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Determining spatial characteristics for circular building design: The case of kitchen alterations

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Abstract. Kitchens are frequently altered leading to unnecessary material flows. End-users' wishes to customise their kitchen based on their changing priorities have been recognised as one cause for frequent alterations. Complementing previous research investigating kitchen alterations, this paper focuses on the spatial characteristics of the room. Spatial characteristics have been identified as determining factors for developing circular solutions for kitchen design which could reduce the extent and impact of alterations. Eleven households in Swedish villas, apartments, and terrace houses have been interviewed about their kitchen alterations to answer the research questions: What spatial alterations do they implement? and How could the spatial design of kitchens be formulated to support a circular built environment?. The outcome of the alterations has been documented through floorplan drawings and photographs. Based on the findings exemplifying end-users' alterations, circular design strategies are recommended for the spatial design of the kitchen. These strategies have the potential of slowing the loops by enabling end-users to reshape their kitchen without extensive alterations and decreasing resource use and waste production. In conclusion, this paper urges professionals in the kitchen industry to use the formulated circular design strategies to create a building stock that is part of a circular economy.

1. Introduction

There's a need to shift towards more circular products and design solutions in the building industry to enable longevity of buildings, reuse of building materials and reduced waste production [1]. Although there are strategies developed for circular building design [2,3] and architects apply these strategies to some extent in their practice [4], there is still a lack of design solutions for specific building elements which could complement or replace conventional building systems and enable the transition to a circular economy (CE) in the built environment [5,6].

This paper examines a central and resource-intensive part of dwellings: the kitchen. Kitchens are frequently altered, which contributes to the overall environmental impact of buildings. The built-in furniture is discarded on average every seven years, which is way below its expected lifespan [7]. It has been estimated that premature replacement of the built-in furniture adds up to 57% of the climate impact of the interior alterations and the maintenance of apartments (measured in CO2 equivalent over 15 years) [8]. A full-scale kitchen renovation - exchanging the built-in furniture and major appliances – has been calculated to lead to a CO_2 emission of 2.4 tones [9].

Circular building design provides strategies to extend the lifetime of built-in materials, facilitate repair, and reduce the climate impact of resources [2]. An important aspect of circular building design,

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that has been less researched, is the spatial design of buildings which influences the extent, complexity and ease of future alterations [10]. Studying the spatial design of building components (such as kitchens) could enhance knowledge on how building units (such as rooms) should be designed to decrease the impact of future alterations.

Another key aspect of developing circular design solutions for the built environment is understanding user behaviours [11]. Pomponi and Moncaster [11] have emphasized that "[t]here is clearly a strong need to accelerate behavioural research in built environment sustainability; it is apparent that it is people, rather than technologies, who are key to embracing circularity" (p. 716). In this paper's case, analysing end-user preferences connected to kitchens could contribute to increasing knowledge on circular design solutions.

The paper is based on empirical data from eleven end-user driven kitchen alterations in a Swedish context. The aim is to identify the most often altered spatial characteristics and provide support to develop circular design strategies for the spatial design of kitchens. The research questions that are addressed are:

- What spatial alterations do end-users implement?
- How could the spatial design of kitchens be formulated to support a circular built environment?

In this paper, the terms related to the kitchen are distinguished as follows [10]. The fixed kitchen furniture is referred to as built-in furniture and the word 'kitchen' is used when referring to the spatial unit of the room. The 'kitchen typology' is defined by the layout of the built-in furniture (straight-, L-, parallel- and U-kitchen). The term 'open floorplan' describes the spatial design in which the kitchen and living room are part of one open space. The room which is created in applying this design is a 'combined kitchen-living room'.

2. Background

In this section, two fields of research connected to the paper's focus are discussed. First, theories and strategies of circular building design are presented (section 2.1.). Second, previous research related to spatial characteristics and alterations of kitchens is outlined (section 2.2.).

