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RESEARCH ARTICLE

Is there a need for new kitchen design? Assessing the adaptative capacity of space to enable circularity in multiresidential buildings

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Abstract This paper aims to contribute to the development of spatial criteria for adaptive capacity, which is identified as one important factor for the transition towards more circular housing design. The paper focuses on the kitchen, as an important function of the home which is connected to large resource flows and is exposed to frequent renovations and replacements. This paper identifies spatial characteristics of the kitchen and evaluates their potential to accommodate circular solutions focusing on adaptive capacity. As a first step, previous literature on the spatial characteristics of kitchens and indicators that support adaptability is reviewed. These are then used to develop an analytical framework to assess the adaptive capacity and circularity potential of 3624 kitchens in contemporary Swedish apartments. A qualitative approach in combination with quantitative methods is employed to analyse the selected sample. The main contributions of this paper include its spatial analytical framework, its descriptive presentation of contemporary kitchen and apartment designs, and its adaptive capacity assessment of the studied kitchens. The results point out that although the overcapacity of the floor area of kitchens and apartments can have significance for adaptability, it is not the only determinative spatial characteristics. The windows' location and distribution, the number of door openings and traffic zones, the shafts' location and accessibility from multiple rooms, the room typology and the kitchen typology can improve the adaptive capacity and circularity potential of kitchens and dwellings. The findings show that in contemporary floorplans advantageous design solutions connected to the identified spatial characteristics are not applied in a systematic way. Further research is necessary to define the exact measures of the individual spatial characteristics and their combined application in multiresidential floorplan design.

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1. Introduction

The building industry's linear operations are responsible for a significant portion of global virgin material exploitation (Khasreen et al., 2009), CO_2 emissions (Word Economic Forum, 2016), and waste production (Ness and Xing, 2017). To replace the linear model, the circular economy (CE) offers strategies such as reducing resource consumption, eliminating waste, and maximising product and material utilisation (Ellen MacArthur Foundation, 2015). In response to newly formulated regulations for a CE (Commission of European Communities, 2015, 2014; European Commission, 2019; European Commission Environment Directorate-General, 2017; Regeringskansliet, 2020), the building sector will need to adapt its processes, design, and business models.

To achieve a CE in the built environment, building adaptability is a key design strategy (Cheshire, 2016). Long-term economic costs of buildings can be reduced through design solutions that enable adaptability and hence prevent extensive retrofits (Pinder et al., 2013; Slaughter, 2001). Such design solutions would extend the lifespan of buildings, building components, and built-in resources as well (Geldermans et al., 2019). Adaptability could also lower the environmental impact of the building industry by minimising premature obsolescence, unnecessary reconstructions, and nonessential material flows (Kendall, 1999; Slaughter, 2001). Geldermans (2016) has described adaptability as a concept that provides extensive customisation possibilities to accommodate various uses of spaces for diverse groups of users.

Previous studies have discussed the connection between residential buildings' adaptive capacity and their spatial configuration. Femenías and Geromel (2019) concluded that the increased number of spatial alterations might imply that the end-users prioritise a variety of spatial qualities other than those which the original floorplan design provided. Manum (2005) noted that current apartment floorplans are more specific regarding their functional utilisation, which reduces the dwellings' ability to accommodate diverse uses. Leupen (2006) highlighted that the size of rooms and their connection to each other influence the adaptive capacity of dwellings. Ross et al. (2016) found that the most effective adaptability strategies are planning buildings with overcapacity, prioritising mechanical connections between building elements over chemical ones, and designing open interior spaces that can be easily modified according to needs. These studies, however, did not examine how the spatial configuration of buildings and building units might contribute to a CE transition. Investigating such a contribution is important since contemporary residential design has shortcomings regarding room dimensions and functional spatial design, which create uncomfortable or unusable spaces (Braide, 2019; West and Emmitt, 2004). These shortcomings and the lack of adaptability prevent households from easily modifying their dwellings, which in turn "undermines the longlivity [sic] of the housing stock" (Braide, 2019, p.163), contributes to large material flows (Femenías et al., 2018), and results in user dissatisfaction with current floorplan designs (Femenías and Geromel, 2019; Tervo and Hirvonen, 2019).

The aim of this paper is to contribute to the definition of spatial characteristics that support housing adaptability as one relevant factor for CE. The study presented in this paper has been limited to the kitchen as an important function and space of the home. The kitchen plays an essential role in people's everyday lives, as it is an arena where — beyond food-related tasks — a considerable part of social activities take place (Willén, 2012). Previous research also showed that the kitchen is one of the functions of the home which is most often subject to renovations and adaptations (Femenías et al., 2016; Shove et al., 2007). The premature alteration of kitchens has been estimated to contribute up to 57% of the climate impact of the interior renovations and the maintenance of apartments (measured in CO_2 equivalent over a 15-year period) which might have been avoided by including adaptability strategies in the initial design of the space and the interior (Femenías et al., 2018).

Ongoing studies investigating CE and circular design in relation to kitchens have studied connected resource use (Hagejärd et al., 2020), financial models (Wouterszoon Jansen et al., 2020), and tools to support the redesign of built-in furniture and appliances (van Stijn and Gruis, 2019). However, there is a lack of studies examining spatial adaptability as an enabler for a CE in kitchen design. Therefore, the purpose of this paper is to identify those spatial characteristics which are determinative to achieve a future CE-compatible spatial configuration for the kitchen. The research questions this paper answers are the following: *Which spatial characteristics define contemporary kitchen design?* and *How do these spatial characteristics relate to adaptive capacity and CE?*

To conceptualise and assess the spatial configuration of the kitchen, an analytical framework was developed based on spatial characteristics identified in the literature. The aim of the analysis was, first, to distinguish contemporary architectural designs and, second, to evaluate them from an adaptability and circularity perspective. The focus on analysing current design solutions helped to create an understanding on how kitchens and apartments are designed today and led to design recommendations for newly built housing stock that supports CE. The results of this paper contribute to the ongoing development of CE strategies for the built environment and raise a discussion about the importance of spatial configurations and adaptability in connection with a CE transition.

1.1. Definitions and delimitations

Some definitions need to be clarified in connection to this study. The "kitchen" is the room or part of a room where the built-in kitchen furniture is located. The "spatial characteristics" are defined as aspects of a spatial unit (e.g., room) that influence how the unit can be used, furnished, and experienced (e.g., floor area, length and width of room, door and window openings, fixed equipment, and infrastructure outlets). The term "open floorplan" refers to a 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". The "kitchen typology" refers to the layout of the built-in furniture (Fig. 1), which influences the spatial use and experience of the room (Krantz-Jensen, 1963). Furthermore, the term "floor area" describes the size of a space (in m^2), and "apartment type" refers to how many bedrooms a dwelling has.

This study focuses on the floorplans of multiresidential buildings in a Swedish context. On a global scale, the population living in urban settlements is increasing (Statistical Office of the European Communities, 2016). In Sweden, a significant portion (51%) of the housing stock consists of apartments (Statistics Sweden, 2019), and the number of new multiresidential housing projects is rising (Statistics Sweden, 2020a).

Due to the aim of this study, the analysis was not designed to point out the most suitable dimensions of the identified spatial characteristics. Rather, this paper employs a descriptive approach to identify and describe the aforementioned characteristics from an adaptability and circularity perspective. Only those spatial characteristics which could be measured in two-dimensional architectural drawings were evaluated in the floorplans. Furthermore, since the main focus of this study is on spatial characteristics, the built-in furniture and appliances were only partially assessed when they related to the spatial design of the kitchen (e.g., kitchen typologies, possibilities for easy retrofits or room personalisation, and connected infrastructure).

2. Literature

This paper's starting point is in existing literature on the adaptability of dwellings and the spatial design of the kitchen. The importance of adaptability in the context of circular building and housing design is presented in Section 2.1. This is followed by an overview of previous studies investigating adaptability in apartment layouts (Section 2.2). Lastly, an overview of the spatial characteristics of the kitchen and other important design features is presented in Section 2.3. These three research topics are important for developing the analytical framework and for discussing the results of the floorplan study.

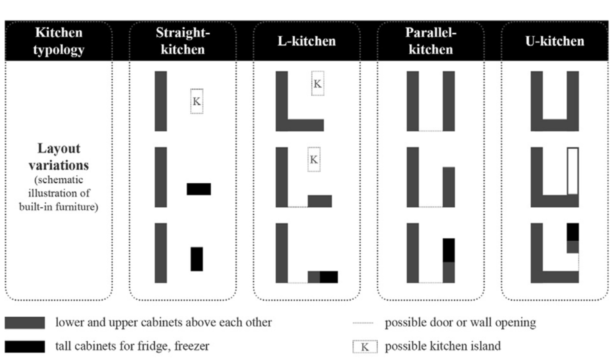

Fig. 1 Classification and layout variations of kitchen typologies (Source: Ollár, 2021).

2.1. The relevance of adaptability and adaptive capacity for circular design

To ensure high-quality utilisation over time, buildings need to advance with various changes (Geraedts et al., 2017). Rockow et al. (2019) have argued that a resilient built environment is achievable through buildings that can be easily adapted to various future scenarios by utilising available resources. Heidrich et al. (2017, pp. 287) have referred to adaptability as "the inherent properties in a building that gives [sic] it the ability to change, or the relative ease with which it can be changed". Sinclair et al. (2012, pp. 40) have defined the adaptive capacity of a building as the ability "to cope with future changes with minimum demolition, cost and waste and with maximum robustness, mutability and efficiency".

For these reasons, designing for adaptability has been recognised as one of the principles for creating circular building designs (Cheshire, 2016). Heidrich et al. (2017) have remarked that adaptive capacity should be established at the time buildings are designed and constructed. Design concepts such as floorplan flexibility (Langston and Shen, 2007), disassembly options (Conejos et al., 2013), modularity and standardisation (Geldermans, 2016; R. Geraedts, 2016), appropriate material choices (Ross et al., 2016), and over-capacity (Gosling et al., 2013) can help architects create adaptive buildings. However, these design concepts are not often used in practice. For instance, over-capacity is especially cumbersome to accomplish since housing developers aim to achieve the minimum requirements for the floorplan design of dwellings in order to lower upfront costs and maximise their profit (Heidrich et al., 2017).

To assess the adaptive capacity of buildings, Geraedts et al. (2014) developed indicators which measure a building's ability to accommodate changing demands (Table 1). These indicators evaluate the ability of buildings to enable minor or major changes connected to materials, spatial configurations, layouts, room organisation, infrastructure, and structural components. In previous publications (Geraedts, 2016; Geraedts and Ruiterkamp, 2017), the adaptive capacity of buildings has been evaluated in office buildings, terraced houses, and schools. However, the adaptive capacity indicators have not yet been tested on an individual building function. In this paper, the indicators of Geraedts et al. (2014) are used to formulate specific adaptive capacity definitions for the kitchen and to assess the kitchen's spatial adaptability (the relevant methods are described in Section 3.2).

