THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Spatial Design for Circularity in Residential Buildings

Exploring the Case of the Kitchen

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Abstract

The building industry is responsible for a large portion of environmental impact, energy use and resource exploitation. There is a need to shift towards more sustainable building design solutions, which could be achieved by adopting circular design strategies. Currently, in the field of Circular Building Design (CBD), there is a primary focus on tackling end-of-life scenarios for buildings, such as construction and demolition waste management and reuse of building components. There has been little investigation on spatial design's contribution to CBD, despite earlier studies indicating its importance to a sustainable built environment. Additionally, there is a lack of investigations in the context of multi-residential buildings; previous works mainly focus on cities, neighbourhoods and other building typologies such as office and commercial buildings. Therefore, this thesis complements the existing knowledge on CBD and expands the discussion on transitioning from a linear to a circular approach in the design, construction and utilisation of multi-residential buildings through studies exploring spatial design's contribution to circularity.

This thesis includes qualitative and quantitative studies exploring stakeholder perspectives and the physical manifestation of spatial design. The studies take a starting point in analysing the kitchen as an eminent function of the home. Studies 1 and 2 investigate stakeholders' processes and preferences connected to the design, construction, utilisation and alteration of the kitchen's spatial design. Study 3 focuses on assessing the circular potential of spatial design of kitchens in contemporary apartment floorplans by identifying and evaluating spatial characteristics as determining aspects of space. Study 4 broadens the scope and investigates currently applied circular design strategies in multi-residential buildings with a particular focus on adaptability features.

The results show that spatial design could contribute to circularity by keeping resources in their current utilisation at their highest value and reducing resource flows resulting from spatial alterations (narrowing and slowing the loops). This can be achieved through implementing functional and adaptable solutions in the spatial design of buildings. The results, however, reveal that current spatial design solutions have shortcomings regarding functionality and adaptability due to the segmented stakeholder network and the down-prioritisation of end-user preferences and adaptable spatial design in multi-residential buildings. To overcome these shortcomings, the results indicate a need for renewed housing research directly informing regulations that foster circularity in the building industry.

The thesis' specific contributions include insights into stakeholder processes and preferences for kitchen design, spatial design recommendations and discussions on the importance of functionality and adaptability for CBD. To support knowledge development in the field of CBD, this thesis also provides methodological pathways, analytical and design frameworks and aspects of contextual challenges regarding the spatial design of multi-residential buildings. In conclusion, this thesis advocates for incorporating adaptable standard design requirements into CBD approaches, ensuring functionality and ease of adaptation in the short- and long-term. Additionally, this thesis identifies the need for enhanced collaboration among stakeholders in the building industry and expanded evaluation and implementation of end-user preferences related to the design of their dwellings.

Keywords: Circular building design, Spatial design, Functionality, Adaptability, Kitchen

Sammanfattning

Byggbranschen står för en stor del av miljöpåverkan, energianvändning och resursutnyttjande. Det finns ett behov av att ställa om till mer hållbara lösningar, vilket skulle kunna uppnås genom att implementera cirkulära designstrategier. Inom området cirkulär byggnadsdesign (CBD) är det för närvarande primärt fokus på omhändertagande av bygg- och rivningsavfall och återanvändning av byggnadskomponenter. Det har genomförts få detaljerade undersökningar av den rumsliga gestaltningens bidrag till CBD, trots att tidigare studier pekar på dess betydelse för skapandet av en hållbar byggd miljö. Dessutom finns det brist på utredningar gällande CBD i flerbostadshus; tidigare arbeten fokuserar främst på städer, stadsdelar och andra byggnadstypologier. Därför kompletterar denna avhandling den befintliga kunskapen om CBD och bidrar till att utöka diskussionen om övergången från linjära till cirkulära processer inom design, konstruktion och utnyttjande av flerbostadshus, genom studier som utforskar rumslig gestaltnings bidrag till cirkularitet.

Denna avhandling inkluderar kvalitativa och kvantitativa studier som utforskar olika intressenters perspektiv och den fysiska manifestationen av rumslig gestaltning. Studierna tar utgångspunkt i att analysera köket som en eminent funktion i hemmet. Studie 1 och 2 undersöker olika intressenters processer och preferenser kopplade till design, konstruktion, utnyttjande och förändring av kökets rumsliga utformning. Studie 3 fokuserar på att bedöma den cirkulära potentialen i rumslig gestaltning av kök i bostadslägenheter genom att identifiera och utvärdera rumsliga egenskaper som avgörande aspekter av utrymme. Studie 4 breddar studiens omfattning och undersökte nuvarande tillämpade cirkulära designstrategier i flerbostadshus med särskilt fokus på anpassningsförmåga.

Resultaten visar att rumslig gestaltning skulle kunna bidra till cirkularitet genom att hålla resurserna i sina nuvarande utnyttjande och därmed på sina högsta värde, samt minska resursflöden till följd av rumsliga förändringar. Detta kan uppnås genom att implementera funktionella och anpassningsbara lösningar i den rumsliga utformningen av byggnader. Resultaten avslöjar dock även att nuvarande designlösningar har brister vad gäller funktionalitet och anpassningsförmåga på grund av det fragmenterade nätverket av intressenter samt nedprioriteringen av både slutanvändarnas preferenser och av anpassningsbar rumslig gestaltning i planeringen av flerbostadshus. För att komma till rätta med dessa brister, tyder resultaten på ett behov av nya områden inom bostadsforskning som direkt informerar och bidrar till att utveckla de regelverk som främjar cirkularitet inom byggbranschen.

Avhandlingens specifika bidrag är insikter i olika intressenters processer och preferenser gällande köksutformning, rekommendationer för rumslig gestaltning och diskussioner om vikten av funktionalitet och anpassningsförmåga för CBD. För att stödja kunskapsutvecklingen inom CBD presenterar denna avhandling även metodologiska verktyg, analytiska och designmässiga ramar samt kontextuella utmaningar gällande utformningen av flerbostadshus. Sammanfattningsvis förespråkar denna avhandling för införliva krav på anpassningsbara standard designlösningar i CBD-metoder, vilket säkerställer funktionalitet och enkel anpassning på kort och lång sikt. Dessutom identifierar denna avhandling behovet av förbättrat samarbete mellan intressenter inom byggbranschen och utökad utvärdering och implementering av slutanvändares preferenser relaterade till deras bostäder.

Nyckelord: Cirkulär byggnadsdesign, Rumslig gestaltning, Funktionalitet, Anpassningsförmåga, Kök

A családomnak | Till min familj | À ma famille | To my family:

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Included publications

PAPER A

[Journal Paper] Ollár, A.; Femenías, P.; Rahe, U.; Granath, K. (2020) *Foresights from the Swedish kitchen: Four circular value opportunities for the built environment.* Sustainability, 12(16), 6394. DOI 10.3390/su12166394

Contributions: The workshop was carried out by the research group of the CIK project (including A.O., P.F. and U.R.). The interviews were planned and performed by A.O. and P.F. The focus group session was organised and carried out by P.F. and U.R. The analysis of the empirical material was conducted by A.O. The four authors developed the paper's outline together. The writing process was led by A.O. As supervisors, P.F., U.R. and K.G. reviewed and edited the paper.

PAPER B

[Conference Paper] Ollár, A.; Femenías, P.; Granath, K.; Hagejärd, S. (2022) *Determining spatial characteristics for CBD: The case of kitchen alterations*. IOP Conf. Ser.: Earth Environ. Sci. 1085, 012065. DOI 10.1088/1755-1315/1085/1/012065

Contributions: The interviews were planned and performed by A.O. and S.H. with the supervision of P.F. The analysis of the empirical material was conducted by A.O. The conceptual outline of the paper was developed by A.O., P.F. and K.G. The writing process was led by A.O. and P.F., K.G. and S.H. reviewed and edited the paper's content.

PAPER C

[Journal Paper] Ollár, A.; Granath, K.; Femenías, P.; Rahe, U. (2022) *Is there a need for new kitchen design? Assessing the adaptative capacity of space to enable circularity in multiresidential buildings.* Frontiers of Architectural Research, Volume 11, Issue 5, Pages 891-916 DOI 10.1016/j.foar.2022.03.009

Contributions: K.G. provided the documentation on the housing projects. A.O. reviewed and sampled the material, identified the spatial characteristics, developed the analytical framework and performed the analysis. K.G. advised on ambiguous decisions related to the floorplan study. The four authors collectively developed the conceptual outline of the paper. The writing process was led by A.O. As supervisors, P.F., K.G. and U.R. helped fine-tune the analytical framework and reviewed and edited the paper's content.

PAPER D

[Journal Paper] Ollár, A. (2024) *Circular building adaptability in multi-residential buildings – The status quo and a conceptual design framework.* International Journal of Building Pathology and Adaptation, Vol. 42 No. 7, pp. 1-17. DOI 10.1108/IJBPA-08-2023-0110

Contributions: A.O. planned the study, conducted the interviews and analysed the empirical material. A.O. developed the conceptual outline of the paper and wrote the manuscript. P.F. gave feedback on the manuscript before submitting it to the journal. A.O. edited and finalised the paper following the journal's review process.

Additional publications and conference contributions

[Licentiate Thesis] Ollár A. (2021) *Spatial design for circularity - Exploring spatial aspects in housing design with focus on the kitchen,* Gothenburg, Chalmers University of Technology

[Journal Paper] Hagejärd, S.; Ollár, A.; Femenías, P.; Rahe, U. (2020) *Designing for circularity - Addressing product design, consumption practices and resource flows in domestic kitchens.* Sustainability, 12, 1006. https://doi.org/10.3390/su12031006

[Conference Presentation] Ollár, A.; Femenías, P.; Rahe, U. (2019) *What shaped the Swedish kitchen? A historical overview to plan for further development.* NAF Symposium 2019 in Gothenburg - Approaches and Methods in Architectural Research, 13-15 June 2019, Gothenburg, Sweden.

[Conference Presentation] Ollár, A.; Bengtsson, M.; Femenías, P. (2019) *The kitchen of the future through an academic lens: An architectural thesis project's knowledge contribution to academic research.* The 11th Annual Symposium of Architectural Research, 3-4 October 2019 Tampere, Finland.

[Extended Abstract] Andersson, S., Ollár, A., Femenías, P., & Rahe, U. (2018). *Retrofitting from the inside/insight perspective: Adapting to users' needs with the kitchen as a starting point.* Retrofit Europe! Innovation Meets Market SBE19 Conference, 5-6 November 2018, Eindhoven, The Netherlands.

Glossary and Abbreviations

Term	Definition or explanation
Adaptability	"[T]he inherent properties in a building that gives [sic] it the ability to change or the relative ease with which it can be changed" (Heidrich et al., 2017, p.287)
Adaptive capacity	A metric to measure a building's ability "[…] to cope with future changes with minimum demolition, cost and waste and with maximum robustness, mutability and efficiency" (Sinclair et al., 2012, p.40)
Circular building	Buildings designed, planned, built, operated, maintained and deconstructed while minimising resource use, waste and emissions by systematically applying value retention processes to slow, narrow and close loops in the associated technical, business and industrial models throughout the entire lifespan of the buildings (inspired by previous definitions such as in Geldermans et al., 2019b; Leising et al., 2018; Pomponi & Moncaster, 2017)
Circular building adaptability	"[T]he capacity to contextually and physically alter the built environment and sustain its usefulness while keeping the building asset in a closed-reversible value chain" (Hamida et al., 2022, p.61)
Circular building design	A design approach that supports the development of circular buildings (following the definition of circular buildings)
Circular design	[verb]: The process of conception or creation of products and services for a circular economy and [noun]: the outcome of this process
Circular economy	A regenerative system that replaces the 'end-of-life' concept for resources by slowing, closing and narrowing loops through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing and recycling in production, distribution and consumption processes to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity to the benefit of current and future generations (based on Geissdoerfer et al., 2017 and Kirchherr et al., 2017)
Circular potential	The accumulated capacity of products or services that contributes to optimising the value retention loops throughout the entire lifespan of said products or services
Combined kitchen-living room	A room that includes the kitchen and living room in one open space
End-user	People inhabiting and using residential buildings and, within that, kitchens
Floorplan	The two-dimensional depiction of the spatial design of a dwelling
Functionality	The quality of being useful, practical and suitable for the purpose of a function of the dwelling (e.g., the kitchen) for diverse individuals and groups of end-users forming various household types (inspired by the definition of functionality of the Cambridge Business English Dictionary, 2024)
Kitchen	The three-dimensional enclosure of the space in which activities associated with the kitchen occur (e.g., food storage and preparation, dining, social activities)
Kitchen typology	The layout of the built-in furniture that influences the spatial use and experience of the room (straight-kitchen, L-kitchen, parallel-kitchen, U-kitchen) (based on Krantz-Jensen, 1963)
Room typology	As defined in Hillier (2007): A: 'dead-end' room; B: 'pass-through' room; C: room in a single ring; or D: room that is part of more than one ring

