchen Name	New or Established in the Kitchen Sector?	Structure Type		Retaining Wall			Demountable Parts	
		Biological Panels	Technical Frame	Yes	Optional	No	Yes	No
Blue Kitchen	New		•			•	•	
Chainable Kitchen	New		•		•		•	
Coulisse Kitchen	New		•			•	•	
Green Kitchen	established	•				•	•	
NeverEnding Kitchen	New	•		•			•	
No Waste Kitchen	New	•		•			•	
the Circular Kitchen	established	• *		• *		• *	•	

* The CIK technical model was redeveloped after the research project to be made of panels instead of a frame and not to have a retaining wall.

5. Discussion

This study aimed to determine which technical, industrial, and business models for circular kitchens are feasible in practice. The circular kitchens that are currently available for the Dutch housing market were analyzed to do so, assuming that implementation adoption in practice is an indicator of feasibility. However, there was no insight into the number of sales or the financial feasibility of these kitchens. Additionally, kitchen types that have not been offered to the market cannot be excluded from being feasible, as this would assume that kitchen manufacturers have exhaustively considered all the design options based on actual feasibility in practice. Therefore, it cannot be claimed with certainty that the studied kitchens are feasible, or that these are the only feasible circular kitchens. Furthermore, the kitchen manufacturers mostly provided information regarding the technical model, and therefore did not indicate the industrial and business models' feasibility, while for a façade, examples can be found for development focusing on a business model [39,55], as well as examples of a more holistic approach [56].

Consequentially, claims made by manufacturers about how "circular" or "sustainable" their circular kitchen is, are difficult to verify: a product or component cannot become circular just by having a circular technical model; a functioning industrial model is needed (if reuse is not organized in the supply chain, it cannot happen), and a business model is needed to incentivize circular behavior (if reuse takes more effort, but has no direct benefits, then it will become more unlikely). This is of special importance to the circular kitchens that rely on reuse to lower environmental impact and material use later in the life cycle.

Furthermore, whether transitioning to technical materials in an industry that uses largely biological materials serves the purpose of the CE should be questioned. These steel structures likely cause a higher environmental impact in the production stage (see for example [61]). Therefore, it can be argued that this transition from biological to technical materials is only beneficial if the purpose of the CE is only to reduce future waste and material use through the long-term reuse made possible by these technical materials. However, lowering human-induced emissions and preventing the depletion of raw materials are important goals of the CE as well. Previous studies have shown that applying circular strategies (especially when using metals for long-term reuse) does not always yield good environmental performance (for example, see [14]). However, combining circular strategies to narrow, slow and close loops has been shown to improve environmental performance [19,22,62–64]. Therefore, using biological materials where possible (narrowing the loop of finite materials, and reducing environmental impact in the production stage), and reusing all the materials (reducing material use, waste, and impact in late stages), as is achieved in the kitchens that use biological materials can be expected to have better environmental performance overall.

Notably, all the kitchens studied have applied designs for future slowing and closing strategies. Only very few have focused on (only) narrowing loops (for example, using smaller kitchens, or no kitchens at all, and using non-virgin materials). Arguably, one would expect kitchens to be designed and manufactured based on these strategies as well. However, kitchens that apply such strategies were not found by searching for "circular kitchen". This could be explained by an expectance of consumers/users not accepting smaller kitchens, users being expected to have a poor perception of non-virgin materials (users want a new product) [65–68], or doubts about the safety and quality of non-virgin materials [62,69,70]. Other explanations can be that fitting non-virgin materials are not available at consistent quantities needed for kitchen production, due to a lack of reverse logistical mechanisms for the recovery of these materials [38,65,68,71,72]. A similar focus on adaptability is seen in Dutch proto-circular design practice, with Habraken [46], IFD [47,48], and Lichtenberg's "Slimbouwen" [49].