2.2. Previous research investigating spatial needs and adaptability in apartments

Earlier studies have examined spatial configurations of homes with regards to adaptability and their capacity to accommodate users' changing spatial needs. One of the most discussed characteristics is the floor area of the dwellings; more specifically its shrinking size in recent decades (Manum, 2005; Tervo and Hirvonen, 2019). The decreasing floor area have been attributed to a lower average number of rooms and a widely used open floorplan design (Manum, 2005) which are driven by economic considerations (Heidrich et al., 2017), regulations allowing and promoting decreasing minimum dimensions and increasing material and production costs (Nylander, 2020). The shrinking floor area mostly favours certain household compositions (such as more wealthy young couples without children or elderly households) and does not suit the needs of other household types (Manum, 2005). Tervo and Hirvonen (2019) pointed out that even "solo dweller" households wished for larger homes than their current one; their ideal dwelling would be of 69 m^2 with two bedrooms. However, even when dwellings are built larger than required by regulations, they are functional only if they are utilised below maximum capacity (West and Emmitt, 2004). Most often, current floorplan designs do not provide enough space for furniture, circulation, access, and storage (West and Emmitt, 2004). Nevertheless, a large floor area is not necessarily a guarantee of functional design. Rather, smaller houses with simple design solutions enabled more functionality (West and Emmitt, 2004). A "good design does not necessarily demand a large increase in floor area and consequent cost" (West and Emmitt, 2004, pp. 299).

The room organisation of apartments have been recognised as an important spatial characteristic that is often modified by end-users. Femenías and Geromel (2019) conclude that during the alterations of their homes, end-users prefer to create "dead-end" or "pass-through" kitchens (as defined in Hillier 2008) and remove internal rings (a path through several rooms of a dwelling that enables re-entering a certain room through a loop; Hillier and Hanson 1984). Geromel (2016) highlighted that freestanding tall cupboard units — often used to create an internal ring - were not favoured by end-users. This preference is supported by current floorplan design; Manum (2005) observed that the number of internal rings have decreased over time. Additionally, the room organisation of contemporary apartments are less general than in previous decades (Manum, 2005). As a result, the increased specificity limits the possibility of different functional utilizations of the rooms.

A popular design solution connected to the floor area and room organisation of the apartments is the open floorplan design. Although the floor area of apartments have decreased, the area of living rooms increased mainly because of combined kitchen-living room solutions (Manum, 2005). Tervo and Hirvonen (2019) found in a large-scale survey ($n = 1453$) that, even though combined kitchen-living rooms are a popular configuration among end-users (56%), a significant portion (40%) prefer a separate kitchen. This distribution of preferences are in contradiction with current apartment designs since apartments today are often constructed with a combined kitchen-living room. Femenías and Geromel (2019) observed that only 22% of the apartments they examined originally had a separate kitchen.

Contemporary floorplan designs have resulted in an increasing number of compact apartments, which are less flexible and adaptable (Geromel, 2016). The lack of adaptability and the applied design solutions less favoured by end-users lead to frequent renovations and alterations. These alterations are often the result of changing spatial needs of households (Braide, 2019). Furthermore, Femenías and Geromel (2019) study revealed that user-driven renovations are motivated by a lack of functional qualities of contemporary floorplans due to standards and regulations leading to certain design solutions and the need for personalisation over time.

The kitchen is one of the rooms most often altered during renovations of dwellings. Hagejärd et al. (2020) found that end-users saw renovation as an essential endeavour for transforming their kitchen into a space they could enjoy. The most common reasons for initiating a renovation were dissatisfaction with the layout, a lack of work surface, a small floor area, obsolete furniture or

Table 1 Overview of original definitions of the adaptive capacity indicators (as in Geraedts et al., 2014).

Indicator	Definition
Quality	Changing the layout and finishing (look and feel) of the user unit in a building
Redesign	Changing the layout of the user units in a building and/or changing the functions of the user units in the building
Relation Internal	Changing the internal relation with other users/stakeholders in the building
Grain size	The number of user units in a building (increasing or decreasing)
Facilities	Changing the facilities (infrastructure) in the user units, in the building, and/or at the location level
Reallocate Internal	Changing the location of the user units in a building
Transfer	Whether or not a building can be transferred to another location
Expansion	To what extent the use surface of a user unit in a building should be extendable in the future (horizontal and/or vertical)
Rejection	To what extent the use surface of a user unit in a building should be contractable in the future (horizontal and/or vertical)

appliances, a wish to enhance the appearance of the kitchen, and an increase or decrease in household size. Furthermore, end-users often enlarge their kitchen (Femenías and Geromel, 2019) and expand it into a combined kitchen-living room (Hand et al., 2007; Judson et al., 2014; Maller et al., 2012) when the floorplan permits it. Kitchen islands are also a favoured addition to the built-in furniture when alterations take place (Femenías and Geromel, 2019); however, a lack of free floor area means that these alterations often result in a loss of some qualities of the floorplan (e.g., minimum requirements for accessibility).

In this regard, adaptable floorplan designs could be suitable solutions for enabling end-user preferences and low-impact modifications. Adaptable building design can also provide more user control and empowerment regarding the resident's spatial needs (Braide, 2019; Till and Schneider, 2005) since it allows for the alteration of the spatial configuration of homes and provides for alternative layout solutions (Braide, 2019).

2.3. Spatial characteristics of the kitchen

Previous research showed that spatial characteristics are important while evaluating residential environments. In their research on architectural characteristics that define how homes are perceived by residents, Nylander et al. (2002) identify seven fields of attributes, namely, materials and detailing, axiality, enclosure, movements, spatial figure, daylight and organisation of spaces. Six of these fields relate to spatiality, which demonstrates their relevance for assessing dwellings.

To analyse the spatial design of kitchens in apartments, it was first necessary to define which spatial characteristics have an influence on the kitchen design. The spatial characteristics of kitchens were identified through studying previous research and Swedish regulations. From 1930 through the 1980s, the Swedish government supported extensive research on the home and the kitchen in order to develop standards (Lee, 2018). Several publications of this research have spread the results and informed the development of Swedish housing regulations (National Board of Housing Building and Planning, 2020), which specify minimum criteria that the kitchen as a space in a home must fulfil (Örnhall, 2019). The detailed description of the findings have been reported in a separate publication (Ollár, 2021).

Table 2 presents the spatial characteristics that form the basis of the spatial analytical framework. Only those spatial characteristics which can be measured in floorplans and are currently less regulated were included in the framework. For instance, even though accessibility is an important characteristic that influences the dimensions and floor area of the kitchen, this characteristic was excluded from the analytical framework since it is highly regulated and enforced. Another example is the work triangle concept (Ranney, 1949), which defines minimum and maximum distances between the three most used work units (the sink, the stove, and the fridge) to eliminate unnecessary effort and to provide enough work surface to comfortably use a kitchen. Although these measures affect the spatial design of the kitchen, the regulations that clearly specify the minimum distances, and the current trend of the shrinking floor area of apartments eliminate the possibility of unnecessary distances.

In total, nine spatial characteristics were identified: room organisation (room typology, open floorplan, and doors), built-in furniture (kitchen typologies and kitchen island), floor area of the kitchen and apartment, infrastructure, daylight and windows, and dining area. Various important features of these characteristics were included in the analytical framework (Table 2). The importance of the different spatial characteristics for a future circular kitchen design is discussed in Section 6.

3. Methods and materials

A qualitative approach in combination with quantitative methods was employed to adequately address the research questions (see Section 1). Qualitative methods have been used to synthetic knowledge from the literature in order to identify spatial characteristics, develop the spatial analytical framework and define the adaptive capacity assessment. The spatial analytical framework and the adaptive capacity assessment were then used to analyse 3624 apartments. The outcome of the analysis was further examined through quantitative methods to summarise the results. In this section, first, the development of the spatial analytical framework (Section 3.1) and the adaptive capacity assessment (Section 3.2) are outlined. This is followed by the description of the sample selection process and the housing projects included in the analysis (Section 3.3).

3.1. The development of the spatial analytical framework

A framework was developed with the aim to analyse the spatial design of kitchens. The development of the framework followed a stepwise approach (Fig. 2). Step 1 consisted of a review of previous literature conducted using a database search and snowball sampling (Handcock and Gile, 2011). A Scopus search was conducted using various combinations of keywords (architect, spatial, design, analysis, framework, requirement, outline, criteria, apartment, kitchen, layout, and typology). The inclusion criteria were the literature's relevance to the aim, the geographical context (prioritising Western culture), and the language of the texts (English or Swedish). Snowball sampling led to publications documenting research on homes and kitchens in Sweden between the 1930s and the 1980s (Lee, 2018). The review aimed to identify spatial characteristics connected to kitchens in apartments (Step 2). The outcome of Steps 1 and 2 is reported in Section 2.3. In Step 3, a set of definitions for assessing the spatial characteristics were developed. These definitions were based on the studied literature. Steps 2 and 3 led to a prototype of the spatial analytical framework, which was tested, iterated, finalised, and applied to 3624 apartment floorplans (Step 4).

Based on the studied literature, the spatial characteristics that can be evaluated in floorplan drawings were

Table 2 Overview of identified spatial characteristics of the kitchen in the studied literature.

Spatial Characteristics		Important design trends and features	Sources/References
Room organisation	Room typology	Kitchen's direct connection with living room, entrance, and outdoor spaces Evolving over time (living room becomes the communication hub instead of the entrance; the kitchen changes from a service zone in the back to the heart of the home and from a separate room to an open space) Space syntax analysis and convex mapping for room organisations Room typology categories: A: "dead-end"; B: "pass-through"; C: part of a single ring; D: part of more rings Advantages of rings: facilitate movement, enable flexible use, and increase the feeling of spaciousness Secondary rings created by freestanding tall cupboard units are less favoured	Hillier and Hanson (1984), Hallberg and Thiberg (1985), Nylander et al. (2002), Bafna (2003), Manum (2005), Thiberg (2007), Manum (2009), Geromel (2016), Hillier (2007), Nylander (2018), Brkanić et al. (2018), Caldenby et al. (2019), Femenías and Geromel (2019)
	Combined kitchen-living room	Saves floor area (m^2) Increased profitability of housing projects Feeling of spaciousness Noise disturbances from kitchen tasks and visual impact of (untidy) kitchen In apartments larger than 55 m^2, the kitchen must be separable (after separation, appropriate floor area for room functions with at least one window for direct daylight)	Nylander et al. (2002), Thiberg (2007), Nowakowski (2015), Femenías and Geromel (2019), Tervo and Hirvonen (2019), Örnhall (2019), Ollár et al. (2020), National Board of Housing Building and Planning (2020)
	Doors	Position of doors influences flexibility of use and furnishability of the space Recommended number of doors in the kitchen is two It is more difficult to create new door openings than to restrict the use of existing ones	Hallberg and Thiberg (1985), Nylander et al. (2002), Thiberg (2007), Nowakowski (2015)
Built-in furniture	Kitchen typologies	Straight-kitchen: sink, work surface, and stove placed along a linear arrangement; additional tall cupboards are optional; most optimal when several people work simultaneously; preferred by end-users & stakeholders L-kitchen: angled built-in furniture with greater distances between the work units; advantageous for working alone as a disabled person in a wheelchair; preferred by end-users and stakeholders Parallel-kitchen: built-in furniture along walls facing each other; min. 130 cm between the two sides; demands more m^2; requires less façade length U-kitchen: two parallel sides of a built-in furniture connected with an extra bench; experienced as cramped, the corners are difficult to fully utilise Open L- or U-kitchen: the different wings of the built-in furniture are separated by a passage or door opening, thus eliminating the closed corner	Krantz-Jensen (1963), Hallberg and Thiberg (1985), Thiberg (1994), Thiberg (2007), Nowakowski (2015), Geromel (2016), Ollár et al. (2020), National Board of Housing Building and Planning (2020)
	Kitchen island	Most common in larger apartments or in open floorplan solutions Added work surface and storage space Might include some appliances (requiring	Nowakowski (2015), Geromel (2016), Femenías and Geromel (2019), Ollár et al. (2020)