Term	Definition or explanation
Services	A shearing layer of a building composed of "components that supply and transport physical flows" (e.g., electricity, plumbing, ventilation) (Schmidt & Austin, 2016, p.55)
Skin	A shearing layer of a building composed of components that constitute the envelope of a building (e.g., façade and roof elements) (based on Schmidt & Austin, 2016)
Spatial characteristic	Determinants of a spatial unit (e.g., room) or dwelling function (e.g., kitchen) that influence how it may be used, furnished and experienced (e.g., size, length and width of room, door and window openings, fixed equipment, infrastructure outlets)
Spatial design	[noun]: The design of components of the shearing layers that shape the spatial enclosure of a specific dwelling function, thereby influencing the activities that occur in this space (inspired by Schmidt & Austin 2016, p.55)
Space plan	A shearing layer of a building composed of "components that enclose the spaces users inhabit" (Schmidt & Austin, 2016, p.55)
Structure	A shearing layer of a building composed of "components which support the primary transferring of vertical loads and horizontal bracing" (Schmidt & Austin, 2016, p.55)
Stuff	A shearing layer of a building. "Components/objects that reside inside the space users inhabit" (Schmidt & Austin, 2016, p.55)
Stakeholder	Actors connected to the commission, design, construction and utilisation of buildings or dwelling functions (such as the kitchen). In this thesis, stakeholders include housing developers (and their suppliers), housing managers, architects, kitchen furniture producers, contractors, real estate brokers and end-users
Value mapping	A method to identify three types of values: value captured, value missed, destroyed or wasted and value opportunities (Bocken et al., 2013)
Work surface	Horizontal surfaces at a comfortable height, used for processing and preparing food (e.g., free countertop surfaces or additional tables in or close to the kitchen)
Workstation	Units forming part of the built-in furniture with designated work functions (sink, stove, fridge and work surface)

Abbreviation	Meaning
BBR	Boverkets byggregler (Boverket's Building Regulations) Boverket: the Swedish National Board of Housing, Building and Planning
CBD	Circular Building Design
CE	Circular Economy
CIK	Circular Kitchen (project)
EU	European Union
HFI	Hemmets Forskningsinstitut (the Home Research Institute)
PBF	Plan- och byggförordningen (the Swedish Planning and Building Ordinance)
PBL	Plan- och bygglagen (the Swedish Planning and Building Act)
RQ	Research Question

Table of Contents

1. Introduction

The linear model of 'take-make-dispose' of the building industry contributes to the premature obsolescence of still-functioning building products and components (Arora et al., 2020). Through this model, the building industry is responsible for 40% of the global virgin material extractions, 30% of greenhouse gas emissions and 40% of the waste worldwide (Ness & Xing, 2017). The concept of Circular Economy (CE) (a set of closed reversible loops for value retention of resources) has been seen as a potential tool for achieving sustainability and addressing issues resulting from the linear processes of the building industry (Hossain & Thomas Ng, 2019; Manninen et al., 2018; Nußholz et al., 2020; Pomponi & Moncaster, 2017). In contrast to the linear model, the concept of CE enables value retention of resources through narrowing, slowing and closing loops (Bocken et al., 2016). This means reducing resource use, preserving resources in their current utilisation and retrieving resources at the end of their service life (Bocken et al., 2016).

Implementing CE principles in the building industry can contribute to environmental, social and economic sustainability. Beyond decreased virgin material extraction and environmental pollution (Hossain & Thomas Ng, 2019; Manninen et al., 2018; Nußholz et al., 2020), implementing CE principles can increase well-being and equality (Su et al., 2013) and can foster new businesses, job opportunities and increased revenues (Ellen MacArthur Foundation, 2015). Recognising the benefits of CE, governmental bodies formulated policies and regulations. For instance, the European Union (EU) puts a significant emphasis on more circular processes through the European Green Deal (European Commission, 2019) and the Circular Economy Action Plan (European Commission, 2020). Such policies and regulations are meant to guide the transition towards circular design of products and production processes through establishing legislative support. Policies and regulations encouraging circularity have been recognised as crucial in overcoming barriers and nudging the shift towards a CE (Genovese et al., 2017; Pomponi & Moncaster, 2017). However, recent reports show that despite the growing initiatives, the global circularity rate is dropping (Circle Economy, 2023) and the EU's CE activities only increased by 0.4% between 2015 and 2021 (European Court of Auditors, 2023). This is due to a magnitude of obstacles hindering the transition to CE. For instance, ownership questions, a lack of integration of sustainability strategies and 'uncertain aftermaths' of CE implementations are primary barriers in the building industry (Mahpour, 2018). Eberhardt et al. (2019) also found that complex and extended supply chains, profit-oriented short-term goals, a lack of standardised methods and unknown future circumstances contribute to the challenges.

To accelerate the uptake of the CE concept in the building industry, there is an expanding body of research developing novel design guidelines, strategies, frameworks, tools and methods for Circular Building Design (CBD) (Hossain & Thomas Ng, 2019). However, these academic contributions often remain theoretical and their adoption into practice is limited (Dokter et al., 2021). Additionally, in current CBD literature, there seems to be a focus on larger scales, such as cities and neighbourhoods, while the building context is receiving less attention (Pomponi & Moncaster, 2017). This implies a need for more detailed studies of buildings and their specific characteristics and impacts. The literature also indicates that actionable knowledge of circularity in the building context is increasingly important (Cambier, 2022; Kozminska, 2019; van Stijn, 2023).

Within the building context, residential buildings are responsible for a high environmental impact. The growing global population and the shift from rural to urban areas have led to a surge in demand for housing in urban regions (United Nation, 2019). This increasing demand exerts pressure on resource extraction and utilisation (Ness & Xing, 2017), leading to increased greenhouse gas emissions and soil, air and water pollution (Rockström et al., 2009). Given these challenges, a shift towards more sustainable practices in the design and construction of residential buildings is needed.

Previous literature investigated how design professionals adopt and apply design for circularity in the building context (Dokter et al., 2021; Kozminska, 2019). Their findings show a strong focus on designing and building with reclaimed building materials and components (Kozminska, 2019) and reusing construction waste (Dokter et al., 2021). These approaches are perceived as an easy way to incorporate circularity in building design (Dokter et al., 2021). However, a building is not only the sum of the physical elements (building materials and components). The non-physical and social components of space are of utmost importance for residential building design (Jager, 2002; Nylander, 2002; Schmidt & Austin, 2016). For instance, how a building's interior spatial design is initially defined, preconditions its utilisation, maintenance, adaptation and end-of-life treatment (Cheshire, 2021). Current explorations in connection to CBD lack a consideration of how the spatial design is affected by the concept of circularity and - vice versa - how prerequisites of the determinants of a spatial unit or dwelling function (spatial characteristics) influence CBD. Therefore, this thesis focuses on exploring spatial design's role and contribution towards circularity in residential buildings. The aim is to investigate how spatial design can facilitate a transition from a linear to a circular approach, not just in the design phase but also in the construction and utilisation phases of residential buildings. In addition, this thesis contributes to the broader knowledge development in the field, enriching the academic and practical discourse around sustainable building design.

To study the contribution of spatial design in supporting circularity in residential buildings, this thesis takes its starting point in analysing the spatial design of kitchens. The kitchen, while being a crucial part of the home as a hub for food-related and social activities (Willén, 2012), also has a significant impact on resource use (Energy Saving Trust, 2013; Hagejärd et al., 2020), is subject to frequent alterations and renovations (Hand et al., 2007; Judson et al., 2014; Maller et al., 2012), resulting in increased material flows (Femenías et al., 2018). It has been estimated that premature kitchen renovations contribute to about 57% of the total climate impact (measured in CO_2 equivalent over a 15-year period) of internal alterations and maintenance of condominiums (Femenías et al., 2018). Moreover, discarded kitchen furniture makes up about 25% of the EU's annual furniture waste of 10 million tonnes, with only 10% being recycled and the rest being incinerated or dumped in landfills (Forrest et al., 2017).

As a function, the kitchen is a space that accommodates various activities such as storing and preparing food, dining, sorting household waste, remote working, performing hobbies and socialising (Hagejärd et al., 2020; Sjöstrand, 2018; Willén, 2012). Furthermore, the kitchen is also a space for storing and utilising an increased amount of stuff (furniture, appliances, kitchenware, utensils, etc.) (Marco, 2022). To provide a functional space sufficient for the activities and stuff of the kitchen, it must be designed with attention paid to spatial design aspects such as room connections, door and window placements, ceiling

height, natural and artificial lighting and infrastructure outlets (Thiberg, 2007). This space also incorporates various built-in and mobile furniture and appliances, which must be arranged efficiently for a smooth workflow (Ranney, 1949). The possibilities for such arrangements are predetermined by the spatial design of the room. Hence, the complexity lies in defining spatial design aspects that accommodate the activities and the stuff stored and utilised within the space. This involves lengthy decision-making and problem-solving processes among the various stakeholders. Consequently, exploring the case of the kitchen allows for a comprehensive examination of the connected stakeholder processes and perspectives as well as the physical manifestation of spatial design.

1.1. Research questions and aim

The overall aim of this PhD research is to contribute to the knowledge development and the discussion on transitioning from a linear to a circular approach in the design, construction and utilisation of residential buildings. This is done by exploring spatial design and its contribution to circularity through three Research Questions (RQs), as shown in Table 1.

The RQs are investigated in four studies. Studies 1, 2 and 4 explore stakeholder processes and preferences concerning the design, construction, utilisation and alteration of residential buildings. Study 3 focuses on the physical manifestation of spatial design to identify its determining characteristics and assess their circular potential with input from the identified stakeholder preferences. Studies 1, 2 and 3 examine one dwelling function, the kitchen. Study 4 complements the first three studies by broadening the scope of the investigation to the overall building scale. The contribution of the four studies to the RQs is further explained in Chapter 4.

Table 1 – Summary of the RQs addressed in the thesis

Research Questions (RQs)		**Contributing Studies**
RQ1	How could spatial design contribute to circularity in residential buildings?	Studies 1-2-3-4
RQ2	What are the gaps in the current spatial design solutions of residential kitchens when assessing their circular potential?	Studies 1-2-3
RQ3	How could stakeholder processes related to spatial design enhance circularity in residential buildings?	Studies 1-2-4

1.2. Definitions of terms

In this thesis, specific terms are employed with distinct meanings, mostly introduced in relation to their associated concepts. The Glossary and Abbreviations chapter also provides a comprehensive collection of the most important terms. This includes not only those related to specific concepts but also terms crucial to define for understanding the content of this thesis. However, the terms ‘spatial design’, ‘kitchen’ and ‘functionality’ warrant special attention. These terms are used in a context-specific manner that forms the foundation of this thesis. The distinct meanings of these three terms are explained in the following.

In this thesis, spatial design is interpreted within the context of interior environments, referring specifically to the artefact rather than the process of design(ing). Drawing inspiration from the concept of shearing layers and their definitions (Schmidt & Austin, 2016,

p.55), spatial design is defined as the design of components of the shearing layers that shape the spatial enclosure of a specific dwelling function, thereby influencing the activities that occur within this space. Certain components of the layers of skin, structure, services, space plan and stuff determine how a dwelling function can be inhabited, utilised and altered over time (elaborated on in Sub-chapter 2.3.1). Traditionally, vertical and horizontal structures constitute the boundaries of a spatial enclosure (von Meiss, 2013). However, in multifunctional spaces (such as combined kitchen-living rooms), the boundaries are more fluid and difficult to define.

The kitchen, as a term, can be understood both as a dwelling function and a collection of furniture. To distinguish between these two meanings, in this thesis, the term kitchen refers to the space of the function and the term built-in and mobile furniture refers to the furnishing. This thesis acknowledges that the kitchen is a highly specific dwelling function in terms of its utilisation, the required infrastructure (electricity, plumbing, ventilation) and connected building regulations (the Swedish building regulations regarding kitchen design are highly programmed – explained in Sub-chapter 3.1). Therefore, in this thesis, the term kitchen is understood as the three-dimensional enclosure of the space (along with the connected infrastructure) in which activities associated with the kitchen occur.

Functionality refers to the quality of being useful, practical and suitable for the purpose of a dwelling function (e.g., the kitchen) for diverse individuals and groups of end-users forming various household types (inspired by the definition of functionality of the Cambridge Business English Dictionary, 2024). The kitchen's purpose can vary among individuals and groups of end-users depending on the activities performed in the space. As described earlier, nowadays, the activities occurring in the kitchen go beyond storing, preparing and consuming food. These activities include socialising with guests and household members, remote working, performing hobbies, playing with kids, sorting household waste or composting (Hagejärd et al., 2020; Sjöstrand, 2018; Willén, 2012). How the space of the kitchen is designed and furnished influences and is influenced by these activities. Therefore, it is increasingly important to explore how kitchens enable functionality and accommodate the expanding range of previously non-dominant activities.