Furthermore, the established kitchen manufacturers (eventually) have developed kitchens that are more similar to the current standard of (non-circular) kitchens. The bio-based frame structure of the prototype version of the CIK was a clear outlier compared to the circular kitchens offered in practice. Although this design performed well environmentally and economically [11,14,20,22], it was eventually not seen as feasible in practice. If feasibility is judged by whether a kitchen is offered in practice, then this study confirmed that the CIK frame design would not have been feasible in practice. That Bribus eventually changed the design and DKG developed a circular kitchen that is more similar to their current non-circular kitchen could be explained by the significant investments that have been made in the existing manufacturing line and supply chain (such as machinery, or long-term supplier relations), incentivizing the development of new products that fit within this manufacturing line and supply chain [16].

6. Conclusions

To gradually achieve a more circular built environment, building components can be replaced by more circular components. One of the logical components to apply this to is the kitchen: a component with a relatively short lifespan that is produced as a standardized product, and for which producing prototypes is relatively affordable. However, knowledge of which types of technical, industrial, and business models for circular kitchens are feasible in practice remains limited. Therefore, circular kitchens were compared that are currently offered or will be offered soon in the Dutch housing sector. The CBC generator was adapted to function as an evaluative framework, data were sourced from company websites and publications, and interviews with two of the outliers took place to confirm and gather additional data.

As a result, six circular kitchens were found and the CIK was included, adding up to seven circular kitchens in total. Of these seven circular kitchens, two of their manufacturers can be described as established kitchen manufacturers, while the other five can be seen as start-ups. The established manufacturers were found to deviate less in terms of technical, industrial, and business models from the non-circular kitchens they are already offering, while the start-ups apply more radical innovations. Most of the kitchen manufacturers mainly provided information regarding the technical model, and all the manufacturers have applied strategies for slowing and closing loops in the future. However, sufficient information is currently unavailable concerning the industrial and business models, and the kitchens or their parts have not yet reached their end of life, as they were developed recently. Hence, the realization of these future loops and the actual benefits of applying circular strategies to these kitchens remains uncertain.

Furthermore, a bifurcation was found based on the choices of materials for the structure, and whether this structure is a frame (in the case of technical materials) or is based on panels (in the case of biological materials), with the CIK being a clear outlier with its bio-based frame structure. The adaptation of the CIK design by its manufacturer before it became a market-ready product confirms the lack of feasibility of a bio-based frame structure. Another clear difference between the circular kitchens was the use of a retaining wall. This wall was not exclusively applied in either frame- or panel-based structure kitchens but appeared in both. Finally, all of the kitchens that were found and compared in this study prioritized circular design options to slow and close future cycles. This strategy has been suggested to improve the environmental performance of circular building components as well [19].

This study is limited to circular kitchens in the context of the Dutch housing sector and relies on information that was available from kitchen manufacturers' websites, online publications, and two interviews. Therefore, the outcomes of this study might not be generalizable in other contexts. Additionally, the feasibility of certain types of circular kitchens can change over time, with currently feasible types potentially becoming unfeasible in the future while new types emerge as feasible alternatives. Furthermore, the absence of certain types in practice does not necessarily indicate their lack of feasibility.

Although this study is not exhaustive, it indicates which types of circular kitchen technical models are feasible in practice. Such knowledge, and knowledge of how circular kitchens differ could facilitate easier implementation of future circular kitchens, as conforming to types that have proven to be feasible can reduce the effort needed to develop such a kitchen, while learning from less successful cases provides useful insights as well. Furthermore, conforming to certain types of circular kitchens can be a step towards industry-wide standardization, making VRPs in a CE more likely. It should be acknowledged that this study has also demonstrated a disparity between ideal and feasible circular designs within a research project (such as the CIK) and what is feasible in practice. Hence, future researchers undertaking circular component development in a research context should prioritize incorporating market implementation as a crucial step. Finally, it is recommended that future researchers investigate the feasibility of circular kitchens in different contexts, as well as explore the feasibility of circular designs for other building components. The adapted CBC generator, utilized in this study, can serve as a valuable tool for such investigations.

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