Table 2 (*continued*)

Spatial Characteristics	Important design trends and features	Sources/References
	flexible infrastructure outlets) Lack of space to install one if the original plans were not designed for it	
Floor area of the kitchen and apartment	Shrinking floor area — compact living Free floor areas enable accessibility, increased wellbeing, reduced risk of accidents, multiple user presence, and possibility of flexibility, adaptability, and remodelling Need for enough floor area for multiple users to work at the same time	Hallberg and Thiberg (1985), Thiberg (2007)
Infrastructure (electricity, plumbing, and ventilation)	Plumbing and ventilation systems starkly define the location of the sink, dishwasher, stove, oven, and ventilation hub Flexible position of the piping and exhaust air duct is an advantage Future relocation possibility of outlets of the plumbing and ventilation system (water pipes behind the lower cabinets or horizontal air vents in the upper cabinets) enables adaptability	Thiberg (2007), Ollár et al. (2020), Lind and Mjörnell (2015)
Daylight and windows	Requires sufficient façade length Disadvantages of "single-sided" apartments: poorer lighting, fewer outlooks, less possibilities for natural ventilation At work surfaces daylight from the side is favoured Need for complementary electrical lighting (above work surfaces) Recommended: at least one window in the kitchen (required by law only in apartments larger than 55 m^2)	Hallberg and Thiberg (1985), Nylander et al. (2002), Thiberg (2007), Nowakowski (2015), National Board of Housing Building and Planning (2020)
Dining area	Important for daily life, everyday tasks (e.g., doing homework, working), and social activities Favourable to have a spacious dining table Functions as an extension of the countertop for kitchen work Recommended to be placed near work surfaces and storage spaces and in or close to the kitchen Advantageous to have a window or outdoor spaces close to the dining area	Thiberg (2007), Örnhall (2019), Hagejärd et al. (2020)

incorporated in the analytical framework. Furthermore, apartment-related characteristics (e.g., apartment floor area) and statistically relevant information (e.g., the number of apartments and the same floorplans in a building) were also measured with the aim to evaluate whether these characteristics and information have an influence on kitchen design. Table 3 summarises the measured characteristics and their related assessment values.

The identified spatial characteristics and the apartment floorplans of the selected housing projects were organised in a Microsoft Excel table, where the spatial characteristics and connected assessment values where organised horizontally and the cases were listed vertically. The analysis was carried out case by case, evaluating each spatial characteristic according to the defined assessment values. Table 4 shows a schematic representation of the spatial analytical framework.

3.2. Adaptive capacity assessment of the kitchens

In this study, the adaptive capacity indicators and their definitions were adjusted to align them with the kitchen and apartment context and to establish evaluation criteria for the adaptability assessment of the floorplans (Table 5). Based on these adjusted adaptive capacity indicators, questions were formulated to evaluate kitchens in contemporary apartments (Table 6).

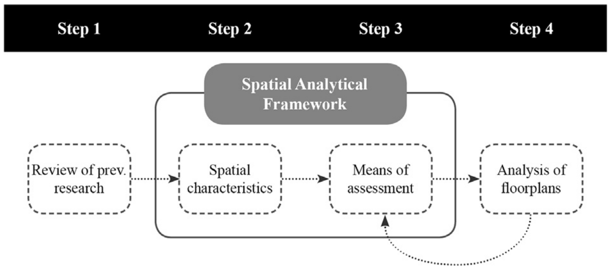

Fig. 2 The iterative process of developing the spatial analytical framework (Source: Ollár, 2021).

Only the indicators which are relevant for spatial changes were included in the evaluation. Two indicators were not studied: Renew and Rewire. The indicator Renew includes changes that the users can easily achieve (e.g., repainting or exchanging the fronts of the built-in furniture) and that do not relate to spatial characteristics. The indicator Rewire was not explored separately but was instead examined as part of the indicator Relocate since the relocation of the kitchen requires the connected infrastructure outlets to be modified.

3.3. The material — contemporary apartment floorplans

Floorplans of all multiresidential buildings in Gothenburg which received a building permit in 2017 were collected from the city planning office. A housing project was included in the sample based on the following criteria:

1. It received an approved building permit in 2017.
2. It was planned to be built within the city of Gothenburg.
3. It was a new building production (renovation and alteration projects were excluded).
4. It was a multistorey and multiresidential apartment building (twin houses, terrace houses, and student housing were excluded).
5. It had available complete floorplan drawings in the archives (partially documented projects with missing drawings were excluded).

Using the first three criteria 46 housing projects were retrieved from the archives. After adding the fourth and fifth criteria, the final sample consisted of 38 housing projects with 3624 apartment units. These represent more than 10% of the total national production in 2017 (35,783 apartments were produced in Sweden (Statistics Sweden, 2020b)). These 38 projects were built in a larger metropolitan area and municipality where a bit more than 5% of the population resides (Statistics Sweden, 2021a; 2021b). Based on the statistics, it is fair to assume that the evaluation of housing projects in Gothenburg gives a well-grounded basis for the analysis both in terms of the number of cases and the relevance of the location.

Within the identified apartment units, some floorplans were repeated multiple times. Ultimately, 574 different apartment floorplans were analysed. The analysis focused

Table 3 The measured spatial characteristics and connected assessment values.

Spatial characteristics and statistically relevant information		Assessment subject	Assessment value
Apartment	Apartment floorplan	Layout and room organisation	Floorplan drawing
	Floorplan variations	Same floorplans in building	Number
	Floor area	Size of the apartment	m^2
	Apartment type	Number of bedrooms	Scroll-down list: studio, one-bedroom (1b), two-bedroom (2b), three-bedroom or more (3b or more)
	Access to private balcony or terrace	Presence of balcony or terrace (outdoor space)	Name through which room it is accessible; otherwise, no
	Daylight and windows	Number of façade sides with windows in the apartment	Scroll-down list: 1, 2-perpendicular (two façade sides with windows perpendicular to each other), 2-parallel (two façade sides with windows on opposite sides of the apartment), 3, 4
Kitchen	Room typology	Kitchen's connections to other rooms	Scroll-down list: A, B, C, D Based on definitions described in Table 2. A combined kitchen-living room is considered as one room, even if it is multifunctional (e.g., entrance hall, living room, kitchen, dining area).
		Presence of freestanding tall cupboard unit	Scroll-down list: yes or no It must contain the fridge and the freezer; a storage cupboard can possibly be attached to them.

Table 3 (*continued*)

Spatial characteristics and statistically relevant information		Assessment subject	Assessment value
	Combined kitchen-living room or separate room	Enclosure of the kitchen as a room	Scroll-down list: combined kitchen-living room, separate room If there is just a short wall opening between the two rooms, then it counts as a separate kitchen.
	Doors	Presence of doors or door openings in the kitchen	Number of doors/door openings that lead to/from the kitchen
	Kitchen typology	Layout of built-in furniture	Scroll-down list: Straight, L, U, Parallel Based on definitions described in Table 2.
	Kitchen island	Presence of kitchen island in the current floorplan design	Scroll-down list: yes or no
	Infrastructure	Type of wall where the infrastructure-dependent appliances and work units are located on	Multiple-choice option: façade wall, perimeter wall (walls between apartments), structural interior wall, lightweight interior wall, installation wall, kitchen island
		Shaft location	Scroll-down list: in kitchen, on perimeter of kitchen, not directly connected to the kitchen, not visible in drawing
	Kitchen floor area	Size of the kitchen	m^2 If the kitchen is a combined kitchen-living room, then measure with imaginary separation of the rooms. If separation is not possible (e.g., very small apartments), then measure the area of the built-in furniture and 130 cm in front of it.
	Daylight and windows	Number of façade sides with window in the kitchen	Scroll-down list: 1, 2, 3, 4 If the kitchen is a combined kitchen-living room, then measure with imaginary separation of the rooms; if separation is not possible (e.g., very small apartments), then measure in open plan.
	Dining area	Location	Scroll-down list: in kitchen, in living room, separate dining room, combined kitchen-living room When the dining area is not indicated on the drawings: in the case of a combined kitchen-living room, choose the option "combined kitchen-living room"; if the kitchen is a separate room, choose between kitchen or living room depending on which room is bigger and hence would better accommodate a dining area.
		Presence of a window close to dining area	Yes: if there is a window on the wall closest to the dining table Otherwise: no

Table 4 Schematic representation of the spatial analytical framework.

Spatial Characteristics and Statistically Relevant Information								
Case	Apartment				Kitchen			
	SC_a1 AV $_{SCa1}$	SC_a2 AV $_{SCa2}$	… …	SC_an AV $_{SCan}$	SC_k1 AV $_{SCk1}$	SC_k2 AV $_{SCk2}$	… …	SC_kn AV $_{SCkn}$
C-1								
C-2								
…								
C-n								

SC_a — apartment-related data, SC_k — kitchen-related data, AV — assessment value, C — case reference.

on the planned design of the floorplans; the end result of the building production was not evaluated in this study. Fig. 3 shows the number of floorplan variations among the different types of apartments.

4. Contemporary apartment floorplans and kitchen design

Four spatial characteristics were evaluated in the apartments: apartment type, floor area, access to private outdoor space, and daylight. For the kitchens, nine spatial characteristics were analysed: room organisation (room typology, open floorplan, and doors), built-in furniture (kitchen typologies and kitchen island), floor area, infrastructure, daylight, and dining area. Fig. 4 illustrates an apartment floorplan with the most typical design solutions of the spatial characteristics identified in the studied sample.

More than half of the apartments in the studied sample are one-bedroom (39%) or studio (21%) apartments (Fig. 5). However, the number of floorplan variations for these apartment types (Fig. 3) are fewer in proportion (respectively 37% and 15% of the 574 layouts). This shows that floorplan designs of smaller apartments are more often repeated within the sample, meaning there is less diversity of spatial configurations for these apartments compared to the larger ones. The average floor area of the apartments is 60.6 m^2. The smallest apartment is 23 m^2, and the largest is 182.9 m^2 (Fig. 6). The average floor area increases by about 20 m^2 with an additional bedroom. The increased floor area includes not only the extra room but also the added space in the shared rooms such as the kitchen and living room.

96% of the apartments are designed with a private outdoor space (terrace or balcony). 80% of the outdoor spaces are connected to the combined kitchen-living room, whereas 4% or 139 of the apartments are designed without one. 90 of these apartments without private outdoor spaces are studio apartments. When the kitchen and living room are separate rooms, the living room is more often the access point to an outdoor space than the kitchen. In a few cases, one or more outdoor spaces are accessible from a bedroom or office room (14% of outdoor spaces) or other secondary spaces, such as an entrance hall, corridor, storage room, bathroom, or sauna (2% of outdoor spaces).