1.3. Scope of research

This research is situated at the intersection of the domains of architecture and circularity, explicitly contributing to CBD by examining spatial design in supporting circularity in the building context. The primary subject of the explorations is residential buildings, more specifically, spatial design solutions contributing to circularity in multi-residential buildings. On the one hand, the research focuses on multi-residential buildings because of their high representation among residential buildings; rental and owner-occupied apartments represent 52% of the Swedish housing stock (Statistics Sweden, 2023). On the other hand, the design, construction and utilisation of multi-residential buildings involve a wide range of stakeholders, which provides a relevant case for examining the complex processes, preferences and reasonings related to spatial design. Moreover, dwellings in multi-residential buildings are often designed for unknown inhabitants, resulting in standardised design solutions that lack the possibility to be adapted to diverse end-user needs (Marco et al., 2021; Saarimaa & Pelsmakers, 2020). Additionally, housing developers tend to maximise their profits by constructing the most dwelling units with the smallest possible floor areas

on a specific plot of land (Marco et al., 2021; Saarimaa & Pelsmakers, 2020). These challenges are intriguing issues regarding transitioning to circularity in the context of multi-residential buildings. Nevertheless, the studies also include other types of residential buildings (villas, terraced houses) where end-users are more in control of their dwelling environment. This aimed to help understand and identify stakeholder preferences, which could be translated into multi-residential building design.

The work is situated in Sweden (the specificities of the Swedish context are explained in Chapter 3). The long tradition of housing and kitchen research in Sweden provided a foundation of knowledge to build upon and contribute to. Between the 1930s and 1990s, state-funded research focused on improving dwelling conditions by studying end-users' interaction with their space, furniture and utensils (Göransdotter & Redström, 2018). These studies resulted in functional requirements and adequate measurements for spatial and furniture design, which directly informed standards and regulations still in use today (BFS 2011:6). Exploring this thesis' topic in the Swedish context allowed expanding the well-established knowledge by analysing spatial design's contribution to a new circular paradigm.

As outlined in the introduction, spatial design's contribution to circularity in residential buildings is studied through the case of the kitchen. The spatial specificity of this dwelling function and the socio-cultural context (of the Swedish kitchen) delimited the generalizability and transferability of the results. To address this, Study 4 broadens the research scope to include aspects of spatial design for circularity at the building level and explores a broader European/Western context. Another delimitation is that the research focuses on design aspects and includes perspectives of key actors of the stakeholder network but does not address considerations of economic and business models in depth. Additionally, this thesis focuses on residential buildings and does not include other building typologies such as office buildings, commercial buildings or healthcare facilities.

The thesis employs an architectural perspective in investigating spatial design in residential buildings. Hence, the primary audience of this thesis is architects engaged in housing design or research. The results and recommendations of this thesis are also relevant for housing developers as clients of the architects and managers of buildings. Additionally, considering the recent changes proposed to the Swedish building regulations (Boverket, 2020), this thesis should be of interest to legislative bodies and policymakers providing input for the formulation of functional requirements regarding the spatial design of residential buildings. Furthermore, the kitchen-specific results and discussions provide insight for manufacturers and building product developers. Finally, (my sincere hope is that) the results of this research can guide the general public (as end-users) to adopt more sustainable behaviour patterns to reduce the environmental, economic and social impacts of everyday domestic life.

1.4. Project context

This thesis was carried out in the Circular Kitchen (CIK) project. The CIK project aimed to develop innovative solutions for designing, testing and distributing circular kitchen furniture that is made of renewable and recyclable materials, easy to repair, refurbish, assemble and disassemble, reduces resource use, consumption and waste generation and is economically competitive with current products. The project involved theoretical knowledge-building, prototyping and testing new CE-based kitchen furniture designs and business models. The

project was conducted in collaboration with academic (TU Delft) and industry partners (housing developers, kitchen furniture producer, appliance producer) in a transdisciplinary setting, involving researchers and practitioners from architecture and product design.

As part of the CIK project, five doctoral students (including me) were conducting their research studies (three in Sweden at Chalmers University of Technology and two in the Netherlands at TU Delft) under the guidance of a group of senior researchers. Each thesis had a different focus, but all were connected to the shared goal of developing circular design solutions. The research areas of the five theses complemented each other, contributing to the knowledge in overlapping areas of CBD. My role was to explore the spatial design of kitchens to identify key characteristics and their potential to support circularity in residential buildings. The other doctoral students studied user behaviour patterns related to resource use in the kitchen (Hagejärd, 2020), the role of collaboration in developing circular design solutions (Dokter, 2023), the development of design and life cycle assessment tools and stakeholder preferences towards circular building components (van Stijn, 2023) and financial and business models related to circular kitchen design (Wouterszoon Jansen et al., 2020; Wouterszoon Jansen et al., 2022a, 2022b). The academic collaboration between the junior and senior researchers of the two universities resulted in multiple co-authored publications.

The CIK project served as a data collection opportunity for my research. The initial partner workshops helped me to understand kitchen-related processes and stakeholder networks, which provided input for Study 1. The end-user studies performed in collaboration with the other doctoral students revealed insights into stakeholder design preferences (the subject of exploration in Study 2). My other investigations (Studies 3-4) were carried out in parallel with the activities of the CIK project. My study results provided input for the development of the furniture design.

1.5. Reading instruction and outline of the thesis

This PhD thesis builds on and continues the research published in my Licentiate thesis (Ollár, 2021). In Sweden, a Licentiate degree is recognised as a pre-doctoral degree and is awarded to doctoral students after completing approximately half of their doctoral study (SFS 1993:100). My Licentiate thesis included the circular value assessment of the design preferences of industry stakeholders (Study 1 - Paper A) and the preliminary results of the kitchen floorplan analysis focusing on the adaptive capacity (as a measure of circular potential) of the spatial design (Study 3 - Paper C). This dissertation complements the work of the Licentiate thesis by including end-user preferences regarding the spatial design of kitchens (Study 2 - Paper B) and exploring adaptability (as a key element of spatial design supporting circularity) within applied circular design strategies in residential buildings (Study 4 - Paper D). This PhD thesis synthesises the results of the four studies while situating the work within the existing literature, explaining methodological choices and discussing the results in a broader context than the papers allowed for.

The thesis is structured as follows. Chapter 1 introduces the primary motivation behind the thesis work and presents the research question, aim, scope and project context. Chapter 2 describes the research field, presents definitions and concepts connected to circular economy, circular buildings and CBD and outlines theoretical considerations. Chapter 3 summarises the specificities of the Swedish context and kitchen design. Chapter 4 explains

the intersubjective research approach, the two-phased research design and the qualitative and quantitative (mixed) methods employed in the thesis. In Chapter 5, the results of Studies 1-4 are briefly reviewed and the validation of the key results is summarised. In Chapter 6, the research questions are answered by discussing the results in relation to the literature. Chapter 7 highlights the main contributions and conclusions of the thesis and identifies further research pathways. The four papers (Paper A-D) are appended at the end of the booklet.

2. Background

This chapter introduces relevant literature on CBD. First, the definition of the CE concept (as adopted in this thesis) and related fundamental principles (closed reversible loops, value creation and retention, integral approach) are explained. Second, the interpretation of circularity in the built environment and the definition of circular buildings are outlined. Third, concepts and strategies supporting CBD are presented. This is followed by an overview of the societal and behavioural dimensions of a circular built environment. Finally, the theoretical considerations that form the methodological foundation of this thesis are explained.

2.1. Circular economy and its fundamental principles

As the concept of CE gained increasing interest, an abundance of interpretations of the meaning of CE became available (Blomsma & Brennan, 2017). In this thesis, two CE definitions are used in combination. While the definition of Kirchherr et al. (2017) captures CE's contribution to sustainability, it focuses exclusively on material cycles. The CE definition of Geissdoerfer et al. (2017) compliments the one of Kirchherr et al. (2017) by expanding the focus to resources in general, including the concept of slowing, narrowing and closing loops and broadening the examples of the value retention processes. Therefore, the combination of these two definitions provides an adequate interpretation of CE for the subject of this thesis:

> *The circular economy is a regenerative system that replaces the 'end-of-life' concept for resources by slowing, closing and narrowing loops through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing and recycling in production, distribution and consumption processes to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations.*

A growing body of research is examining the contribution of CE to sustainable development (Merli et al., 2018). A significant portion of this research draws upon the work of the Ellen MacArthur Foundation (2013) which lays out the core principles of a CE: a set of closed reversible loops for technical and biological materials (Figure 1). The work of the Ellen MacArthur Foundation builds on previous concepts, such as the self-replenishing system (Stahel, 1982), biomimicry (Benyus, 1997), cradle-to-cradle (McDonough & Braungart, 2002), industrial symbiosis (Ayres & Ayres, 2002), regenerative design (Hes & Du Plessis, 2015) and eco-design (Anastas & Zimmerman, 2003; Brezet et al., 1997; Ricard et al., 2023). The primary goals of these concepts – including CE – are to keep resources in their original utilisation at their highest value as long as possible and, afterwards, at the end-of-life, recirculate resources to eliminate waste (den Hollander et al., 2017; Ellen MacArthur Foundation, 2015; Webster, 2017).

A fundamental approach to managing resources in a CE is establishing narrowing, slowing and closing loops (Bocken et al., 2016). Narrowing the loops reduces the amount of resources used throughout the lifetime of a product. Slowing loops keep resources in their current function by mending them if needed until they can no longer fulfil their designated

purpose. Once resources reach their end of life, it is crucial to implement closing loops to retrieve valuable resources and recycle them into new products. Narrowing, slowing and closing loops can be facilitated through value retention processes such as the ones summarised by the 9R framework of Potting et al. (2017): refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover.

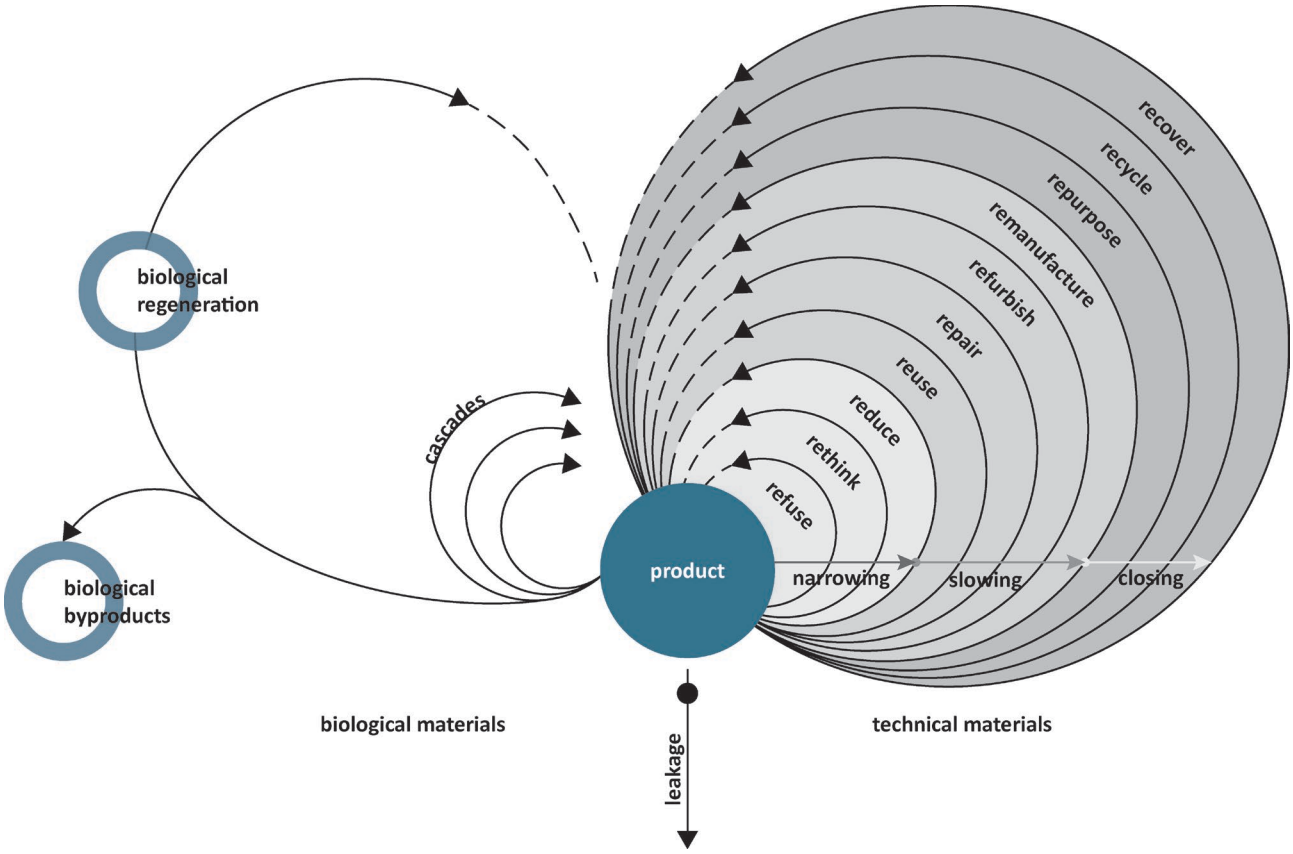


Figure 1 – The closed reversible loops of a CE (based on Bocken et al., 2016; Ellen MacArthur Foundation, 2013; Potting et al., 2017)

Implementing the value retention processes requires an integral approach, meaning that it is crucial to align the technical model (design) with viable business models (marketing and financing) and throughout the entire industrial model (supply chain or stakeholder network) (Bocken et al., 2016; van Stijn & Gruis, 2019). While design plays a pivotal role in achieving circularity, with an estimated 80% of the circular potential of products being defined at the design stage (European Commission, 2012), it needs to be supported by compatible business models. In contrast to linear business models, circular business models focus on value creation (Nußholz, 2017; Richardson, 2008) and incentivise value capture through capitalising on the value retention processes (Achterberg et al., 2016) throughout the entire industrial model. In this thesis, the industrial model refers to the stakeholder network, including the end-user, as previous literature emphasises their crucial role in developing circular products and services (Daae et al., 2018; Lofthouse & Prendeville, 2018; Pomponi & Moncaster, 2017; Selvefors et al., 2019). In the industrial model, collaboration is an important aspect of value creation (Bocken et al., 2013). Previous research shows that an early engagement of the entire stakeholder network in the collaborative development of a circular product or service is an important factor in successfully implementing the CE concept (Dokter et al., 2021). Through such collaboration, the stakeholders can define and

align their circular value proposition, the cornerstone of the accompanying business and technical models (Bocken et al., 2013). The lack of such collaboration in current industrial models is a challenge in transitioning to a CE (Adams et al., 2017; Hart et al., 2019).