2.1. Circular building design and the CBC-generator

Based on the Ellen McArthur Foundation's circular economy strategies [12], five circular building design principles have been defined by Cheshire [2]: building in layers, designing out waste, design for adaptability, design for disassembly and selecting appropriate materials and products. To support these principles multiple circular design frameworks have been developed. To convene a comprehensive overview of strategies that can support the development of circular building components, van Stijn and Grius [3] reviewed existing circular design frameworks. This resulted in the parameter-option matrices for technical, industrial and business models [3], which contain strategies for the three circular resource cycles (narrowing, slowing and closing loops) defined by Bocken et al. [13].

Through further iteration of the identified strategies, van Stijn and Grius [3] constructed a design tool called the circular building component generator (CBC-generator) which consists of three steps: ideate, generate and refine. The CBC-generator provides a design table and three design canvases tailored for the technical, industrial, and business models to synthesise design solutions for a holistic circular design. The design table supports the 'ideate' step, while the design canvases guide the 'generate' and 'refine' steps. In this paper, the design table has been used to identify circular design strategies for the spatial design of the kitchen (technical model), which needs to be further iterated and tested in upcoming research.

2.2. Spatial characteristics and alterations of kitchens

In a previous step of this research, characteristics that are important for the spatial design of the kitchen have been identified [10]: the room organisation (room typology, floorplan, and doors), built-in furniture (kitchen typology and kitchen island), floor area, infrastructure, daylight, and dining area. While evaluating the circularity potential of these spatial characteristics, Ollár et al. [14] pointed out that the over-capacity of the floor area, the window location and distribution, the number of door openings and traffic zones, the shaft location and accessibility, the room typology, and the kitchen typology are important to be considered when developing circular design solutions for buildings. They concluded that these characteristics need to be further defined to enable a holistic circularity approach for the kitchen. As a next step toward defining these spatial characteristics, it is important to evaluate connected end-user preferences.

One dominating feature of contemporary apartment floorplan design is the combined kitchen-living room [13]. The question of whether this solution is preferred by end-users is divided. Some studies have shown that end-users change their floorplan to create a combined kitchen-living room [15–17], while some studies have found that separate kitchens are just as sought after [18,19]. Other spatial alterations identified in previous research include modifying the room typology of kitchens (creating “dead-end” or “pass-through” kitchens) and kitchen typology (prioritising straight- or L-kitchen typologies), putting up or tearing down walls and installing a kitchen island [18].

Insights into preferences connected to end-user driven alterations of kitchens have been earlier explored. Previous studies have pointed out that kitchen alterations are driven by the lack of functional qualities of contemporary floorplans, design trends, regulations, inadequate quality of built-in materials and lack of adaptability of space that leads to unnecessary changes in surrounding layers [18]. Hagejärd et al. [20] additionally found that motivations for kitchen alterations include a dissatisfaction with the kitchen typology, a lack of worksurface and storage, insufficient floor area, obsolete furniture or appliances, a wish to enhance the appearance of the kitchen, and fluctuating household sizes.

3. Method

The empirical data was collected from 2018 to 2019. Some results with a focus on resource consumption have already been reported in Hagejärd et al. [20]. In this paper, a complementary analysis is provided by evaluating the spatial alterations of the kitchen.

Eleven households in Swedish apartments (4), villas (6) and a terrace house (1) have been interviewed about their recent kitchen alterations. A set of questions in the semi-structured interviews focused on the alterations related to the spatial characteristics of the kitchen. The result of the kitchen alterations has been documented through photographs and floorplan drawings. The interviews were recorded, transcribed and analysed through qualitative content analysis [21] in NVivo. Codes were predefined based on the research questions (e.g.: spatial alterations and design strategies). These codes were complimented in case new themes were discovered during the analysis. The outcome of the analysis is presented in section 4.

Based on the interviewees’ spatial alterations, circular design strategies for the spatial design of the kitchen have been formulated using the design table of the CBC-generator (described in detail in section 2.1.). The developed circular design strategies are presented in section 5.