The apartments most commonly receive daylight from two perpendicular directions (40%). This is followed by apartments with one (29%), three (16%), and two parallel daylight directions (14%). Examples of apartments with the two most common daylight directions are illustrated in Fig. 7. 81% of studio apartments and 30% of one-bedroom apartments have only one daylight direction. The large portion of apartments with one daylight direction might contribute to the housing stock with lower quality dwellings which have poorer lighting, fewer outlooks, and less

Table 5 Overview of the adjusted adaptive capacity indicators and their definitions.

Indicators[a]	Adjusted indicators	Adjusted definitions
Quality	Renew	Changing the usability and user experience of the kitchen (e.g., refreshing the look of or exchanging some parts of the built-in furniture)
Redesign	Rearrange	Changing the layout or functions of the kitchen (e.g., altering the kitchen typology)
Relation Internal Grain Size	Reconfigure	Changing the kitchen's relation with other rooms in the apartment (e.g., opening, removing, or relocating doors or walls)
Facilities	Rewire	Changing the facilities (infrastructure outlets) in the kitchen
Reallocate Internal Transfer	Relocate	Changing the location of the kitchen within the apartment
Expansion Rejection	Expand or reduce	Changing the kitchen's use surface, increasing or decreasing its floor area

[a] Based on Geraedts et al. (2014).

Table 6 Questions assessing the adaptive capacity of contemporary kitchen designs.

Adaptive capacity indicator	Assessment question	Means of assessment
Rearrange	Is there any other kitchen typology possible within the same kitchen space?	Yes, with minor changes: when only the built-in furniture needs to be changed and infrastructure outlets do not need to be relocated Yes, with major changes: when the infrastructure outlets, doors, or walls need to be relocated in order to accommodate another kitchen typology Otherwise: no
Reconfigure	Is it possible to open new doors towards adjacent rooms which are currently not connected?	Yes: if there is a neighbouring room that is currently not connected to the kitchen with a doorway and there is a lightweight wall between them, and the new door opening would not reduce the furnishability or usability of the rooms Otherwise: no
	Is it possible to remove existing doors or room connections?	Yes: if there is more than one door leading to/from the kitchen and all disconnected rooms are still accessible from another room Otherwise: no
	In combined kitchen-living room: Is it possible to separate the kitchen?	Yes: if there is enough free floor area and, in apartments larger than 55 m^2, there will be a window in the kitchen after separation Otherwise: no
	In separate kitchen: Is it possible to create a combined kitchen-living room?	Yes: if there is a lightweight interior wall and on the other side of this wall there is a room that could be suitable for a living room area Otherwise: no
Relocate	Is it possible to easily establish the kitchen in another room or in another part of a combined kitchen-living room?	Yes: if a shaft is accessible from another room/part of a room and, in apartments larger than 55 m^2, there is a window at the new location Otherwise: no
Expand or reduce	Is there a buffer space to expand or reduce the kitchen's floor area over time (without losing a bedroom or living room)?	Yes: with combined kitchen-living rooms, if there is space to take from the living room; with separate kitchens, if there is a lightweight wall that can be moved without reducing the usability of the neighbouring room, if there is an adjacent room (e.g., storage room, not bedroom or living room) that can be merged with the kitchen, or if the floor area of the kitchen can be reduced Otherwise: no

possibilities for natural ventilation. As apartments' floor area increases, so do their number of daylight directions. This aspect is not surprising since larger apartments usually have more rooms which require direct daylight.

The average floor area of the kitchens in the sample is 11.3 m^2, and, on average, 19% of an apartment's floor area is occupied by this room. The minimum, maximum, and average floor areas of the kitchen in different apartment types are presented in Fig. 8. Although the average floor area of the kitchen increases by about 3 m^2 with an additional bedroom, the minimum floor area of the kitchen in different apartment types does not follow such a progressive development. The smallest kitchens for each apartment type stay similarly small.

Considering the room organisation of the kitchens, the open floorplan design with a combined kitchen-living room dominates in the studied sample (95%). The kitchens have

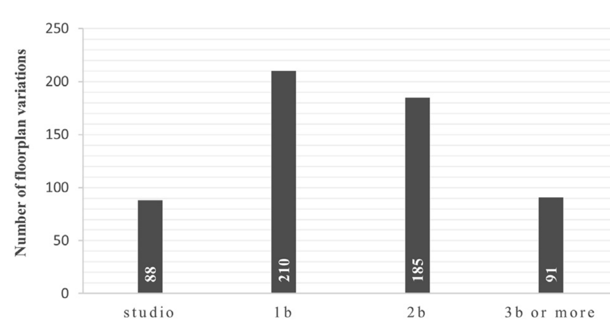

Fig. 3 Number of floorplan variations in connection with the different groups of apartment types (studio, one-bedroom [1b], two-bedroom [2b], three-bedroom or more [3b or more] apartments).

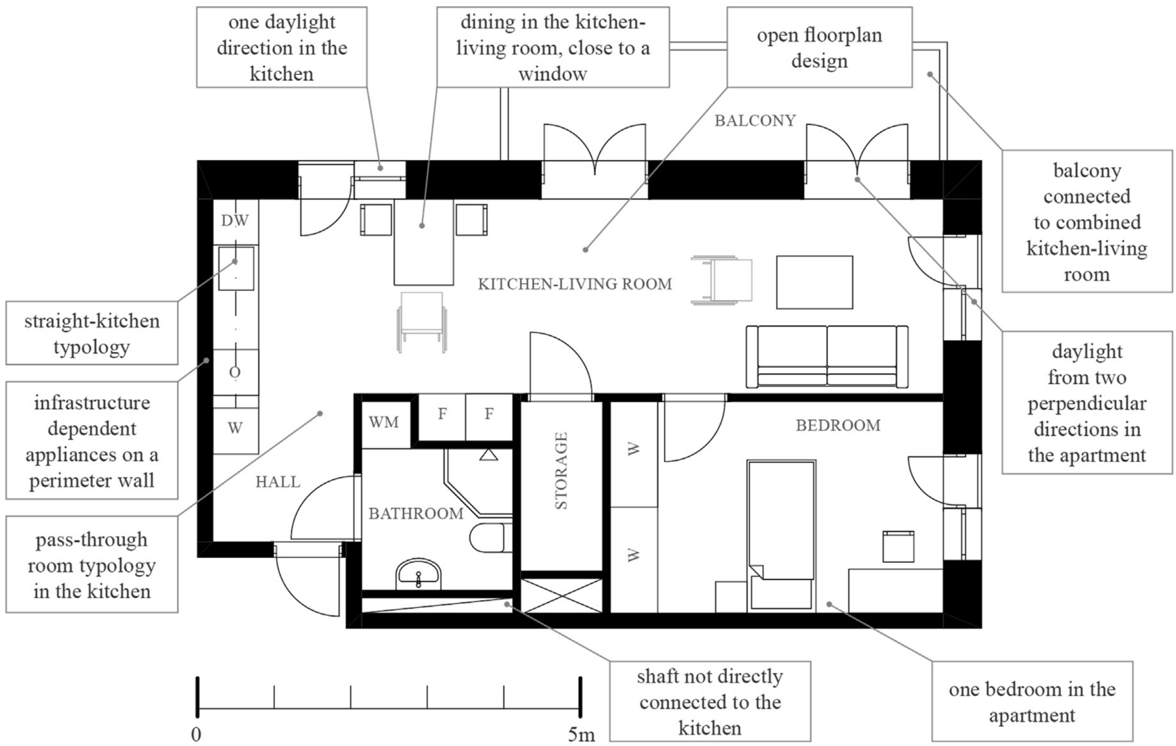

Fig. 4 Apartment floorplan example (50.8 m^2) with the most typical contemporary design solutions identified in the studied sample (Source: illustration by Anita Ollár, original floorplan by Kanozi Arkitekter). DW: dishwasher, F: fridge and freezer, O: oven and stove, W: wardrobe, WM: washing machine.

mostly two door openings (54% of the apartments). Three (25%) and one (19%) door openings occur less often. Only 18% or 636 of the kitchens were designed with a freestanding tall cupboard. The kitchens have a pass-through room typology (B) in 55% of the apartments. The second most common room typology is C, with an internal ring (25% or 889 of the apartments). However, in 593 of the 889 C room typology kitchens, the internal ring is created by a freestanding tall cupboard unit. This means that, in many C room typology kitchens, there is no circulation between the rooms of the apartment, only around the freestanding tall cupboard unit.

Regarding the built-in furniture, the straight-kitchen (64%) and L-kitchen typologies (31%) are the most common layouts, while U-kitchens (3%) and parallel-kitchens (2%) are designed only in a few cases (Table 7). Fig. 9 illustrates examples of straight- and L-kitchen typologies, as the two most common design solutions found in the studied sample. Straight- and L-kitchen typologies occur most commonly in pass-through (B) kitchens, parallel-kitchen typologies in rooms with one ring (C), and U-kitchens in dead-end (A) rooms (Table 7). Only 3% or 117 of the apartments have a kitchen island. Surprisingly, out of these 117 apartments, a fair number are one-bedroom apartments, having almost as many kitchen islands as apartments with three or more bedrooms (Table 8). Furthermore, these kitchen islands are a complement only to straight- and L-kitchens.

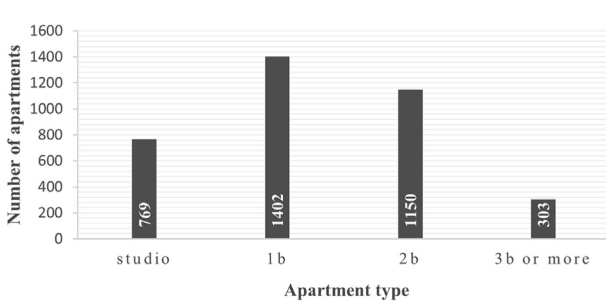

Fig. 5 Number of apartments by type (studio, one-bedroom [1b], two-bedroom [2b], three-bedroom or more [3b or more] apartments) in the studied sample.

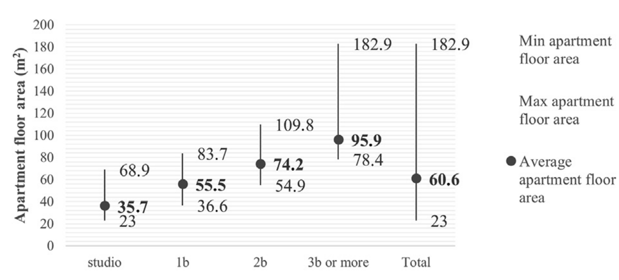

Fig. 6 Minimum, maximum, and average floor area among different apartment types (studio, one-bedroom [1b], two-bedroom [2b], three-bedroom or more [3b or more] apartments).