While this thesis acknowledges the importance of the integral approach, the studies did not investigate the technical, business and industrial models to an equal extent. The primary focus was on one aspect of the technical model of residential buildings (spatial design's contribution to CBD). With regard to the industry model, the investigations explored the perspectives of selected key stakeholders connected to kitchens while acknowledging that they represent only a fragment of the overall residential design process. Furthermore, the research did not address compatible business models, although aspects of value creation have been explored in Study 1.

2.2. Circular buildings in a circular built environment

Transitioning to a circular built environment is promoted as a potential remedy for the environmental effects of the current linear processes (as outlined in Chapter 1). Such transition needs to address the intertwined system of the micro-level (building components, materials), the meso-level (buildings) and the macro-level (cities, urban areas, settlements) elements of the built environment (Pomponi & Moncaster, 2017). Therefore, circularity (just like sustainability (Ceschin & Gaziulusoy, 2016)) "needs to be understood as a property of a system […], rather than a property of an individual product or service" (Konietzko et al., 2020, p.2). Hence, incorporating CE approaches in buildings can only fulfil their potential if adopted across the whole system.

In pursuit of comprehending the systems-level implications of interpreting circularity in the building context, Leising et al. (2018) suggest that applying a CE approach "optimizes the buildings' useful lifetime, integrating the end-of-life phase in the design and uses new ownership models where materials are only temporarily stored in the building" (p.977). Pomponi & Moncaster (2017) define the concept of a circular building as "a building that is designed, planned, built, operated, maintained and deconstructed in a manner consistent with CE principles" (p.771). Another definition of circular building is "[the manifestation of] the dynamic total of associated processes, materials and stakeholders that accommodate circular flows of building materials and products at optimal rates and utilities" (Geldermans et al., 2019b, p.2).

As the diverse definitions illustrate, there is no consensus regarding interpreting circular buildings. In this thesis, combining and building on previous interpretations, circular buildings are defined as buildings designed, planned, built, operated, maintained and deconstructed while minimising resource use, waste and emissions through systematically applying value retention processes to slow, narrow and close loops in the associated technical, business and industrial models throughout the entire lifespan of the buildings. Expanding on this definition in line with the arguments of Cambier (2022), this thesis advocates that "how circular a building is [or was] can only be determined at the end of its service life" (p.34). Implementing circular design strategies in buildings establishes and predetermines its circular potential (Cambier, 2022). Despite the use of the term 'circular potential' in the literature related to circular buildings (Antonini et al., 2020; Cambier, 2022; Gomes et al., 2022), a definition of the term is yet to be established. In this thesis, circular potential is understood as the accumulated capacity of products or services that contributes

to optimising the value retention loops throughout the entire lifespan of said products or services.

Although interest regarding CE in the built environment has increased, there is still only a limited number of built examples of circular buildings (Cambier et al., 2021) and circular products are scarce (Minunno et al., 2018; Ness & Xing, 2017). Most examples are pilot projects focusing on office and commercial buildings, only addressing a few value retention processes and failing to undertake a systems approach (Cambier et al., 2021; Dokter, 2023; Kozminska, 2019). In current practice, there is a focus on closing loops by tackling the end-of-life scenario of buildings, such as demolition waste management and reuse of building components and materials (Askar et al., 2022; Dokter et al., 2021; Kozminska, 2019; Munaro et al., 2020). The selective application of the value retention processes is due to a combination of barriers such as cultural barriers (e.g., hesitant company culture, lack of collaboration among stakeholders), regulatory barriers (e.g., obstructing laws and regulations, lack of incentives for CE), market barriers (e.g., high upfront investment costs, low virgin material prices) and technological barriers (e.g., lack of standardisation, lack of design and collaboration tools, long product lifecycles) (Hart et al., 2019; Kirchherr et al., 2018). To overcome these barriers, it is necessary to investigate currently under-explored value retention processes connected to narrowing and slowing loops and incorporate them into CBD.

2.3. Circular building design

In this thesis, circular building design refers to a design approach that supports the development of circular buildings. The following sub-chapters outline important approaches, definitions and strategies within CBD that are relevant to this thesis's scope.

2.3.1. Systems approach in circular building design

As previously outlined, it is essential to consider CBD from a systems-level perspective. Existing studies also advocate for using a systems approach in circular design (Bocken et al., 2016; Geldermans, 2016; Mendoza et al., 2017; Pomponi & Moncaster, 2017). The systems approach empowers designers to transcend specific problems and examine the broader system in which these problems are situated (Meadows, 2008). This holistic perspective allows for identifying and resolving root causes rather than merely addressing symptoms. A systems approach within the building context means considering the building as a combination of all parts, much the same as the shearing layers concept (Schmidt & Austin, 2016, building on the works of Brand (1994) and Duffy (1992)), considers buildings as a combination of eight layers (Figure 2):

- surroundings (physical context in which the building sits),
- site (the lot the building sits on),
- skin (façade and roof elements),
- structure (foundation and load-bearing parts),
- services (infrastructures – electrical wires, plumbing, ventilation, heating, etc.),
- space plan (room organisation, partition walls, flooring),
- stuff (furnishings),
- social (humans in and around the building; e.g., end-users, owners, neighbourhood communities).

These various layers possess lifespans that vary from as short as a few days (stuff) to as long as millennia (site). The manner in which they are interconnected determines their ability to be repaired or replaced. This thesis (and particularly Study 4) adopts the shearing layer model of Schmidt & Austin (2016) to describe the boundaries and interactions among system elements. However, one distinction in adopting the model is that the social layer is considered as 'input' for design solutions rather than something that should be 'designed'.

As introduced earlier (Sub-chapter 1.2), spatial design is defined by the layers of skin, structure, services, space plan, stuff and social. For instance, window placements and orientation of the façade (skin) affect access to daylight and the structural design of the whole building (e.g., slab dimensions, column placements, ceiling height) influences the design and utilisation of the interior spaces. Spatial design also relies on function-specific services (e.g., electricity, plumbing, ventilation), is delineated by components of the space plan (e.g., partition walls, room connections) and hosts built-in and mobile furniture (stuff). Additionally, the social interaction anticipated within the space should guide how these components are designed. Hence, the design of the shearing layers as an interconnected system impacts the spatial design. Therefore, to implement a holistic systems approach to CBD, it is essential to consider the implications of spatial design across the shearing layers.

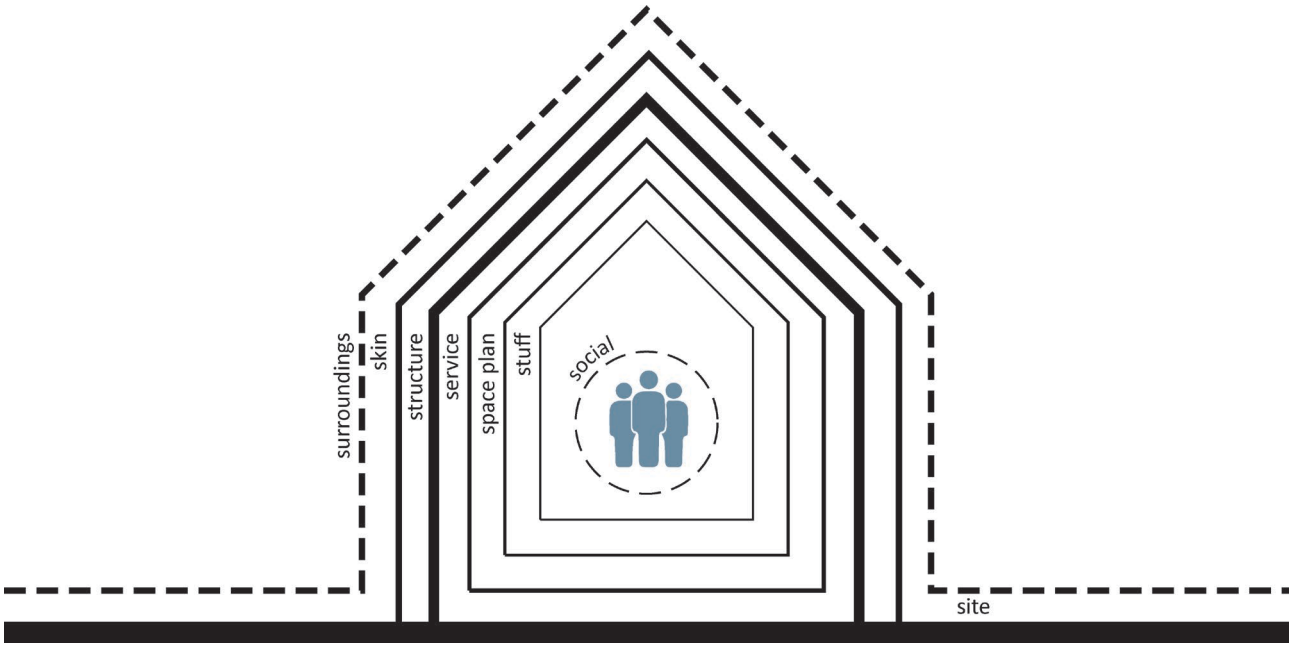


Figure 2 – Shearing layers (adapted from Schmidt & Austin, 2016)

2.3.2. Synthesising and assessing circular building design

To support design professionals in creating circular buildings, there is a wide range of frameworks and tools (Askar et al., 2022). These frameworks and tools primarily address basic design principles (Askar et al., 2022) and do not meet the needs of practitioners (Cambier et al., 2021). Instead of general guidelines, practitioners need support in synthesising CBD solutions (generative aids) and assessing the circularity of the generated solutions (evaluative aids) (van Stijn & Gruis, 2019). With regard to evaluative aids, material flow analysis and life cycle analysis tools are being developed to assess the circularity of building design solutions. However, these tools focus on environmental aspects and evaluate the building design as a sum of the individual materials and components. As a

result, the tools do not assess the spatial design of buildings from a circularity perspective and lack considerations regarding social implications.

There is scattered literature on generative aids, presenting various frameworks and design guidelines for circular design. To synthesise the knowledge of the existing literature and adapt it to the building context, van Stijn & Gruis (2019) reviewed existing circular design frameworks. They developed a comprehensive design tool (circular building component generator) employing an integral approach to incorporate CBD strategies into the technical, business and industrial models. These CBD strategies support implementing the value retention processes to narrow, slow and close resource loops in the building context (Figure 3).

This thesis contributes to knowledge development on CBD strategies, specifically focusing on the strategy design for adaptability. The significance of design for adaptability in achieving circularity is frequently underscored in the literature (Cheshire, 2021; Dams et al., 2021). Despite the widely recognised significance of adaptability in the successful implementation of CBD, current frameworks and tools lack sufficient consideration of the subject (Askar et al., 2022).