4. Spatial alterations of the kitchens

The interviewees performed extensive alterations to their kitchens, even though it was time-consuming and caused inconvenience to their everyday habits. The summary of the alterations can be seen in Table 1. It was important for them to have a kitchen that suits their lifestyle, kitchen habits and family situation. In our sample, 10 out of the 11 interviewed households moved in and lived with the existing kitchen for several years before the renovation. They thought about and planned for the alterations for a long time before they started, even though it meant living with a kitchen that did not fully fit their needs. The alterations’ duration varied from a week to one and a half years. The length of the process was influenced by the size of the kitchen, the extent of the alteration and whether the alterations were carried out by professionals or the owners themselves. Three interviewees (I-4, I-9, I-10) mentioned that they had a temporary kitchen for several months before the new kitchen was operational. These temporary kitchens were located in an extra room, in the laundry room, or outdoors on a terrace.

Table 1. Features of the interview participants' dwelling and kitchen before and after the alterations (changes marked with grey).

Case	Dwelling type	Dwelling size (m^2)	Room typology[a]		Floorplan[b]		Door[b]		Built-in furniture, storage, worksurface[c]		Kitchen typology[d]		Kitchen island		Window		Dining area[b]	
			Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
I-1	Condo.	83	C	C	separate room	separate room	3 (H, LR, Ba)	3 (H, LR, Ba)	7 u. lower c. 7 u. upper c. 3 u. tall c.	+ 4 u. tall c. - 5 u. upper c.	S	S	no	no	1 window	1 window	1 (K)	1 (K)
I-2	Villa	133	B	B	separate room	separate room	2 (La, LR)	2 (La, LR)	9 u. lower c. 9 u. upper c. 2 u. tall c.	- 3 u. upper c.	L	L	no	no	1 window	1 window	2 (K, LR)	2 (K, LR)
I-3	Terraced house	106	A	B	separate room	combined K-LR	1 (H)	0 (K-LR)	9 u. lower c. 9 u. upper c. 2 u. tall c.	+ 1 u. tall c. + 4 u. long KI - 3 u. lower c. - 6 u. upper c.	U	S+KI	no	yes	1 window	1 window, 1 large glazed door	1 (K)	1 (K-LR)
I-4	Condo.	74	A	A	separate room	separate room	1 (H)	1 (H)	10 u. lower c. 10 u. upper c. 2 u. tall c.	Same number of cabinets, new furniture	P	P	no	no	1 window	1 window	2 (K, LR)	2 (K, LR)
I-5	Villa	120	A	B	separate room	separate room	1 (H)	2 (H, DR)	4 u. lower c. 4 u. upper c. 1 u. tall c.	+ 6 u. lower c. - 2 u. upper c.	S	L	no	no	1 window	1 window	1 (K)	1 (DR-LR)
I-6	Condo.	109	C	C	separate room	separate room	4 (H, La, LR, Ba)	4 (H, La, LR, Ba)	7 u. lower c. 7 u. upper c. 3 u. tall c.	+ 1 u. tall c. - 1 u. lower c. - 3 u. upper c.	P	P	no	no	1 window	1 window	1 (K)	1 (K)
I-7	Villa	240	B	B	separate room	separate room	2 (H, DR)	2 (H, DR)	12 u. lower c. 10 u. upper c. 2 u. tall c.	+ 5 u. tall c. - 1 u. lower c. - 10 u. upper c.	L	U	no	no	1 window	1 window (new location)	1 (DR)	1 (DR-LR)
I-8	Villa	170	C	C	separate room	combined K-LR	2 (H, DR)	0 (K-LR)	7 u. lower c. 7 u. upper c. 4 u. tall c.	+ 1 u. tall c. + 8 u. long KI - 2 u. low c. - 7 u. upper c.	P	S+KI	no	yes	1 window, 1 sky roof	1 sky roof, 2 windows, 4 large glazed doors	1 (K)	2 (K-LR)
I-9	Villa	180	B	B	separate room	separate room	2 (H, La)	2 (H, La)	9 u. lower c. 7 u. upper c. 3 u. tall c.	+ 1 u. tall c. - 2,5 u. lower c. - 1,5 u. upper c.	L	L	no	no	1 window	1 window	1 (K)	1 (K)
I-10	Villa	~90	A	C	separate room	separate room	1 (H)	3 (H, T, H)	9 u. lower c. 5 u. upper c. 2 u. tall c.	+ 3 u. lower c. + 1 u. upper c. + 1 u. tall c.	L	U	no	no	2 windows	2 windows, 1 large glazed door	1 (K)	1 (K-DR)
I-11	Rental apartment	45	A	A	combined K-LR	combined K-LR	1 (H)	1 (H)	3 u. lower c. 3 u. upper c. 1 u. tall c.	+ 3 u. lower c. + 3 u. upper c.	S	S	no	no	2 windows	2 windows	1 (K-LR)	1 (K-LR)