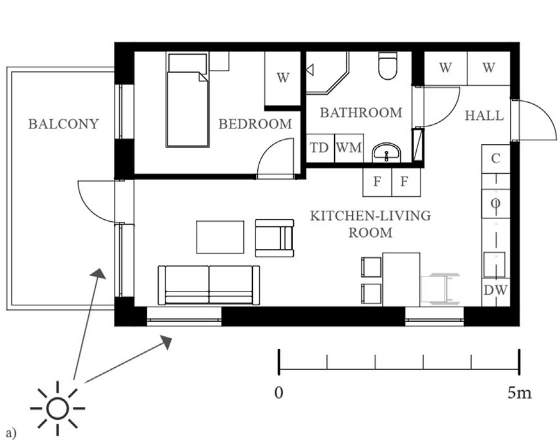

Fig. 7 Apartment examples with (a) two perpendicular and (b) one daylight directions (Source: illustration by Anita Ollár, original floorplans by Efem Arkitektkontor). C: cupboard, DW: dishwasher, F: fridge and freezer, O: oven and stove, TD: tumble dryer, W: wardrobe, WM: washing machine.

The infrastructure-dependent appliances (including the sink) are mostly established on perimeter walls (45% of all walls with infrastructure-dependent appliances) and on lightweight interior walls (35% of all walls with infrastructure-dependent appliances). Other solutions place infrastructure-dependent appliances on façade walls, installation walls, structural interior walls, or in kitchen islands. The shaft is not directly connected to the kitchen in 36% of the apartments. In other solutions, the shaft is in the kitchen (32%) or on its perimeter (22%). In 10% of the apartments, which shaft supplies the kitchen is not clearly indicated.

The dining area is established in the combined kitchen-living room in 95% of the cases. When the kitchen and the living room are separate rooms, the dining area is in the living room or in the kitchen in an almost equal number of cases (3% and 2% of the apartments, respectively). The dining area is located close to a window in 82% of the apartments, which enables qualities such as an outdoor view and daylight. Daylight in the kitchen is provided from one direction in 90% of the kitchens.

5. Adaptive capacity of contemporary kitchen designs in apartment floorplans

Four adaptive capacity indicators connected to the kitchens were assessed: Rearrange, Reconfigure, Relocate, and Expand or reduce. In connection with each indicator, enabling and hindering design solutions were observed. As Table 9 shows, some of the separate adaptive capacity indicators perform relatively well (e.g., possibility to Rearrange 89%, possibility to Expand or reduce 76%). Despite this good performance, only in 23% (or 827) of the apartments it is possible to implement all four adaptive capacity indicators.

5.1. Rearrange

Most of the kitchen floorplans can be rearranged into another kitchen typology with minor (47%) or major (42%) changes (see example in Fig. 10). In those cases where it is not possible to adopt another kitchen typology, the most common limitations are a lack of space (62%), the limited width of the room (24%), and the existing connections to other rooms (14%). With open floorplan solutions, a new kitchen typology can be adopted with minor changes in 54% of the cases, while in separate kitchens, an alteration more often requires major changes (48% of the floorplans). In those floorplan drawings where another kitchen typology is not possible, 77% of the kitchens are of the B room typology. This can be explained by the greater number of traffic zones in such a room typology. The floor area of the kitchen influences the possibility to rearrange it: the larger the floor area a kitchen has, the more likely it is that another kitchen typology can be placed in the same space with minor modifications. Kitchens smaller than 10 m^2 account for 82% of the kitchens where no other kitchen typology is possible. Furthermore, apartments with a floor area larger than 35 m^2 need fewer major changes than minor changes for rearrangement.

The analysis highlighted design solutions which enabled the rearrangement of the built-in furniture. As expected, when a kitchen has a "squarish" enclosure, it is more likely

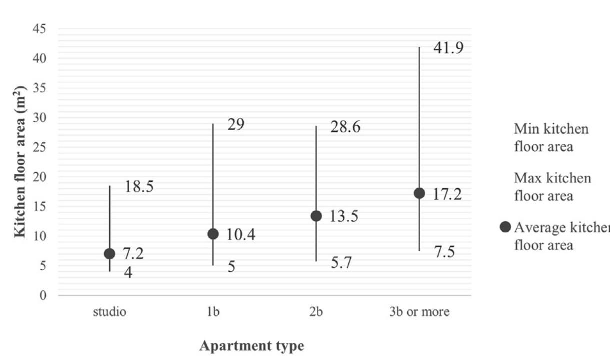

Fig. 8 Minimum, maximum, and average floor area of the kitchen in different groups of apartment types (studio, one-bedroom [1b], two-bedroom [2b], three-bedroom or more [3b or more] apartments).

Table 7 Interconnections between kitchen typologies and room typologies.

Kitchen typology	Room typology				
	A	B	C	D	Total (100%)
Straight-kitchen	240 (10%)	**1481 (64%)**	548 (24%)	50 (2%)	2319
L-kitchen	360 (32%)	**466 (42%)**	292 (26%)	2 (0%)	1120
Parallel-kitchen	11 (13%)	25 (30%)	**37 (45%)**	10 (12%)	83
U-kitchen	**60 (59%)**	30 (29%)	12 (12%)	0 (0%)	102
Total	671 (19%)	2002 (54%)	889 (25%)	62 (2%)	3624

A: dead-end room typology, B: pass-through room typology, C: room typology in one ring, D: room typology in multiple rings.

that multiple kitchen typologies would fit in the space, whereas narrow rooms are harder to rearrange. Continuous interior wall surfaces (without door openings) also better enable rearrangement variations. As presented above, it is easier to rearrange kitchens with a larger floor area and fewer traffic zones.

5.2. Reconfigure

Reconfiguring a room by removing existing doors or opening new ones in the kitchen is often not possible. The main limitation to removing an existing door is the lack of alternative access to the adjacent room. This type of alteration is mostly possible in kitchens of C and D room typologies since these room typologies often contain a freestanding tall cupboard unit where one wall opening next to the unit can be removed with the kitchen remaining accessible through the other opening. For 90% of the floorplans, opening a new door connection is not possible because there are no adjacent unconnected rooms, or the built-in furniture or fixtures block the way. In cases where the kitchen is located in a combined kitchen-living room, it

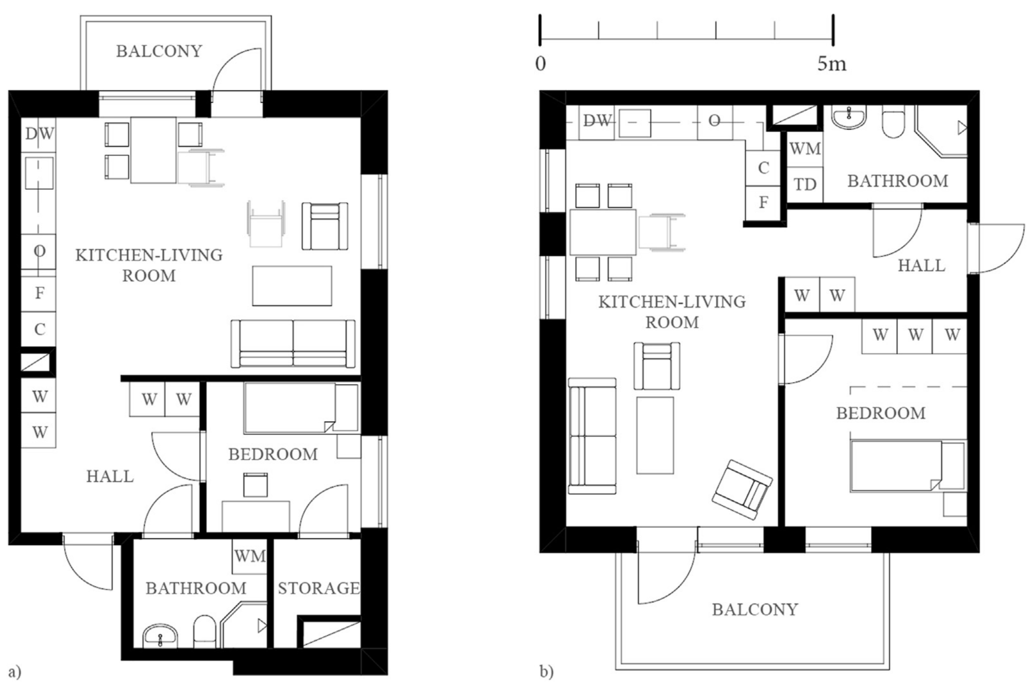

Fig. 9 Examples of (a) straight- and (b) L-kitchen, the two most typical kitchen typologies in the sample (Source: illustration by Anita Ollár, original floorplans by (a) NorConsult, (b) Tengbom). C: cupboard, DW: dishwasher, F: fridge and freezer, O: oven and stove, TD: tumble dryer, W: wardrobe, WM: washing machine.

Table 8 Presence of kitchen island in relation to the apartment types (studio, one-bedroom [1b], two-bedroom [2b], three-bedroom or more [3b or more] apartments).

Presence of kitchen island	Apartment type				
	Studio	1b	2b	3b or more	Total (100%)
Yes	18 (15%)	**37 (32%)**	17 (15%)	**45 (38%)**	117
No	751 (21%)	1365 (39%)	1133 (32%)	258 (8%)	3507

Table 9 Overview of adaptive capacity of kitchens in the studied apartment floorplans.

Adaptive capacity indicator		Part of the sample with possibility to adapt	Hindering factors	Enabling design solutions
Rearrange		89%	-lack of space limited width of the room -existing connections to other rooms	-"squarish" enclosure of the room -continuous interior wall surfaces -larger floor area -fewer traffic zones
Reconfigure	Open new door	10%	-no adjacent unconnected rooms -built-in furniture or fixtures in the way	-location and number of windows (e.g., multiple windows arranged along a façade side)
	Remove existing door	26%	-lack of alternative access to the adjacent room	-room organisation -larger floor area
	Separate open kitchen	76%	-lack of window access -lack of space	
	Open separate kitchen	79%	-short wall connection between the kitchen and an adjacent room -structural wall in the way -no adjacent room that could function as living room area	
Relocate		32%	-limited shaft access -inability to utilise the current location of the kitchen as another room or function	-shaft access from multiple rooms -multiple shafts in the apartment (e.g., connected to the kitchen or the bathroom) -location and number of windows
Expand or reduce		76%	-lack of space -lack of window access -existing connections to other rooms	-storage room next to the kitchen -open floorplan design -larger floor area

is less likely that a new door can be opened to connect a currently unconnected room. This might be due to how combined kitchen-living rooms are often placed in the centre of an apartment and other rooms are already connected to it and accessible by passing through this space.