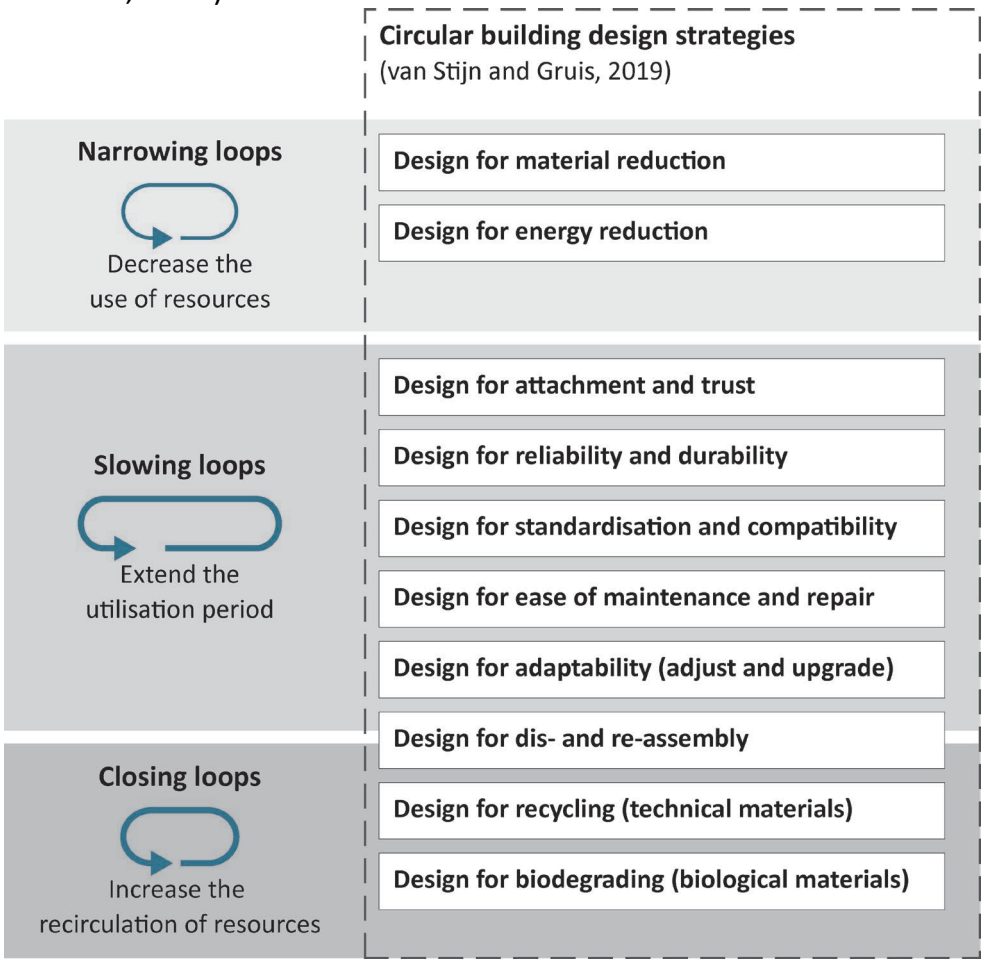


Figure 3 - Circular building design strategies (based on van Stijn & Gruis, 2019)

2.3.3. Circular building adaptability

Adaptability refers to "the inherent properties in a building that gives [sic] it the ability to change or the relative ease with which it can be changed" (Heidrich et al., 2017, p.287). The concept of adaptability has a history dating back to the 1920s (Habraken, 1972). Today, it is explored as an aspect of achieving a circular built environment (Cheshire, 2021; Dams et al.,

2021). Hamida et al. (2022) compare the concepts of circularity and adaptability and point out that CBD relies on adaptability-driven solutions and the determinants of circularity and adaptability overlap. They formulate the term circular building adaptability, which is defined as "the capacity to contextually and physically alter the built environment and sustain its usefulness while keeping the building asset in a closed-reversible value chain" (Hamida et al., 2022, p.61).

Adaptable design solutions seemingly have many advantages that support circular design principles. Adaptable design could ensure extended lifespan for buildings and building components and optimised use of built-in resources (Geldermans et al., 2019a). Additionally, it could prevent premature obsolescence and redundant material flows (Kendall, 1999; Slaughter, 2001), which could reduce the environmental impact of buildings. Adaptable design solutions could also help end-users take control of their living environment by providing the possibility to adapt it to their needs and preferences (Braide, 2019; Habraken, 1972; Till & Schneider, 2005). In combination with well-dimensioned free floor areas, adaptability features proved to be beneficial when households needed to adapt to rapidly changing circumstances (e.g., lockdowns during the pandemic) (Marco et al., 2022). Furthermore, adaptable design solutions can potentially reduce long-term economic costs since the inherent ability of a building to adapt to changing demands would reduce the cost of extensive reconstruction (Pelsmakers & Warwick, 2022; Pinder et al., 2013; Slaughter, 2001). However, it is important to acknowledge that adaptable design solutions sometimes require higher initial investments during the building's construction phase, which should be supported by favourable financial incentives (Heidrich et al., 2017; Till & Schneider, 2005).

Despite the advantages of adaptable design solutions, successful implementation of adaptable housing design is rare (Tarpio et al., 2021). This is due to barriers, such as the lack of initial economic incentives (Schmidt & Austin, 2016), technical solutions (Cellucci & Sivo, 2014), practical guidelines and design tools (Askar et al., 2022) and regulatory support (Giorgi et al., 2022). The renowned interest in adaptability as an important principle for achieving circularity in the built environment (Askar et al., 2021) might facilitate opportunities to overcome the barriers.

Based on a literature review comparing and synthesising the concepts of circularity and adaptability, Hamida et al. (2022) identify ten determinants of circular building adaptability (Table 2). These determinants safeguard the long lifespan of buildings, diminish waste production and reduce the environmental impact of buildings (Hamida et al., 2022). Hamida et al. (2023) further investigate how circular building adaptability and its determinants were applied in adaptive reuse. Their findings show that the influencing factors for applying adaptability-related strategies were organisational (collaboration and partnerships, motivation and capability, conservative sector), economic (viability, feasibility), knowledge-based (expertise, technologies, warranties), regulatory (legal and legislative support) and building design-related (building characteristics).

Concerning building characteristics, Hamida et al. (2023) identify design strategies applied in the original building design that facilitated circular building adaptability during their adaptation. These strategies included overcapacity, modularity, standardisation, design for disassembly, flexible infrastructure systems, open floorplan concept, shared facilities, using recyclable or reused products, retrieving still functional products and materials, repairing and retaining building components, implementing renewable energy systems, installing

energy-efficient alternatives and strategically placed infrastructure cores. Hamida et al. (2023) conclude that while all circular building adaptability determinants were supported by some of these design strategies, in none of their studied cases (individually) were all determinants applied in a holistic and systematic way. The most supported circular building adaptability determinants were configuration flexibility, product dismantlability and material reversibility. At the same time, the least addressed determinants were functional convertibility and building maintainability. Furthermore, they observed that the original design decisions restricted the implementation of some circular building adaptability determinants, such as design regularity or volume scalability.

Since circular building adaptability research is an emerging field, research gaps still need to be explored. Previous works concerning circular building adaptability primarily focused on office and commercial buildings and explorations in the context of multi-residential buildings are still lacking. Furthermore, Hamida et al. (2022) highlight the need for a better understanding of how circular building adaptability could be enabled by design strategies and the need for "a practical and evidence-based framework" (Hamida et al., 2022, p.64) for the implementation of the concept.

Table 2 - Overview of circular building adaptability determinants and their definitions (Hamida et al., 2022)

Circular building adaptability determinants	**Definition**
Configuration flexibility	Changing the space layout without additional material flows.
Product dismantlability	Demounting building components without damage or waste and enabling their reuse.
Asset multi-usability	Using building assets for multiple purposes (e.g., multi-purpose spaces, shared facilities)
Design regularity	Designing buildings and their spatial configurations following regular patterns (e.g., modularity, standardised components)
Functional convertibility	Changing the primary function of the building (or a part of it).
Material reversibility	(Re)Using building materials as long and as effectively as possible in a reversible value chain.
Building maintainability	Prolonging the usefulness of buildings and sustaining their performance.
Resource recovery	Regenerating and reducing the resources consumed in the building (e.g., renewable energy techniques, natural ventilation and lighting).
Volume scalability	Expanding or shrinking buildings or building units.
Asset refit-ability	Refitting building assets to adjust them to improved requirements.

2.4. The societal and behavioural dimensions of a CE

The lack of a societal dimension of CE interpretations has been widely discussed, particularly in terms of neglecting key social factors such as consumption behaviour and the adoption of sufficiency-oriented lifestyles (Murray et al., 2017; Schulz et al., 2019). The literature on design for circularity needs to broaden its perspective to include a more theoretically informed understanding of how people behave and use products and services (Lofthouse & Prendeville, 2018).

There is a growing recognition that designers need to develop a richer understanding of end-user behaviour to effectively design for circularity (Daae et al., 2018; Lofthouse & Prendeville, 2018; Selvefors et al., 2019). This involves a shift from an economic and material focus to a more balanced approach that also considers the roles and behaviours of people in their everyday activities (Kirchherr et al., 2017; Pomponi & Moncaster, 2017). For instance, new design strategies are needed to involve end-users in activities they may not have previously been involved in (Daae et al., 2018). These could include returning or reselling an item, self-repairing products, purchasing pre-owned or remanufactured items, renting rather than purchasing items, paying more for an item that will last longer and keeping and using items as they are instead of purchasing a new one (Daae et al., 2018). Smith (2014) emphasises that the success of many of these activities is deeply rooted in social connections. For instance, before repair is considered a potential solution, it is crucial to understand how people value, maintain, utilise and dispose of items (Smith, 2014). Such principles and considerations are also applicable to building components and products.

To frame research on CE for the built environment, Pomponi & Moncaster (2017) identify six key research dimensions (Figure 4). Pomponi & Moncaster (2017) highlight that research dimensions evolved over time as the initial green building research (investigating primarily environmental and technical dimensions) expanded with additional considerations regarding sustainability (economic and societal dimensions) and, later on, circularity (governmental and behavioural dimensions). Pomponi & Moncaster (2017) emphasise that "the greatest challenges that lie ahead will deal with the role of people, both as individuals and society as a whole" (p. 717.) and that interdisciplinary research is essential to address these challenges. Beyond the societal dimension, the behavioural aspect has surfaced as a pivotal component in the ongoing discourse towards achieving circularity in the built environment. Pomponi & Moncaster (2017) conclude that the societal and behavioural dimensions currently lack consideration in the literature connected to circular building research and there is a need to expand investigations within these areas.

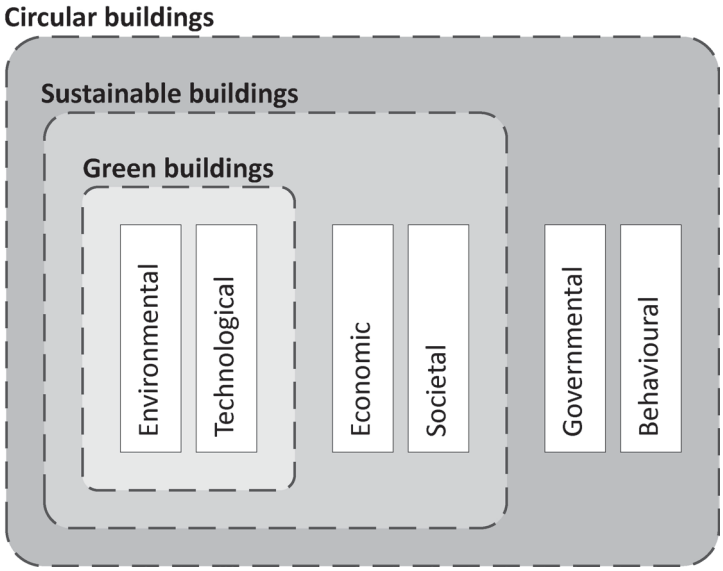


Figure 4 – The evolution of the research dimensions of building research (adapted from Pomponi & Moncaster, 2017)

2.5. Theoretical perspective

The definitions, principles and design methodologies introduced in relation to circular buildings demonstrate that studying circularity in residential buildings, particularly focusing on spatial aspects, necessitates exploring complex systems of physical objects inhabited and used by various end-users. Consequently, a comprehensive understanding of this subject requires an examination of both social and material aspects of spatial design, as well as their implications for circularity. Therefore, this thesis examines spatial design inspired by spatial theory, a theoretical perspective within the approach of sociomateriality (Moura & Bispo, 2020).

The approach of sociomateriality enables researchers to study the entangled nature of social phenomena and materiality (Leonardi, 2012, 2013; Moura & Bispo, 2020; Orlikowski, 2007). These two aspects of sociomateriality mutually influence and shape each other (Leonardi, 2012, 2013; Moura & Bispo, 2020; Orlikowski, 2007). Materiality refers to the inherent properties of physical and non-physical objects, including material and form (Leonardi, 2012). Social phenomena include, for instance, discourses, decision-making, strategy formulation (Leonardi, 2012), symbols, meanings or desires (Fenwick, 2014). Sociomateriality is mainly used in organisation and management research to understand the relationship between technology and humans (Orlikowski, 2007). However, in architectural research, these theories have also proved helpful in investigating and discussing how end-users influence the evolution of space (e.g., Acton, 2017; Buser & Carlsson, 2017).

Socio-material studies primarily employ qualitative methods, although it is not unusual to see quantitative methods incorporated into the research design. For instance, Bispo (2015) noted that interviews focus mainly on participants' discourse and put less emphasis on material elements. In such cases, a quantitative method may complement the data collection and help understand the interrelationships of the social and material aspects. The employed methods often depend on the adopted theoretical perspective. Scholars can study socio-material questions from a broad spectrum of theoretical perspectives. Moura & Bispo (2020) identified seven theoretical perspectives that embrace socio-material approaches: new materialism, actor-network theory, cultural-historical activity theory, complexity theory, spatial theory, organisational aesthetics and science and technology studies.