[a] A: dead-end room typology, B: pass-through room typology, C: room within an internal ring.
[b] Ba: balcony, DR: dining room, H: hall, La: laundry room, LR: living room, K: kitchen, T: terrace.
[c] including built-in appliances, c.: cabinets, u.: unit = 60 cm wide cabinet.
[d] L: L-kitchen, S: straight-kitchen, P: parallel-kitchen, U: U-kitchen, KI: kitchen island.

The kitchen renovations exemplified a diverse variety of spatial alterations. The most comprehensive alteration among the cases is shown in Figure 1. The extent of the alterations was mostly influenced by the dwelling type. In villas and in the terraced house where there was more space for change, the owners initiated a larger alteration, including constructing additional rooms, opening new doors, moving windows, removing walls, or installing kitchen islands. In apartments, there was no opportunity to expand the physical boundaries of the dwelling. In these cases, the layout of the built-in furniture was kept, there were no structural changes to the room and the alterations focused on aesthetical improvements, replacing the furniture and appliances, exchanging the flooring, or repainting the walls.

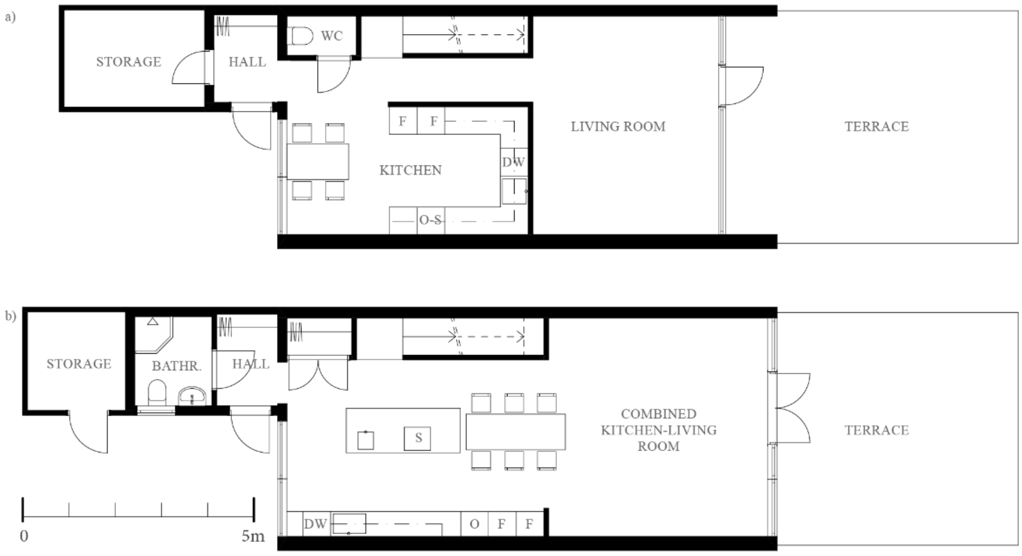

Figure 1. The floorplan of the terraced house of case I-3 before (a) and after (b) the alterations (DW: dishwasher, F: fridge or freezer, O: oven, S: stove).

Although almost all the kitchens (except for I-11) were separate rooms before, only two households created combined kitchen-living rooms during the alterations. In fact, several households (I-1, I-2, I-3, I-4, I-6, I-9) expressed that they prefer a kitchen as a separate room. They argued that a combined kitchen-living room would mean a loss of storage opportunities, increased noise disturbances or unwanted odours in other parts of the home. However, the changes in the room typologies (more pass-through [B] and ring [C] typologies after the alterations) indicate that the end-users wish to have a kitchen well-connected to other parts of their dwelling. These connections were created by removing walls (I-3, I-8, I-10), opening a new door (I-5), and building an extension to the house (I-7).