It is easier to reconfigure the room organisation by separating the kitchen (see example in Fig. 11) in an open floorplan (76% of kitchens in an open floorplan) or creating an open floorplan where the kitchen is initially a separate room (79% of separate kitchens). Separating the kitchen is often difficult in smaller apartments. In apartments of less than 35 m^2, kitchens cannot be separated in 85% the cases, and no open kitchen of less than 5 m^2 is separable. In apartments larger than 35 m^2 with an open floorplan design, it is possible to separate the kitchen in 83% of cases. However, even though there is a strong relationship between the possibility to separate a kitchen in an open floorplan and the floor area of the apartment and kitchen, this is not the only determinative characteristic. In 56% of the apartments between 35 and 55 m^2 with open floorplans, the kitchen can be separated. Separation is enabled by multiple and well-distributed windows along the façade side and the room organisation. The main obstacles in separating a kitchen in an open floorplan include a lack of window access (71%) and lack of space (27%). In one-bedroom apartments, the narrow width of the room is an obstacle in more cases than the average (40% of one-bedroom apartments). Kitchens where an open floorplan is not possible are mostly of the A room typology (74% of the related floorplans) or located in one-bedroom apartments (52% of the related floorplans). The limiting factors are the short wall connection between the kitchen and an adjacent room (74%), a structural wall in the way (13%), and no adjacent room that could function as a living room area (13%). The number of doors also hinders the potential for an open floorplan. The fewer doors there are in the kitchen (which indicates fewer adjacent rooms), the less likely it is that an open floorplan can be created.

In apartments where reconfiguration is possible, the room organisation and window distribution enable the new floorplan design. The location and number of windows influence the possibility of reconfiguring a room. For example, separating the kitchen is easier in cases where multiple windows are arranged along a façade side, while single large windows hinder the option of constructing a partition wall.

Fig. 10 Exemplifying the concept 'rearrange': (a) An apartment floorplan (74.1 m^2) with the planned kitchen (Source: illustration by Anita Ollár, original floorplan by Semrén & Månsson Arkitektkontor). (b) A possible rearrangement of the kitchen typology (proposal by Anita Ollár). C: cupboard, DW: dishwasher, F: fridge and freezer, KI: kitchen island, O: oven and stove, TD: tumble dryer, W: wardrobe, WM: washing machine.

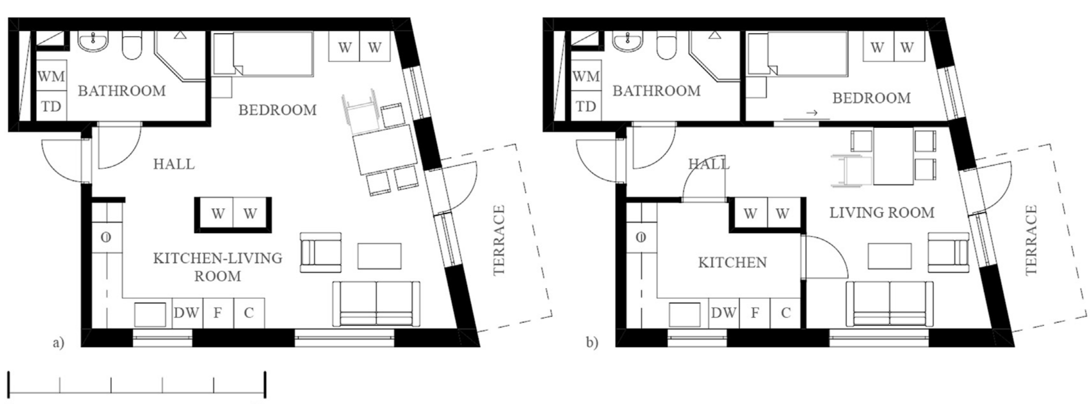

Fig. 11 Exemplifying the concept 'reconfigure': (a) An apartment floorplan (37.9 m^2) with the planned room organisation (Source: illustration by Anita Ollár, original floorplan by Tengbom). (b) A possible reconfiguration through separating the kitchen (proposal by Anita Ollár). C: cupboard, DW: dishwasher, F: fridge and freezer, O: oven and stove, TD: tumble dryer, W: wardrobe, WM: washing machine.

5.3. Relocate

Relocating the kitchen to another part of the apartment is only possible in 32% of the apartments (see example in Fig. 12). Surprisingly, it is most often possible to relocate the kitchen when the shaft is in the kitchen. This is enabled either by an adjacent room which is also connected to the shaft and could function as a kitchen or by a secondary shaft (e.g., connected to the bathroom) which could supply the kitchen in the new location. In 9% of the studied floorplans, it is not possible to measure the possibility of a relocation since the shaft is not clearly indicated on the drawings or there is no secondary shaft in the apartment. In 59% of the cases, relocating the kitchen is not possible. Relocation is predominantly hindered by limited shaft access (91%) and the inability to utilise the current location of the kitchen as another room or for another function (8%).

The kitchen can be relocated in only 26% of the studio apartments. In studio apartments the hindrance is more often the current location of the kitchen than in larger apartments. This is because in studio apartments the kitchen is often connected to the entrance and has a pass-through room typology. Therefore, this area of the apartment cannot be utilised for another room function. Kitchens in apartments smaller than 55 m^2 feature a lower-than-average possibility for relocation. Kitchens larger than 15 m^2 (and hence, belonging to larger apartments) can more likely be relocated. This point can be explained by how larger apartments have more rooms which could fulfil different functions.

The following design features enable the relocation of the kitchen: the shaft is accessible from multiple rooms; there are multiple shafts in the apartment which are equipped with electrical, plumbing, and ventilation installations (e.g., connected to the kitchen and the bathroom); and there are numerous and well-distributed windows in several rooms. The numerous windows enable the kitchen to be moved to another part of the apartment and still fulfil the direct daylight access regulations for kitchens.

5.4. Expand or reduce

It is possible to expand or reduce the kitchen's floor area for 76% of the floorplans (see example in Fig. 13), while in 24% it is not possible. The main hindering factors are a lack of space (67%), a lack of window access (20%), and the existing connections to other rooms (11%). In half of the apartments where expansion is possible, the kitchens are of the B room typology. However, 72% of the kitchens where expansion is not possible are also of the B room typology. This observation can be explained by the dominance of the B room typology in the sample. The potential to expand or reduce the floor area of a kitchen grows with an increase in the floor area of an apartment. For apartments larger than 55 m^2 and for kitchens with a floor area greater than 10 m^2, expansion or reduction is more likely to be possible.

The findings reveal that a storage room next to the kitchen is convenient for providing extra space when users wish to expand their kitchen. In most cases, the two rooms are separated with a lightweight wall which can easily be removed. The open floorplan design also enables expansion and reduction. As expected, larger apartments have more potential for expanding or reducing the kitchen's floor area.

6. Discussion

This study identified spatial characteristics of apartments and kitchens that are relevant for housing adaptability. These are the over-capacity of the floor area, the window location and distribution, the number of door openings and

Fig. 12 Exemplifying the concept 'relocate': (a) An apartment floorplan (75.6 m^2) with the planned location of the kitchen (Source: illustration by Anita Ollár, original floorplan by Tengbom). (b) A possible relocation of the kitchen (proposal by Anita Ollár). C: cupboard, DW: dishwasher, F: fridge and freezer, O: oven and stove, TD: tumble dryer, W: wardrobe, WM: washing machine.

traffic zones, the shaft location and accessibility, the room typology, and the kitchen typology. Although some of these characteristics have been recognised by previous research (Femenías and Geromel, 2019; Leupen, 2006; Manum, 2005; Ross et al., 2016), this paper provides a large-scale analysis ($n = 3624$) that confirms and expands on the list of relevant spatial characteristics and identifies design choices that enable adaptability and hence promote more circularity in housing design. The next sections provide reflections on the aforementioned spatial characteristics and design choices, discuss the limitations of this study and give recommendations for further research.

6.1. The relevance of spatial characteristics for adaptive capacity of the home

As an important finding of the analysis, this paper shows that although the over-capacity of the floor area has an influence on the adaptive capacity of kitchens and apartments, it is not the only determinative factor. As observed in the spatial analysis, a large portion of kitchens in apartments below 55 m^2 show potential for adaptability. Design solutions, namely, numerous well distributed windows, shaft access from multiple rooms with windows, adequate room width and length, storage room next to the kitchen, limited traffic zones, and continuous interior wall surfaces without doors enable adaptive capacity. As West and Emmitt (2004, pp. 298) have remarked, "[c]areful design decisions and simplicity appear to have more success in providing workable plans" than merely delivering large apartments. Nylander (2020) also points out that there is low interest from the buyers' side towards larger apartments.

6.1.1. Floor area

The over-capacity of the floor area of the kitchen and apartment is an important spatial characteristic, not only in terms of its relevance for adaptive capacity but also in connection with other spatial characteristics. However, the floor area does not need to be excessively large to provide space for a spatial design that enables adaptability. According to the analysis, in apartments larger than 35 m^2, adaptive capacity increases, and in apartments larger than 55 m^2, adaptability is significantly higher. Similarly, kitchens larger than 10 m^2 have higher adaptive capacity. As the example shows (Fig. 14a), providing several daylight directions, prioritising multiple windows over large single openings, planning various shafts that are accessible from several rooms with windows and designing the kitchen with available free floor area to rearrange it, separate it, extend it or compliment it with a kitchen island, is possible already in an apartment of 62 m^2. Such an apartment could be suitable for various households (singles, couples, or small families), since the room organisation, free floor area and window distribution makes it possible to separate an extra bedroom. Nevertheless, in apartments smaller than 35 m^2 implementing advantageous spatial design solutions is not achievable due to the lack of space. As Fig. 14b illustrates, in such apartments the daylight access is diminished, all living functions are compressed into one small room, there is no separation in private and public room functions, the

Fig. 13 Exemplifying the concept 'expand or reduce': (a) An apartment floorplan (48.9 m^2) with the planned floor area of the kitchen (Source: illustration by Anita Ollár, original floorplan by White Arkitekter). (b) A possible expansion through removing the walls of the storage room (proposal by Anita Ollár). DW: dishwasher, F: fridge and freezer, KI: kitchen island, O: oven and stove, W: wardrobe, WM: washing machine.

kitchen is meagre, the traffic zones make up all the free floor area and there is no possibility for adaptation. Such apartment is only suitable for one occupant and cannot evolve with changing household compositions.

The results regarding the relationship of the floor area and adaptive capacity is in accordance with findings of previous studies. Larger apartments are altered more often than smaller ones (Femenías and Geromel, 2019), most likely because their space provides more possibilities for alterations. As Thiberg (2007) has remarked, reasonably large kitchens with adequate free floor areas are essential for enabling a high quality of life for end-users. However, the findings of this paper indicate that newly produced apartments (and hence kitchens) are becoming smaller. This study reported an average apartment floor area of 60.6 m^2, which is smaller than averages found in the literature (e.g., 83 m^2, as in Femenías and Geromel, 2019) or what end-users consider as a desirable apartment size (minimum of 69 m^2, as in Tervo and Hirvonen 2019).

Tervo and Hirvonen (2019) also noted that small housing units do not satisfy end-user needs and that the mass production of small apartments is mostly driven by the market and housing regulations. However, there is a conflict between the floor area of apartments and their affordability (Heidrich et al., 2017). In Sweden, sales prices of apartments have increased significantly in the past 20 years (Statistics Sweden, 2020b). Producing larger dwellings with larger kitchens have higher costs, which do not fit with the budget of many households. Furthermore, the extra resource use connected to larger dwellings and the energy needed for heating larger spaces are also important factors that need to be considered in connection with a circular built environment. Identifying the suitable floor area for different apartment types requires further research, which would consider user needs, economical questions, and environmental impacts.