This thesis adopts spatial theory’s consideration of space. However, the research does not delve into the methodological doctrines of this theoretical perspective and does not attempt to engage in the scholarly debate related to the theoretical stances. Within spatial theory, space is a dynamic environment functioning as scenery for the activities of diverse actors and is shaped by simultaneous activities (Fenwick et al., 2011). This consideration of space is used in this thesis to understand how physical spaces create the social context and, in turn, how the social context influences the physical spaces. Although the separate studies did not incorporate spatial theory, the data collection and analysis methods used in the studies (interviews, workshops, focus group sessions, floorplan analysis) align with the methodologies of spatial theory. How the social and material aspects were studied in the research is further explained in Sub-chapter 4.2.

3. Swedish context

This chapter provides an overview of residential building design and kitchen design in the Swedish context. First, it presents an overview of the relevant characteristics, research and regulations connected to Swedish multi-residential housing. Second, a historical overview gives insight into the influencing factors that shaped Swedish kitchen design in the past century. Lastly, current end-user preferences related to kitchen design, as identified in the literature, are summarised.

3.1. Swedish multi-residential housing: characteristics, research and regulations

Apartments in multi-residential buildings represent 52% of the housing stock in Sweden, of which 58% are rental apartments and 42% are owner-occupied apartments (Statistics Sweden, 2023). The number of newly built multi-residential buildings has continuously increased in recent years (Statistics Sweden, 2024). The Swedish National Board of Housing, Building and Planning (Boverket) estimates that there is a need to build 60,000 new dwellings annually from 2021–2030 to meet the demand of the increasing population and tackle the current housing shortage (Boverket, 2021). The surge in demand is similar to what was experienced in the 1940s, a period marked by rapid urban growth and the recovery following World War II.

As a reaction to the increased housing demand and the inadequate housing solutions in the urban areas in the 1930s, various organisations and architects studied end-user perspectives and housing standards (e.g., Åkerman, 1941; Curman, 1944; Wærn-Bugge & Göransson-Ljungman, 1936). At the same time, the state recognised the need to improve the poor housing conditions and established institutions to, for instance, provide advantageous loans for building new homes (1941 - Statens byggnadslånebyrå [the National Swedish Construction Loan Agency]) and study and standardise adequate housing solutions (1942 - Statens kommitté för byggnadsforskning och byggstandardiseringen [the National Swedish Committee for Building Research and Building Standardization] and 1944 - Hemmets Forskningsinstitut (HFI) [the Home Research Institute]) (Nylander, 2018). The results of the housing studies were distributed through various publications (e.g., Algott, 1946)

The work of HFI focused on rationalising chores carried out in the home (Lee, 2018). This included research systematically studying end-user activities and habits, as well as the equipment needed to carry out tasks more efficiently and effortlessly (Göransdotter, 2020). The systematic research of housing design continued until the 1990s within the work of Konsumentinstitutet [the Swedish Consumer Agency] (previously HFI) and Statens institut för byggnadsforskning [the National Swedish Institute for Building Research]. During these decades, methodological procedures were developed, incorporating sociological and ethnological approaches (Nylander, 2018). The employed research methods included foremost qualitative data collection (such as interviews, home visits, photographing, floorplan drawings and observations of enactments in laboratories) combined with quantitative data collection (such as surveys and measuring dimensions of rooms, furniture and equipment) (Nylander, 2018). The evidence-based and end-user-focused findings of this continuous research directly informed the Swedish building regulation (BFS 2011:6).

In the 1990s, the state removed financial support from housing research and building development. As a result, the perpetuity of the Swedish housing research was disrupted and costs associated with building production dramatically increased (Nylander, 2018). Although the tact of housing research slowed down and the coordinated efforts dissolved, the subject remained of interest among researchers and architects. Between the 2000s and the 2020s, various independent research studies continued developing knowledge of evidence-based housing design. Amongst these, a group of researchers at Chalmers University of Technology also initiated Centrum för Boendets Arkitektur [Centrum for Housing Architecture] for practice-based research and collaboration with the industry. The practice-based research conducted by the Centrum for Housing Architecture continues to generate valuable insights through, for instance, evaluating residential buildings post-production (e.g., Granath et al., 2022; Nylander et al., 2021; Nylander & Braide, 2011).

Housing research performed after the 1990s highlighted that the architectural qualities of dwellings are important to end-users (Nylander, 1998). Nylander (1998) identifies seven architectural qualities: materials and detailing, axiality, enclosure, movements, shape of rooms, daylight and organisation of spaces. Six of these qualities relate to spatiality, which indicates spatial design's relevance for end-user satisfaction. However, preferences related to these qualities vary among end-users. Ekeblad (1997) describes the end-users of dwellings as a heterogeneous group and advocates for the need for various housing types. Additionally, end-user preferences cannot be described in finite terms; they change over time as their family situation and household compositions evolve (Braide, 2019; Werner, 2003). Previous research shows that dwellings have shortcomings in accommodating such changes (Braide, 2019). These shortcomings prevent households from effortlessly adjusting their dwellings, which in turn "undermines the longlivity [sic] of the housing stock" (Braide, 2019, p.163), contributes to unnecessary material flows (Femenías et al., 2018) and results in end-user dissatisfaction, leading to alterations to current floorplan designs (Femenías & Geromel, 2019; Tervo & Hirvonen, 2019). Femenías & Geromel (2019) found that an increased number of spatial alterations of dwellings might imply that the end-users prioritise a variety of spatial qualities other than those provided by the original floorplan design. One possible explanation is the difference between architects' perceptions regarding what end-users would appreciate and what end-users prefer (Braide, 2019; Werner & Grange, 2011). Braide (2019) further describes that design processes connected to residential architecture are characterised by a top-down approach that does not respond to the changing spatial requirements of households. Werner & Grange (2011) emphasise the importance of evaluating building projects post-production to learn about end-user preferences and implement learnings into new production. In conclusion, the housing research of the most recent decades shows the need to reintroduce studying end-user preferences regarding their dwelling to formulate functional requirements and design recommendations. Such studies are increasingly important in order to inform and update building regulations (Granath, in press).

Today, Plan- och byggförordningen (PBF) [the Swedish Planning and Building Regulation] (SFS 2011:338), Plan- och Bygglagen (PBL) [the Swedish Planning and Building Act] (SFS 2010:900) and Boverkets byggregler (BBR) [Boverket's Building Regulations] (BFS 2011:6) define the design of newly produced buildings. According to the PBF (SFS 2011:338), a dwelling has six distinctive functions that need designated spaces: sleep and rest, socialising,

cooking, dining, hygiene and storage. The BBR (BFS 2011:6) further specifies that a room or a separable part of a room needs to accommodate the functions of sleeping and resting, socialising and cooking. This formulation allows a more fluid spatial design of dwellings, where rooms with combined functions can be designed (e.g., combined kitchen- living room, sleeping alcove in the living room). To make separation possible, there must be a sufficient number of windows so that each room would have appropriate daylight conditions after separation. This regulation only applies to apartments larger than 55 m^2. According to Granath (in press), the current trend in the building sector is that a large portion of newly built apartments are just below the 55m^2 threshold to, for instance, avoid the requirement for daylight in the kitchen (e.g., having at least one window in the separated room of the kitchen).

Regarding kitchens, the BBR (BFS 2011:6) mandates that the built-in furniture and major appliances must be installed in the apartment upon delivery and remain there when the dwelling changes owners. Therefore, the design and construction processes connected to the kitchen are an integral part of a housing project. Currently, regulations and standards govern kitchens' minimal dimensions and furnishings. A proposal is under consideration to reduce these specifications to facilitate more cost-effective production of new multi-residential buildings. However, this proposal has sparked a debate on whether such changes would compromise the quality of dwellings for end-users (Boverket, 2023). Interestingly, this proposal has been put forth without conducting comprehensive research on contemporary end-user preferences. Additionally, despite the existence of national regulations and policies aimed at enhancing sustainability and circularity – such as Klimatlagen [the Swedish Climate Act] (SFS 2017:720) and Cirkulär ekonomi – strategi för omställningen i Sverige [Sweden's National Strategy for a Circular Economy] (Regeringskansliet, 2020) - these aspects have been largely overlooked in the proposal of the new building regulations. This highlights a need to reintroduce research-informed regulations (Granath, in press). Therefore, this thesis seeks to contribute to the tradition of Swedish housing research and the formulation of upcoming regulatory changes by exploring how spatial design could support the requirements of the emerging circular paradigm, with attention to aspects of end-user preferences.

3.2. Historical evolution of the Swedish kitchen

As the first step of my PhD studies, I carried out a literature review on the historical evolution of Swedish kitchen design over the past century. An extensive summary of this literature review was published as part of my Licentiate Thesis (Ollár, 2021, pp.9-20). The literature review helped me to understand the changes in the design of the Swedish kitchen and the influencing factors guiding these changes. These influencing factors were observed to be related to four categories: (1) lifestyle and societal changes, (2) governmental regulations, (3) technological advances and (4) kitchen research.

One of the most significant shifts in lifestyle and societal changes was the emancipation of women (Lee, 2018). While in the first half of the previous century, the kitchen was essentially the women's domain, this is not the case today. HFI's research primarily focused on women (the contemporary representative end-user group of the kitchen) and their tasks (Thiberg, 2007). In retrospect, the resulting guidelines, such as furniture or room dimensions, are comfortable or suitable for 33% of adults (Hallberg & Thiberg, 1985). Although women

still perform a significant portion of cooking and housework (European Institute for Gender Equality, 2016; Organisation for Economic Co-operation, 2023), there is no longer a representative end-user group active in the kitchen. As a result, the diverse individuals or groups of end-users possess a wide range of preferences regarding the functionality of their kitchen. There has also been a change in the activities performed in the kitchen. Earlier, the kitchen was seen as a hidden, dirty and noisy place where mostly food-related tasks were carried out (Lee, 2018). Even in the floorplan of a dwelling, the kitchen had a secluded location concealed from social spaces (Movilla Vega & Hallemar, 2017). Nowadays, the kitchen has a central role and location in the dwellings' room organisation to accommodate food-related activities (e.g., storing raw ingredients and equipment, cooking, cleaning, sorting waste), social events, hobbies and working from home (Hagejärd et al., 2020; Willén, 2012) To develop suitable design solutions, we must explore this shift in who and why uses the kitchen and the new activities occurring in the space.

As an aftermath of the Industrial Revolution(s), a large portion of the population migrated to urban areas at a rapid speed. To house the new dwellers of the cities, apartment buildings with low building standards were constructed (Movilla Vega & Hallemar, 2017). As described earlier, between the 1940s and 1980s, the research and recommendations of HFI played an active and robust role in creating evidence-based housing regulations. This role diminished when the state deregulated the building industry in the early 1990s. Today, a new wave of deregulation is in the plans, reducing the current requirements (Boverket, 2020). This shift in governmental regulations entails two significant concerns: (1) a lack of guidance from evidence-based research and (2) a lack of prioritising housing qualities supporting end-users' preferences and needs.

Technological advances enhanced the efficiency of tasks in the kitchen. First, establishing running hot and cold water, sewage systems and electricity in all homes made it easier to carry out kitchen choirs (Lee, 2018). Additionally, electrical (and smart) devices, such as small appliances (toaster, kettle, mixer, etc.), fridges, freezers, microwaves, stoves, ovens or dishwashers enable the end-users to execute their tasks faster and more efficiently. These devices have become an integrated part of almost all kitchens, reducing the time people spend on kitchen-related tasks and increasing spatial requirements to store and use these devices (Hagejärd et al., 2020). Furthermore, introducing prefabricated ingredients and meals also changed how food is purchased, stored and prepared at home (Lee, 2018). The large pantries and 'skafferi' cabinets (externally cooled small pantries in the kitchen often part of the built-in furniture) disappeared and were replaced by a few shelves in the built-in furniture. This shift in technological advances seems to be partially accommodated by the market and regulations (e.g., microwave ovens or dishwashers are often integrated into the built-in furniture in the original design). However, increased spatial requirements connected to appliances, food storage, work surfaces and waste sorting are possibly under-dimensioned and not addressed in current residential building design (Hagejärd et al., 2020; Marco et al., 2021; Sjöstrand, 2018).

As described earlier, the research of HFI focusing on the kitchen involved studying women performing kitchen-related tasks, measuring adequate heights and widths of the built-in furniture and experimenting with various kitchen equipment (Göransdotter, 2020; Lee, 2018). The researchers of HFI conducted a series of time studies in a laboratory kitchen, observing the tasks performed by housewives and considering their anatomical

characteristics (Göransdotter & Redström, 2018). This meticulous and systematic approach by HFI established the foundation for user-centred design methodologies in Sweden (Göransdotter & Redström, 2018). The findings of the work of HFI were a comprehensive guide to optimal kitchen design, which included specifications for the heights and widths of built-in furniture, the ideal number of cupboards, the placement of major appliances and the necessary storage space. These findings were disseminated through reports and books and contributed to developing the first building standard (Lee, 2018). However, this research tradition has been discontinued and new considerations, such as socio-technical changes and sustainability demands, have not been followed up.