The alterations in all cases included modification to the built-in furniture which mostly meant a complete replacement of the cabinets. In one household (I-2) the cabinets were only repainted, and the countertop was replaced. Overall, within the eleven cases combined, the end-users added 20,5 lower cabinet units (24% increase), removed 33,5 upper cabinet units (43% decrease), and installed 14 additional tall cabinet units (56% increase). These were to provide more storage (I-1, I-5, I-6, I-10), extend worksurfaces (I-4, I-5, I-6) and create a more suitable workflow (I-5, I-6, I-7, I-8, I-10). Even when expansion was not an option - due to lack of free floor area - the interviewees expressed a wish for more storage and worksurfaces (I-2, I-3). Two of the households (I-3, I-8) included a kitchen island when they created a combined kitchen-living room. These kitchen islands complemented a straight-kitchen typology. Although the kitchen typology changed in five households, the overall distribution of the different typologies did not change much.

Five households enlarged the floor area of their kitchens. This has been done by creating a combined kitchen-living room (I-3, I-8), merging it with a neighbouring room (I-10), moving the dining area to another room (I-5) or building an extension to the house (I-7). All these cases were villas or terraced houses where the free floor area was more generous and such alterations were possible. The motivations for the expansions included the wish to create space for extra storage, social activities, and occasions when multiple people are working in the kitchen.

The dining area requires sufficient free floor area on its own. After the alterations, in two cases the dining area was directly in the kitchen (I-1, I-6), in two cases was a separate room (I-5, I-10), in three cases it was in the combined kitchen-living room (I-3, I-8, I-11) and in four households (I-2, I-4, I-7, I-9) there were two dining areas: one smaller for quick meals in the kitchen and one more generous for special occasions and social activities in the living room. The interviewees expressed that when they have guests it is nice not to be cramped in the kitchen. For this reason, it might be advantageous to provide a slightly larger dining area in the initial floorplan design of the kitchen.

In seven cases (I-3, I-5, I-6, I-7, I-8, I-9, I-10) the infrastructure systems (electricity, plumbing and ventilation) were modified. This occurred when infrastructure dependent working stations (e.g.: the sink or stove) have been relocated to a new position. As a result, the piping of the plumbing was extended, new ventilation ducts were installed, and additional electrical outlets were created. The installation of the kitchen islands (I-3, I-8) required extensive modifications to the infrastructure systems since the kitchen islands included stoves, sinks and dishwashers.

There have not been many changes to the windows on the facades. The reason behind this is likely that such alterations require extensive construction work. The most common practice was to move the location of daylight-depended activities close to existing windows. In one case (I-7) the interviewee explained that when they built an extension to their house for relocating the kitchen, they chose to put in a larger window. Another strategy to increase daylight in the kitchen was merging it with another room, such as the living room or a spare neighbouring room (I-3, I-8, I-10).

5. Circular design strategies for the spatial design of the kitchen

The spatial characteristics of the kitchen are defined in the design phase of the building. Certain spatial characteristics are more difficult to change (infrastructure, the location and distribution of windows, free floor area, room organisation and door locations) and there are some that the end-user has more control over (built-in furniture, location of the dining area). It is important to design the characteristics which are more difficult to alter with adaptability and multifunctional utilisation in mind. This would enable low-impact alterations and reduce resource use and waste production too.

Circular design strategies have been formulated based on the alterations identified during the analysis of the interviews. These strategies facilitate the ‘slowing loops’ resource cycle, which focuses on reuse, repair, refurbishment, remanufacturing and repurposing already existing assets. The circular design strategies are summarised in Table 2.

Table 2. Circular design strategies for the spatial design of the kitchen as a room.