6.1.2. Windows and doors

The location and distribution of windows proved to be an important design component for increasing the adaptive capacity of apartments. Although many kitchens in smaller apartments are designed with a window, Swedish regulations allow kitchens in apartments smaller than 55 m^2 to be built without direct daylight access (National Board of Housing Building and Planning, 2020). In apartments where kitchens are designed without a window, the adaptive capacity is lower compared to apartments where the kitchen has a window. The location and distribution of windows influence the possibility to both reconfigure and relocate the kitchen. As an example, Fig. 15 shows two apartments of the same housing project with similar floor area. The apartment in Fig. 15a has one long window and in Fig. 15b there are several windows along the façade. While it's possible to for example separate the kitchen in Fig. 15b, this is not an option in the other floorplan (Fig. 15a), since the separated rooms would not have their own windows. Therefore, even in apartments with daylight provided only from one direction, it could be advantageous to design windows that are well distributed along the façade and one at least connected to the kitchen. This distribution would also make situating the dining area close to a window easier, which is currently more difficult in smaller apartments.

Another important spatial characteristic is doors which define not only wall openings and room connections but also traffic zones and available continuous wall surfaces. As Fig. 16a shows, in smaller apartments the free floor area is usually equals with the traffic zones. This limits adaptability, furnishability and useability of the apartment. However, design choices such as less fragmented room organisation, fewer door openings and optimised room connections can enable access free floor area (as illustrated

Fig. 14 Spatial design solutions in relation to floor area: (a) An apartment floorplan of 62 m^2 (Source: illustration by Anita Ollár, original floorplan by Liljewall Arkitekter). (b) Apartment floorplan of 29.5 m^2 (Source: illustration by Anita Ollár, original floorplan by Bornstein Lyckefors Arkitekter). DW: dishwasher, F: fridge and freezer, O: oven and stove, TD: tumble dryer, W: wardrobe, WM: washing machine.

Fig. 15 Apartment floorplans of (a) 35.6 m^2 with one long window and (b) 39.5 m^2 with several windows along the façade (Source: illustration by Anita Ollár, original floorplans by Tengbom). C: cupboard, DW: dishwasher, F: fridge and freezer, O: oven and stove, W: wardrobe, WM: washing machine.

in Fig. 16b), which can be used to add a kitchen island or extra walls for supplementary furniture.

6.1.3. Shaft location and accessibility

The possibility to relocate the kitchen was, rather naturally, found to be dependent on the presence of multiple shafts in the apartment (usually one connected to the kitchen and one to the bathroom), which enables more than one access point, often from various rooms (as illustrated in Fig. 17). Additionally, this design solution also allows different room organisation possibilities in the whole apartment. Some earlier studies have indicated that the renovation of a plumbing and ventilation system is often followed by the renovation of a kitchen, which usually includes replacing the kitchen furniture (Lind and Mjörnell, 2015). This suggests that the more flexible and accessible

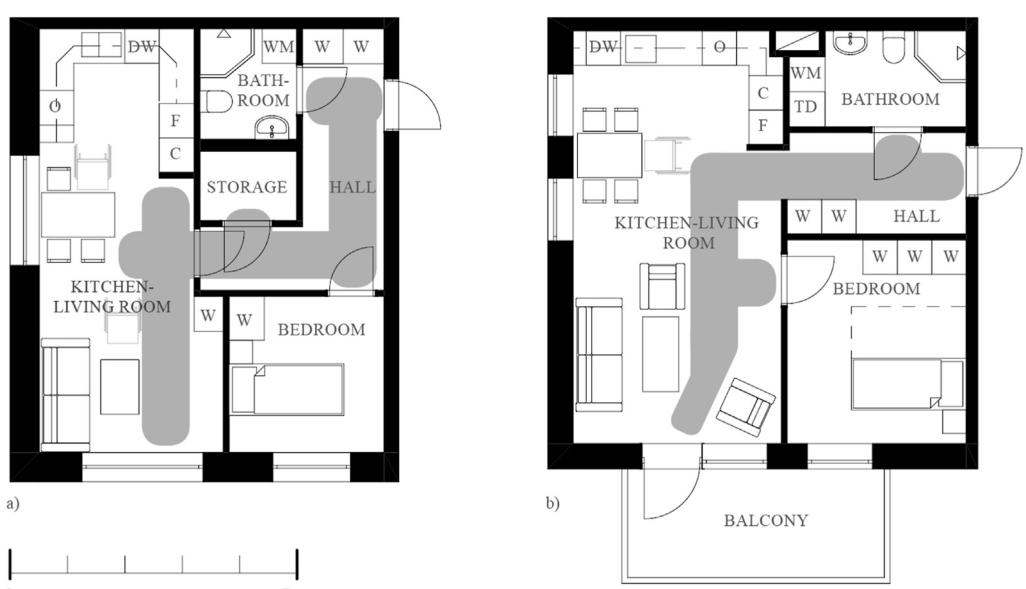

Fig. 16 Apartment floorplan with (a) increased number of doors and traffic zones (46.9 m^2; Source: illustration by Anita Ollár, original floorplan by White Arkitekter) and with (b) fewer doors and traffic zones, allowing extra free floor area (49.7 m^2; Source: illustration by Anita Ollár, original floorplan by Tengbom). C: cupboard, DW: dishwasher, F: fridge and freezer, O: oven and stove, TD: tumble dryer, W: wardrobe, WM: washing machine.

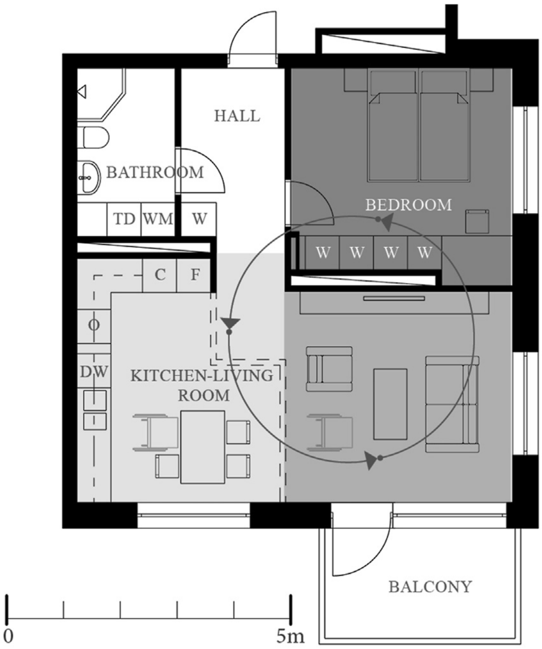

Fig. 17 Apartment floorplan (65 m^2) with multiple shafts accessible from several rooms with windows (Source: illustration by Anita Ollár, original floorplan by Tengbom). C: cupboard, DW: dishwasher, F: fridge and freezer, O: oven and stove, TD: tumble dryer, W: wardrobe, WM: washing machine.

these infrastructure outlets are, the less extensive renovations must be, which ultimately might lower the amount of waste resulting from kitchen renovations.

6.1.4. Room organisation

The kitchens in the studied sample most often have B or C room typologies, which is partially in line with what Manum (2005) observed regarding the decreasing number of internal rings in contemporary apartments. Pass-through (B) room typologies seem to hinder expansion, while C and D typologies (including one or more internal rings) appear to enable more options for reconfiguration. Our analysis also showed that A and B (dead-end and pass-through) room typologies allow easier rearrangement. The room typologies facilitate different types of adaptive capacity, and the results do not point at one of them as a single recommended design solution. Depending on what outcome is prioritised, various room typologies can increase certain types of adaptive capacity.

Regarding design solutions connected to room organisation, the results reveal that freestanding tall cupboard units are rare in contemporary apartment designs. This is in line with previous studies which showed that freestanding tall cupboard units are not favoured by end-users (Femenías and Geromel, 2019). Solutions such as designing a narrow pass-through kitchen at the entrance of the dwelling with reduced free floor area in front of the built-in furniture (Fig. 18a) limit possibilities both for rearrangement, reconfiguration, and expansion. Placing the kitchen in a location with less traffic zones, closer to the living and dining area, near to a window and with a dead-end room typology (Fig. 18b) creates increased possibility for functionality which might contribute to end-user satisfaction and reduce alterations in the future.

Creating appropriate room connections are also crucial for providing liveable spaces for the end-user and increasing floorplan adaptability. The apartment in Fig. 19a shows a room organisation where the fragmented spaces lead to reduced functionality. Furthermore, the bedroom (private area) is situated right next to the entrance, while the combined kitchen-living room (public area) is located at the back of the apartment. A remedy for this adverse room organisation could be as simple as interchanging the bedroom and bathroom with the combined kitchen-living room (Fig. 19b).

The majority of the apartments in this study are designed with a combined kitchen-living room, a design solution that enables expansion of the kitchen, which has also been previously recognised by Femenías and Geromel (2019). As earlier studies have shown, end-users are divided in their wish for either a separate kitchen or an open floorplan design (Femenías and Geromel, 2019; Tervo and Hirvonen, 2019). Therefore, it would be preferable to design combined kitchen-living rooms with the possibility of an easy separation. The results of this study reveal that not only kitchens in apartments larger than 55 m^2 have the possibility to be separated, which in fact is required by Swedish regulations, but also a high portion of apartments smaller than 55 m^2 are designed to be separable. This is enabled by the room organisation of the apartment and numerous windows well distributed along the façades. This indicates that architects already apply some design solutions that enable adaptability.

6.1.5. Kitchen typology and kitchen islands

The most common kitchen typologies among the studied apartment floorplans are straight- and L-kitchens. This coincides both with user wishes (Geromel, 2016; Thiberg, 2007) and stakeholder preferences (Ollár et al., 2020). This match between demand and supply can have a positive effect on optimising resource use and enabling a CE. For instance, by providing design solutions that align with end-user preferences, the number of extensive renovations with large material flows can be reduced.

The results reveal that kitchen islands are not planned for in contemporary apartment designs. However, previous studies showed that kitchen islands are a common addition to the built-in furniture when alterations are made (Femenías and Geromel, 2019). Therefore, it could be advantageous to provide space in floorplan designs to enable end-users to potentially install a kitchen island without compromising other spatial qualities, such as accessibility. As shown in Fig. 20, even an apartment of 47.6 m^2 can be designed in a way that leaves space for kitchen islands or for the rearrangement of the kitchen typology. This overcapacity of the floor area could further promote easy alterations of the kitchen depending on the changing needs and wishes of end-users and could also increase inhabitants' wellbeing and control over their spatial needs, which earlier studies have noted as an important value for end-users (Braide, 2019).