In conclusion, lifestyle and social changes, as well as shifts in governmental regulations, technological advances and kitchen research, necessitate a renewed investigation of kitchen design. Furthermore, such an investigation must incorporate the emerging requirements of sustainability and circularity that present challenges to contemporary architectural design.

3.2.1. End-user preferences of kitchen design

My review of the literature on kitchen design (an extensive summary is available in Ollár, 2021, pp.30-36) shows that guidelines regarding the design of kitchens are widely available in publications based on the findings of the housing research of the 20th century. One of the most comprehensive summaries of these guidelines is published in the book *Kök: planering och utformning* [Kitchen: planning and design] by Alice Thiberg (Thiberg, 2007). However, only a limited number of in-depth evaluations have been conducted on how well these guidelines are followed in residential building design and how satisfied end-users are with the kitchen design in their dwellings.

Nylander & Braide (2011) investigate end-user satisfaction related to their dwellings in a neighbourhood of Gothenburg built between 1969 and 1972. Their findings show that end-users appreciate a good connection between the living room and the kitchen, large spaces for socialising, access to a balcony and a spacious dining area. However, many interviewees expressed that the size of the apartment and the kitchen were not sufficient for their households´ needs. This indicates that the design solutions realised in older buildings do not fully meet current end-user preferences. Similarly, another study of a recently built multi-residential building complex (finished in 2019) shows that certain design features of the dwellings, such as the spacious combined-kitchen living room, large windows providing daylight and outlook, ample work surfaces, generous storage spaces and a kitchen well-connected to other rooms in the apartment were highly appreciated by the residents (Nylander et al., 2021). Nevertheless, these features are not always present in recently built multi-residential buildings; especially smaller apartments lack these appreciated design solutions (Granath et al., 2022).

Contemporary designs typically feature a combined kitchen-living room (Nylander, 2018; Willén, 2012), reflecting the kitchen's evolution from a separate service zone to the dwelling's heart (Brkanić et al., 2018). Combined kitchen-living rooms are created to save floor area (m^2) in apartments (Thiberg, 2007) and to provide a larger room for family gatherings (Nylander, 2018). This design solution is meant to establish a feeling of spaciousness and enable social activities (Nowakowski, 2015), which end-users often appreciate (Hagejärd et al., 2020; Nylander et al., 2021). However, disadvantages include noise disturbance from cooking activities or the visual impact of an untidy kitchen (Thiberg,

2007). Tervo & Hirvonen (2019) surveyed a large number (n = 1,453) of 'solo dweller' households living in one-room apartments. Their findings show that even though open floorplans were the most popular among respondents (56%), a significant portion (40%) of participants would have preferred a separate kitchen. They further highlight that this contradicts the current design trend in dwellings as they are usually built with combined kitchen-living rooms.

A similar phenomenon is observed in a study exploring alterations performed by end-users in apartments of multi-residential buildings built between 2001 and 2008 (Femenías & Geromel, 2019). Femenías & Geromel (2019) note that kitchens were combined with or separated from living rooms in almost equal number of cases (Femenías & Geromel, 2019). The end-user-driven alterations often resulted in a larger kitchen floor area that was expanded into the living room. This was usually possible in the larger apartments thanks to the available free floor areas. However, some residents of the larger apartments have expressed dissatisfaction, noting that the size of their kitchens and available work surfaces were not sufficient for their households. To mitigate this issue, the built-in furniture was replaced in some cases and the residents mostly opted for a new L-kitchen typology complemented by a kitchen island or tall cupboard unit (Geromel, 2016).

The small size of the kitchen, along with insufficient work surfaces, storage spaces and daylight sources, are also reported in the interview study of Hagejärd et al. (2020). The interviewees expressed that, whenever feasible, changes were made to address these shortcomings of the original design. The motivations behind the changes were functional needs, aesthetical preferences, obsolete parts of the furniture or room and other alterations already ongoing in the dwelling (Hagejärd et al., 2020).

In conclusion, although existing studies have provided insight into contemporary end-user preferences for some aspects of kitchen design, there is a gap in the literature. Namely, further research is needed to explore end-user preferences concerning more comprehensive aspects of the spatial design of kitchens. This means going beyond the size of the room or its connection to other parts of the home and delving into the nuances of spatial design. Factors such as the placement of the built-in furniture, windows and doors, the location and size of dining areas and infrastructure systems also impact end-user satisfaction (Thiberg, 2007). By gaining a more profound understanding of end-user preferences, spatial design solutions that support circularity in residential buildings could be prioritised.

4. Methodology

To articulate the methodological choices of this research, Groat & Wang (2013) distinctions between systems of inquiry (set of assumptions and worldviews), schools of thought (theoretical perspective), strategy (research design) and tactics (methods) are employed. An intersubjective approach was adopted to establish the worldview and knowledge construction pathways of the research. Spatial theory was used as a theoretical perspective for understanding and studying the research subject (spatial design). Through a two-phased research design, a mixed-method approach was implemented, combining qualitative and quantitative data collection and analysis methods. The following sub-chapters describe these approaches, theories and methods and provide the reasoning behind and reflections on the connected methodological choices.

4.1. Worldview and knowledge construction

The intersubjective approach lies between positivism and constructivism. While positivism "assume[s] the existence of a reality that can be objectively described or measured" (Groat & Wang, 2013, p.77), constructivism takes a more subjective stance and embraces multiple realities that are socially constructed (Groat & Wang, 2013). The intersubjective approach lies between these two poles of worldviews and knowledge constructions. Adopting such an approach was guided by dualities connected to the subject of this thesis. On the one hand, capturing stakeholder preferences and behaviour patterns required a subjective approach. On the other hand, the stakeholders were situated in established systems which could be described and measured objectively. To capture this duality, the intersubjective approach provided a suitable ground for knowledge construction.

Epistemologically, the intersubjective approach has two characteristics: (1) the researcher is an integral element of the sociocultural subject under study and (2) knowledge is created through exploring qualitative and quantitative aspects of the studied phenomenon (Groat & Wang, 2013). Following this approach, the research was carried out in collaboration with the research team (including myself), the industry partners and the participants in the research activities. This qualitative collaborative knowledge development aimed to explore relationships, interactions and design preferences among stakeholders and was complemented by studies seeking to describe characteristics of the physical manifestation of space through a quantitative approach. This combination of qualitative and quantitative focus defined the epistemological grounds of the thesis, which also influenced the research design (see Sub-chapter 4.3).

Ontologically, the intersubjective approach acknowledges "diverse realities situated in a socio-cultural context" in which shared understandings of those realities are possible (Groat & Wang, 2013, p.76). This view allowed studying the complex engagement between social and material aspects within spatial design and circularity in the Swedish/Western context. The studies explored this complexity through the diverse perspectives of groups of individuals with shared value systems (stakeholders such as housing developers, architects, kitchen furniture producers, real estate brokers and end-users). These perspectives constructed the multiple realities embraced by the intersubjective approach. Constructing a shared understanding of these various realities was imperative to conceptualise spatial design in circularity.

4.2. Social and material aspects explored in the studies

As outlined in Sub-chapter 2.5, in this thesis, spatial theory was employed as a theoretical perspective. This means that spatial design was studied as an entangled phenomenon of social and material aspects. The social phenomena were studied through selected key stakeholders' processes and design preferences and materiality was examined by analysing aspects of spatial design in dwellings. It is important to acknowledge that the selected social and material aspects are not exhaustive; instead, they represent the most important segments identified during the collaborative knowledge development with the industry partners of the CIK project and the study participants.

The four studies of this thesis explored social and material aspects with varying focus and depth (Table 3). Overall, social aspects were studied through processes and preferences of the selected stakeholder groups and material aspects were investigated by analysing the physical manifestation of spatial design in kitchens. In Study 1, stakeholders included representatives of a housing developer, three architectural firms, a kitchen furniture producer, a contractor, a real estate broker and one end-user. These stakeholders were selected based on their crucial role in and contribution to developing and realising current design solutions in residential buildings. As Study 1 primarily focused on the industry stakeholders, Study 2 complemented the identified processes and perspectives by exploring end-user views as a crucial factor in developing viable circular solutions (Daae et al., 2018; Lofthouse & Prendeville, 2018; Pomponi & Moncaster, 2017; Selvefors et al., 2019). Through Studies 1 and 2, the goal was to understand the design, construction, use and modification of kitchens and the underlying reasonings behind connected decisions. This understanding was important in describing current design processes and solutions and providing reflections on them when considering the new circular paradigm. The identified stakeholder processes and perspectives of Studies 1 and 2 called for comparison with existing design solutions to identify discrepancies between desired and actual outcomes and their alignment with the principles of circularity. Hence, Study 3 delved into material aspects by identifying kitchens' spatial characteristics, describing current design solutions and assessing the solutions' circular potential. The results of the first three studies suggested that spatial designs' contribution to circularity lies within functionality and adaptability. In line with the literature, Study 3 highlighted the need to strengthen adaptability considerations in the context of CBD. Therefore, Study 4 investigated how architects, as key stakeholders of the design process, consider and incorporate adaptability into CBD.

Table 3 - The social and material aspects studied in the four studies

	Social aspects	**Material aspects**
Study 1	Processes and preferences of key stakeholder groups: housing developers, architects, kitchen furniture producers, constructors, real estate brokers and end-users	The design, construction, utilisation and alteration of the kitchen's (spatial) design
Study 2	Processes and preferences of one stakeholder group: end-users	The design, utilisation and alteration of the kitchen's spatial design
Study 3	Enabling stakeholder preferences through spatial design	Spatial characteristics of kitchens Current design solutions for kitchens Circular potential of kitchens' spatial design
Study 4	Design processes and reasonings of architects in connection to CBD projects	Circular design strategies Adaptability features

4.3. Research design

This thesis includes four studies (Table 4) published in four papers (see appendices). The studies were carried out through a mixed-method approach. Additionally, a two-phased research design was applied to align and integrate the studies. The following sub-chapters describe the mixed-method approach and the two-phased research design while introducing the data collection and analysis methods applied in the studies.

Table 4 - The research design of the thesis

	Study 1	**Study 2**	**Study 3**	**Study 4**
Aim	Exploring industry stakeholders' processes and preferences connected to the design, construction and utilisation of the kitchen's design	Exploring end-user processes and preferences connected to the design, utilisation and alteration of the kitchen's spatial design	Identifying spatial characteristics and assessing the circular potential of spatial design	Identifying adaptability strategies in CBD and enhancing circular building adaptability in residential architecture
Data collection	Semi-structured interviews Workshop Focus group	Semi-structured interviews Floorplan drawings	Archival documents (floorplan drawings)	Semi-structured interviews
Data analysis	Qualitative content analysis Value mapping	Qualitative content analysis Floorplan analysis	Floorplan analysis Descriptive statistics	Qualitative content analysis
RQ	RQ1, RQ2, RQ3	RQ1, RQ2, RQ3	RQ1, RQ2	RQ1, RQ3
Output	Paper A journal paper	Paper B conference paper	Paper C journal paper	Paper D journal paper

4.3.1. Mixed method approach

A mixed method approach was applied in alignment with and based on the intersubjective approach and spatial theory. Foremost qualitative data collection and analysis methods were combined with quantitative ones. This choice was called for by investigating spatial design's entangled social and material aspects and the complexity of circularity in the building context (as described in Chapter 2). The qualitative explorations focused on the processes and perspectives of stakeholders (social aspects) and analysed them through an interpretive process. Through this approach, the aim was to understand spatial design in the context of circularity and the associated relationships, meanings and values. The quantitative investigations helped provide a descriptive overview of a large sample of apartment floorplans to analyse the material aspects. A mix of these methods complemented and strengthened the qualitative interpretation of empirical material with quantitative data (and vice versa).