	Technical model
Narrowing loops: (refuse, rethink, reduce)	-
Slowing loops: (reuse, repair, refurbish, remanufacture, repurpose)	- Ensure the central location of the kitchen in the dwelling floorplan - Provide multiple room connections to the kitchen: prioritise connections to the entrance hall, living room and outdoor spaces - Design multiple solutions for how the room can be furnished with mobile and built-in furniture - Provide flexible and adjustable infrastructure systems, establish outlets that can supply different kitchen typologies and several locations for the built-in furniture - Design generous but not wasteful free floor areas (e.g.: for additional kitchen island, dining area, social activities, multiple users at the same time in the kitchen) - Create easy solutions for separating or opening the kitchen - Use materials that are durable and can be personalised (e.g.: repainting) multiple times - Distribute multiple windows along the façade, preferably from several daylight directions - Provide room dimensions that can facilitate different kitchen typologies - Plan for generous worksurfaces and storage opportunities - Align the modular measurements of the built-in furniture with the dimensions of the room - Create easily adjustable workflows based on end-user wishes
Closing loops: (recycle, recover)	-

6. Discussion and Conclusion

This paper contributes to the transition to a circular built environment by outlining circular design strategies for the spatial design of the kitchen based on the analysis of eleven end-user driven kitchen alterations in a Swedish context. The results show that a kitchen design that supports circularity - and end-user wishes - includes adequate free floor area (for the built-in furniture, dining area and social activities), flexible infrastructures, adaptable room divisions, well-connected room organisation, sufficient number and distribution of windows, more storage opportunities, and longer worksurfaces.

The findings confirm and expand on the list of spatial characteristics that are important for a circular kitchen design as identified by earlier studies [14]. This paper provides additional insight from the end-user perspective and exemplifies the importance of the free floor area, the windows, the door openings, the infrastructure systems, the room organisation, and the kitchen typology. The analysis identified ten types of spatial alterations implemented by end-users:

- Modified free floor area - increasing or decreasing the built-in furniture (10 cases)
- Adjusted infrastructure systems (7 cases)
- Removed or added doors (5 cases)
- Changed kitchen typology (5 cases)
- Relocated or additional dining area (5 cases)
- Increased daylight - merging the kitchen with another room or creating new windows (4 cases)
- Removed or added walls (4 cases)
- Increased connectivity of the kitchen – changing the room typology (3 cases)
- Combined kitchen and living room (2 cases)
- Added kitchen island (2 cases)

Although many of the interviewees expressed a preference for a separate kitchen, their alterations increased the connectivity of the room. This indicates that rather than building dwellings mostly with combined kitchen-living rooms (a widely used contemporary design [14]), it would be advantageous to equip the room with a flexible division solution so that the end-users could open and separate the kitchen according to their momentary needs. Furthermore, increasing the variety of enclosure designs of the kitchen in newly built dwellings - by providing separate, semi-separate, and open layouts - would enable opportunities for satisfying various user preferences, especially in apartments, where the end-users have no direct influence on the initial spatial design of their home.

Another important factor for the interviewees was their workflow in the kitchen which influenced the size and layout of the built-in furniture, the sequence of the workstations and the location of the connected infrastructure outlets. They altered the built-in furniture to create an ideal workflow which led to a diverse variation of kitchen typologies. This suggests that it would be beneficial to design the initial kitchen floorplan and connected infrastructure systems in a way that fits several kitchen typologies. Such design solutions combined with adjustable features of the built-in furniture would allow end-users to easily create a workflow matching their needs.

Further research is necessary to test, iterate and specify the strategies, possibly with the involvement of various stakeholders. This is important since the implementation of circular design solutions requires a system-level change from the building industry. It is necessary to engage all stakeholders to ensure a holistic approach for a future circular built environment. The transition needs to be supported by CE education platforms, interdisciplinary collaboration, and international standardisation. Additionally, regulations could be evaluated to identify how they could support circular building design and ensure the identified spatial design qualities for newly produced kitchens.

In conclusion, this paper urges professionals (e.g.: architects, engineers, and manufacturers) connected to the kitchen industry to use the formulated circular design strategies to create a building stock that is planned for circularity. These strategies contribute to a CE in the built environment by slowing the loops, namely, by decreasing the extent of future alteration, expending the lifetime of already built-in materials, limiting resource use, and decreasing waste production.

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