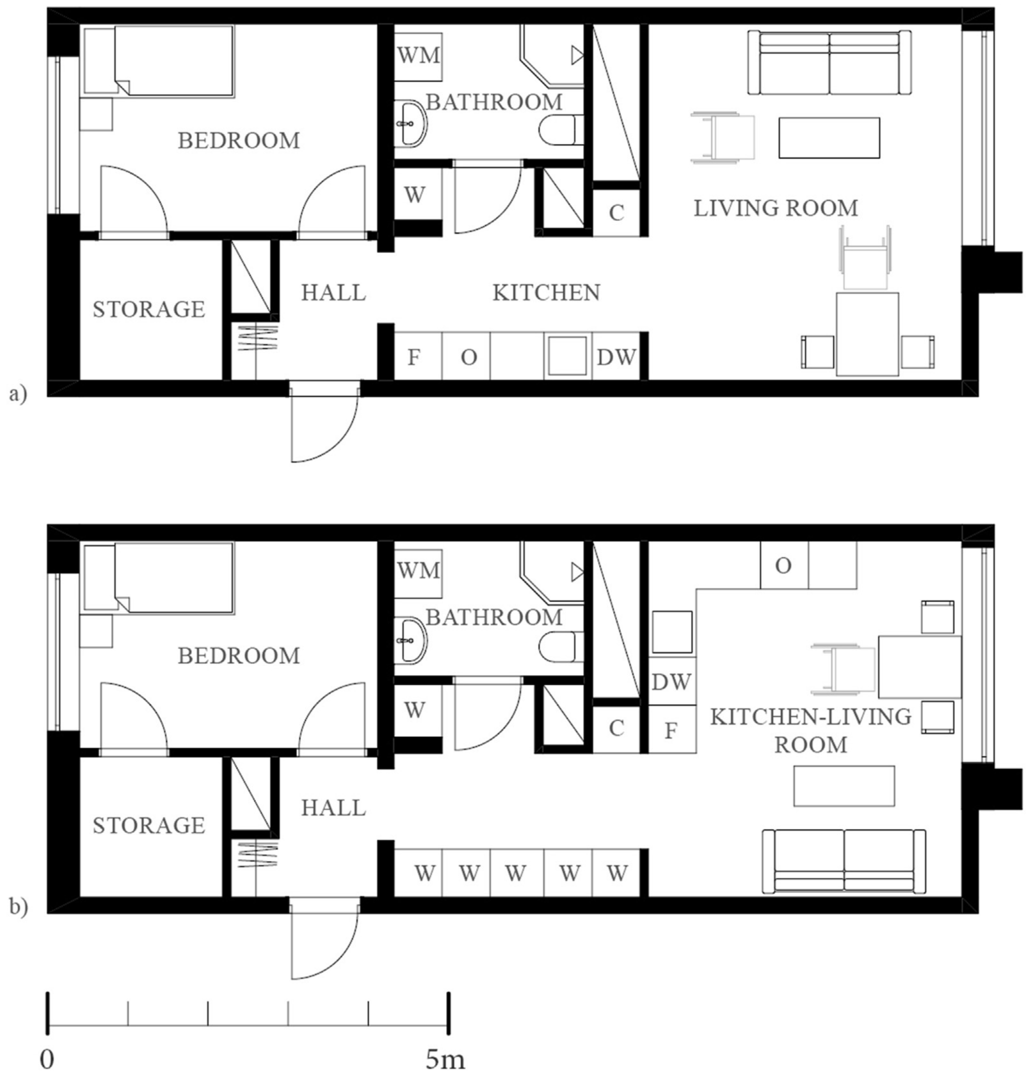

Fig. 18 Apartment floorplan (a) with narrow pass-through kitchen at the entrance (49 m^2; Source: illustration by Anita Ollár, original floorplan by Erséus Arkitekter) and (b) with a possible relocation of the kitchen to enable better room organisation and functionality (proposal by Anita Ollár). C: cupboard, DW: dishwasher, F: fridge and freezer, O: oven and stove, W: wardrobe, WM: washing machine.

6.2. Limitations and future research recommendations

This paper examined apartment floorplans in recently built Swedish multiresidential buildings. We acknowledge the limitations of this approach. First, due to the Swedish context, the studied apartment designs are defined by national legislation. For example, in Sweden the kitchen furniture and major appliances are delivered as part of the home, and there are strict regulations outlining the minimal equipment and dimensions regarding the space and built-in furniture; this might not be the case in other countries. Second, the Swedish context represents a specific case, even though similarities may exist in other Western societies. Third, the analysis focused on floorplans and hence on spatial characteristics that can be evaluated in two dimensions. As a result of this approach, spatial characteristics related to the third dimension (e.g., room height, window placements, artificial light positions, upper cabinets, technical installation of the plumbing and ventilation system) or requiring visual audit were not evaluated. The spatial analytical framework could be expanded with additional characteristics to capture and evaluate characteristics related to the third dimension.

As stated in the delimitations, this study focused on identifying the determinative spatial characteristics of kitchens in apartments and on evaluating these characteristics from an adaptability and circularity perspective. Further research is necessary to establish the exact dimensions and design of these spatial characteristics in order to create a new spatial configuration for kitchens that would better enable a CE in the built environment.

In this study, the adaptive capacity indicators of Geraedts et al. (2014) were adjusted and tested on a single

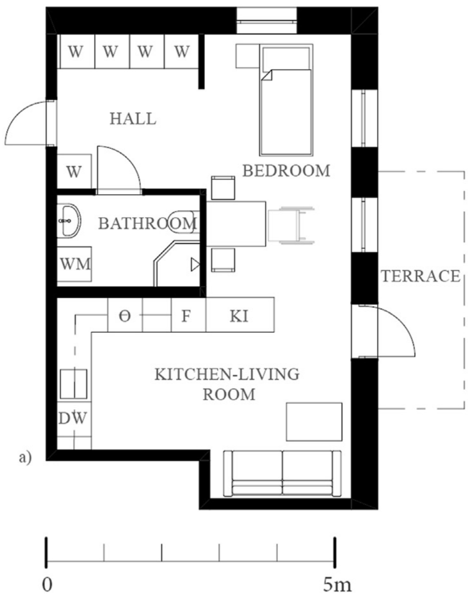

Fig. 19 Apartment floorplan (a) with an adverse initial room organisation (42 m^2; Source: illustration by Anita Ollár, original floorplan by White Arkitekter) and (b) with a possible rearrangement of the floorplan design (proposal by Anita Ollár). DW: dishwasher, F: fridge and freezer, KI: kitchen island, O: oven and stove, W: wardrobe, WM: washing machine.

function of buildings, the kitchen. The indicators showed great flexibility, and they appear to be an efficient method for measuring the adaptive capacity of a certain part of a

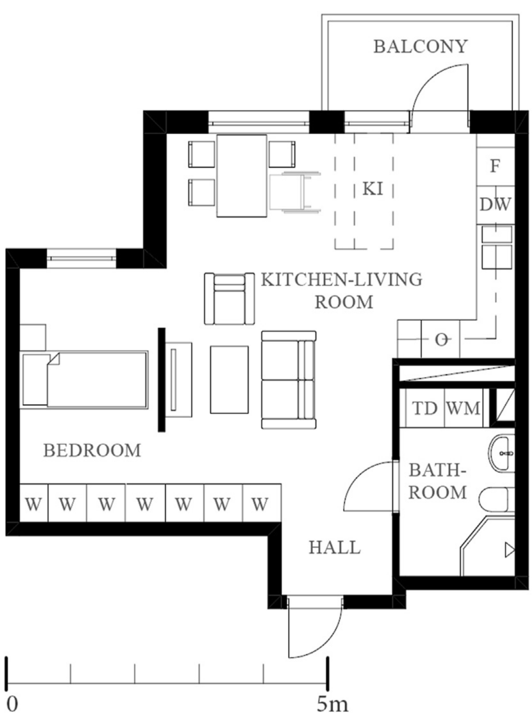

Fig. 20 Apartment floorplan (47.6 m^2) with free floor area for installing a kitchen island or reconfiguring the kitchen typology (Source: illustration by Anita Ollár, original floorplan by Tengbom). DW: dishwasher, F: fridge and freezer, KI: kitchen island, O: oven and stove, TD: tumble dryer, W: wardrobe, WM: washing machine.

building. The list of indicators and measured aspects could potentially be expanded and finetuned to assess a wider range of adaptive characteristics of space.

Another important aspect that needs to be investigated is the spatial experience of end-users. Heidrich et al. (2017) have emphasised that, in addition to the adaptive capabilities of building design, end-users' actions connected to dwelling alterations must also be considered. Additionally, future research may tackle questions that emerged from the present study such as the following: How should the identified spatial characteristics based on CE principles be designed? What spatial characteristics define other spaces of the home, and how can those spaces be designed based on CE principles?

The developed spatial analytical framework could be adjusted to assess other rooms or functions in floorplan designs. Doing so would enable an overarching analysis of the whole apartment and could potentially lead to a holistic design strategy for housing designs based on CE principles. These new design solutions must be evaluated and disseminated in architectural practices and aligned with production technologies and business models of the industry.

7. Conclusion

This paper examined 3624 apartment floorplans in recently produced multiresidential buildings in Gothenburg, Sweden. The paper's aim was to identify current architectural design solutions connected to the spatial configuration of the kitchen. These design solutions were then assessed for their inherent adaptability potential. The main contributions of this paper are its spatial analytical framework applied to a large sample of contemporary floorplans, its descriptive overview of contemporary kitchen and apartment designs, and the highlighted spatial characteristics that are important for adaptability and hence for a future circular kitchen design.

The results showed that the floor area of the apartment and the kitchen play important role for adaptability and circularity. In apartments larger than 55 m^2 and for kitchens larger than 10 m^2, design solutions enabling adaptability, fostering circularity and favoured by end-users are more often implemented. However, the analysis revealed that there are other spatial characteristics that improve the adaptive capacity and circularity potential of dwellings. These design solutions include numerous and well-distributed windows in the apartment, limited number of door openings in the kitchen, strategically placed traffic zones, centrally located shafts accessible from multiple rooms with windows, advantageous room typology and room organisation (e.g.: open kitchen-living rooms with the possibility to separate the rooms or outdoor spaces connected to the kitchen), and end-user favoured kitchen typologies (such as straight- and L-kitchens) which could further contribute to circularity by reducing the impact and extent of alterations.

This paper contributes to research on the adaptive capacity of buildings (and hence to circularity) with quantitative evidence on contemporary apartment designs. Adopted from Geraedts et al. (2014), four adaptive capacity indicators were measured: Rearrange, Reconfigure, Relocate, and Expand or reduce. The findings showed that current floorplans have a relatively good adaptive capacity: rearranging the kitchen is possible in 89% of all the studied apartments; reconfiguring the kitchen's room organisation by opening up or separating the kitchen is possible in 76% and 79% of the applicable apartments, respectively; and expanding or reducing the kitchen's floor area is possible in 76% of the apartments. However, the possibility of relocating the kitchen or reconfiguring its room organisation by opening or removing door openings is rather limited. These could be improved by strategically placing the shaft, traffic zones and door openings in the initial floorplan design with the aim of enabling alternative room organisation options.

In conclusion, to answer the question posed in the title of this paper, there is a need for a new design of kitchens. Although there are design solutions that support adaptability and circularity already applied by architects, we observed that these design solutions are employed not in a systematic way and probably not with the purpose of increasing adaptability or circularity in residential design. This was apparent in the results, which showed that it was possible to apply all four adaptive capacity indicators only in 23% of the apartments. Therefore, this papers' recommendation is that the identified design solutions should be used more consciously and in combination with each other. Further research is necessary to define the exact measures of the individual spatial characteristics and their combined application in multiresidential floorplan design.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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