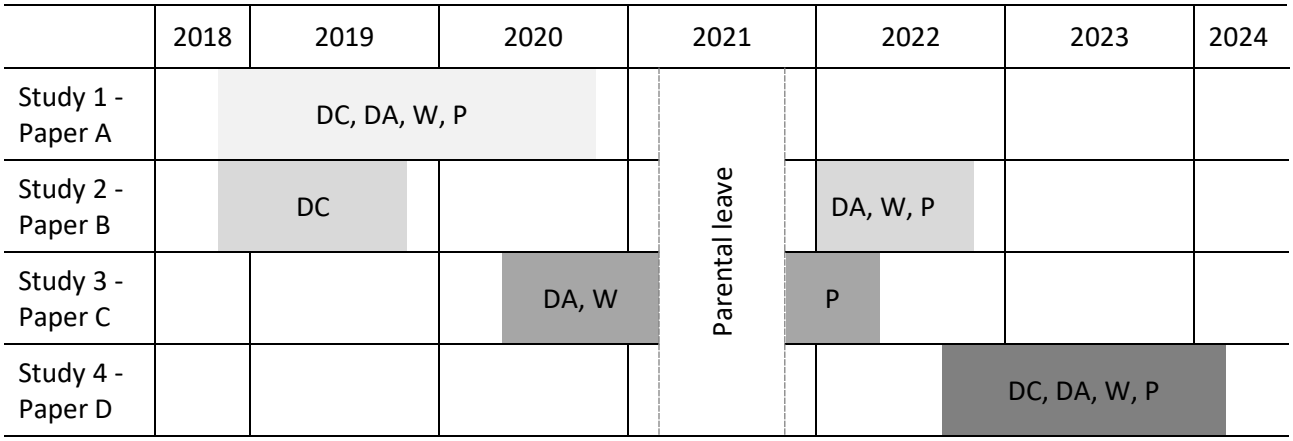
Studies 1, 2 and 4 used qualitative data collection and analysis. In these studies, data was collected primarily through semi-structured interviews. In Study 1, in addition to the interviews, a workshop helped identify potential interview participants and the results of the interviews were validated in a focus group session. In Study 2, the interview study was complemented with a floorplan analysis. Using interviews as the primary data collection method allowed to explore stakeholders' processes, preferences and reasonings. The

strengths of a qualitative approach include its ability to handle vast quantities of rich data and assess real-life situations (Groat & Wang, 2013). However, guidelines for conducting qualitative research are open to context-specific adaptation and sensitive to interpretations and perceived meanings (Groat & Wang, 2013). To mitigate these weaknesses, Studies 1, 2 and 4 were developed based on established methodologies for systematic and reliable research (Flick, 2018c; Gioia et al., 2012).

To complement and strengthen the qualitative interpretation of the empirical material, Study 3 was designed with a quantitative approach. Archival documents of apartment floorplan drawings were collected to assess spatial design. Due to the lack of tools suitable to assess the identified spatial characteristics, in Study 3, a novel spatial analytical framework and adaptive capacity assessment criteria were developed. The results of the assessments were summarised through descriptive statistics (Fisher & Marshall, 2009; Thompson, 2009). The quantitative approach enabled the analysis of the breadth of the studied phenomenon (Groat & Wang, 2013). However, this approach needed a provision for understanding the depth of the material. In particular, meanings and non-statistical correlations were unlikely to be discovered (Groat & Wang, 2013). Consequently, the results of Study 3 were linked to the qualitative investigations of Studies 1, 2 and 4.

4.3.2. Two-phased research design

Groat & Wang (2013) argue that a mixed method approach is not merely mixing qualitative and quantitative data collection and analysis in research; the relationship between the methods needs to be aligned and integrated. Therefore, while outlining the mixed method approach of this thesis, a two-phased research design (Groat & Wang, 2013) was used. This means that the studies were designed to combine investigations into a sequence building on and complementing the results of the other inquiries. A fundamental aspect of the two-phased research design of this thesis was that the studies were carried out mostly parallel, providing input to each other simultaneously. Hence, the four studies should be understood not as a linear course of knowledge development but as an intertwined exploration of the complex phenomenon of the subject.



data collection (DC), data analysis (DA), writing process (W), publishing process (P)

Figure 5 – Timeline of the studies and resulting publications

To help the reader navigate the narrative of this dissertation, it is important to clarify the timeline and sequence of the studies. With regard to the timeline (Figure 5), the studies were initiated in the order of Study 1, Study 2, Study 3 and Study 4. However, the

corresponding papers were published in the order of Paper A, Paper C, Paper B and Paper D. The reversed order of publishing Paper C and B was due to the large scale of the data analysed in Study 3 requiring sole focus. Hence, the work on Paper B was halted and only continued after the submission of Paper C. Due to the reversed publishing order of Paper C and Paper B, the comparison of end-user preferences and the existing spatial design of apartment floorplans in Study 3 could not consider the results of Study 2. Instead, this comparison had to rely on the literature on contemporary end-user preferences regarding kitchen design.

Regarding the sequence of the studies, each study built on the results of the preceding studies. In the early stages of the research, the investigations of Study 1 facilitated the research orientation while exploring contemporary kitchen designs with an underlying aim of facilitating circularity in a residential context. For this reason, Study 1 had several objectives: (1) to identify circular value opportunities for the built environment by examining stakeholder activities and the value proposition associated with Swedish kitchens, (2) to explore relations and processes among stakeholders and their preferences and priorities regarding kitchen designs, (3) to develop an understanding of how kitchens are commissioned, designed, built and installed and (4) to anchor the focus of the overall PhD research. The main contribution of Study 1 was identifying spatial design as an important factor for circularity in the residential context. Additionally, the results pointed out research gaps that were pursued in further studies. First, Study 1 indicated important spatial characteristics that determine the spatial design of the kitchen. These characteristics needed to be further explored to identify all of which contribute to the spatial design of kitchens. Second, Study 1 provided insights into industry stakeholders' processes and preferences regarding kitchen design, including spatial aspects. This needed to be complemented by an exploration of end-user preferences. These new inquiries were carried out in Study 2 and Study 3.

Study 2 was designed to explore the end-user perspectives connected to the spatial design of kitchens. Additionally, Study 2 examined end-user alterations performed in their kitchens, comparing the spatial design before and after the alterations in floorplan drawings. The choice of exploring spatial alterations was based on the interest in investigating adaptability as an important principle of circularity that fundamentally relates to spatial design. Study 2 revealed end-users' preferences and priorities regarding the spatial design of the kitchen, complementing the industry perspectives of Study 1. At that stage, the research data outlined that spatial design's contribution to circularity lies in functionality and adaptability. Thus, the pursuing studies explored how functionality and adaptability were enabled or could be enhanced through spatial design.

Complementing Studies 1 and 2 (which focused primarily on the social aspects), Study 3 explored the materiality of spatial design by assessing the functionality and adaptability of floorplans. The aim was to compare stakeholder preferences and existing design guidelines with actual design solutions in contemporary residential buildings and their alignment with the circular paradigm. The functionality of space was explored by identifying and assessing determinants of a space (spatial characteristics). This assessment revealed current design solutions related to the kitchen, which was compared with the stakeholder preferences and design guidelines identified in Study 1 and previous literature. Adaptability was assessed through the adaptive capacity indicators of current design solutions connected to the

identified spatial characteristics. Due to the lack of suitable tools available to perform the assessments, in Study 3, a novel spatial analytical framework and adaptive capacity assessment criteria were developed (further explained in Sub-chapter 4.4.2.2). Evaluating the results of Study 3 once again led to a new line of inquiry. First, Study 3 identified a need to increase the adaptive capacity of multi-residential buildings' spatial design. Hence, exploring how this could be achieved required new investigations. Second, Study 3 assessed multi-residential buildings designed with a linear approach and prompted curiosity to evaluate how adaptability is addressed and enabled specifically in CBD. These aspects were explored in Study 4.

Study 4 stepped out of the kitchen context and broadened the explorations to the building level through two objectives: (1) identifying and analysing strategies enabling circular building adaptability and (2) outlining a conceptual design framework to enhance the concept's practical application. In this study, design solutions and strategies applied in CBD were explored through the reasonings of architects to understand how and to what extent circular building adaptability was considered or implemented in CBD.

4.4. Methods

The following sub-chapters provide an overview of the qualitative and quantitative data collection and analysis methods. The appended papers offer more extensive descriptions of the study-specific methods.

4.4.1. Data collection

In Studies 1, 2 and 4, the data was collected primarily through semi-structured interviews involving identified key stakeholders (such as housing developers, architects, a kitchen furniture producer, contractors, a real estate broker and end-users). In studies 2 and 3, floorplan drawings were collected. The data collection methods and reasonings for their relevance to the studies are presented in the following sub-chapters.

4.4.1.1. Semi-structured interviews

In alignment with the method of semi-structured interviews (Flick, 2018a), predefined study-specific questions guided each session. The semi-structured interview method was chosen to ensure that the topics of interest were investigated consistently in each study and in each interview while providing opportunities to explore additional topics emerging during the discussions with the interviewees. This method facilitated examining previously uncharted topics and was especially helpful in collecting data to reconstruct subjective viewpoints (as suggested by Flick, 2018a). The participants were introduced to the questions and study focus prior to the interviews. The interviews were recorded and transcribed with the consent of the interviewees. The collected data were handled according to GDPR.

In Study 1, the semi-structured interviews were carried out between 2019 and 2020. The interview participants (Table 5) were identified through a workshop organised by the CIK project team with employees of the project's key industrial partner (kitchen furniture producer). The workshop's objective was to map stakeholders connected to the kitchen using a power-interest grid for stakeholder prioritisation (adapted from Mendelow, 1981). Interviews focused on processes and preferences regarding how kitchens are commissioned, designed, built and installed in multi-residential buildings.

Table 5 - Overview of the participants of the interviews in Study 1 (as published in Paper A)

Case	Organisation	Participant	Relevance for study
A	Housing developer 1	Responsible for interior finishes (A1)	Coordinates end-user choices for kitchen and bathroom
		Project developer (A2)	Leads the project development from the first stages up to construction
B	Architect firm 1	Senior architect	Has long experience in multi-residential building design
C	Architect firm 2	Architect, CEO	Works regularly for the interviewed housing developer (A) and has 20 years of experience in housing projects
D	Architect firm 3	Senior architect, director of unit at a large international architecture and engineering firm	Acts as project leader for housing projects and has significant experience in drawing newly produced multi-residential houses
E	Real estate agency	Senior real estate broker	Has knowledge of sales processes and end-user preferences
F	Kitchen furniture producer	Business area manager (F1) *(construction projects)*	Oversees construction projects, develops collaboration processes for housing developer clients and handles contract negotiations
		Sales manager (F2) *(construction projects)*	Oversees project processes and has knowledge of production drawing process
G	Contractor and housing developer 1	Sustainability specialist (G1) *(project development)*	Manages sustainability questions connected to building projects
		Customer manager (G2)	Deals with client satisfaction and selects and manages the company's assortment of kitchens
H	End-user	Resident	Has recent experience in the sales process

Study 2 was part of a collaborative interview study, included in the research of two doctoral students of the CIK project (Sofie Hagejärd's and mine). The interview themes (spatial alterations, design preferences, activities performed in the kitchen, resource consumption and circular design strategies) incorporated questions related to the research topics of both of us. Part of the results (focusing on kitchen activities, resource consumption and circular design strategies) were reported in the publication of Hagejärd et al. (2020), while the analysis of the spatial alterations and connected design preferences of end-users were reported in Paper B. Due to the restrictions on the length of Paper B, certain details of the methods of Study 2 were not published. In the following, the method section of Paper B is complemented with additional information.

In total, 20 households were interviewed between 2018 and 2019. The interviewees were recruited following a convenience sampling (Flick, 2018b) via social media advertisements, a housing developer's newsletter, personal contacts and snowballing. The selection criteria had a broad scope and included various ages, household compositions and dwelling types. The interviews were performed in Swedish or English in the interviewees' homes. This enabled the interviewers to observe the interviewee's kitchen and the interviewees had the chance to show examples, enact certain activities or point to specific parts of the room while answering the questions.

Eleven of the twenty interviewed households performed alterations in their kitchens (Table 6). As per the subject of Study 2 (spatial alterations), only these eleven interviews were included in the data analysis. The selected interviewees represented a middle- to high-income segment of society living in relatively large apartments (n=4), villas (n=6) and terraced houses (n=1). Ten of the eleven households had some form of ownership of their dwelling. The ownership allowed them to perform spatial alterations more freely according to their preferences. In rental apartments, the tenants are usually limited to options that the landlord allows or performs. Consequently, tenants seldom are permitted or willing to perform alterations themselves. To demonstrate an exception, the sample included one case (I-11) where the tenant performed alterations at their own cost (permitted by the landlord). Studying alterations performed in owner-occupied dwellings helped to understand end-user preferences regarding spatial design solutions. These preferable spatial design solutions could also be implemented in multi-residential building design.

Table 6 - Summary of the demographical data of the interview participants of Study 2 and the features of their dwellings

Case	Gender	Age	Adults	Children	Monthly income (SEK)	Dwelling type	Dwelling size (m^2)	Number of rooms[1]
I-1	Woman	35-44	2	1	45 000 or more	Condominium	83	3
I-2	Woman	35-44	2	3	45 000 or more	Villa	133	5
I-3	Man	25-34	2	2	30 000 - 44 999	Terraced house	106	4
I-4	Man	25-34	2	0	30 000 - 44 999	Condominium	74	3
I-5	Woman	35-44	2	2	30 000 - 44 999	Villa	120	5
I-6	Woman	45-54	2	2	30 000 - 44 999	Condominium	109	5
I-7	Woman	45-54	2	3	45 000 or more	Villa	240	9
I-8	Man	35-44	2	3	45 000 or more	Villa	170	7
I-9	Woman	45-54	2	0	45 000 or more	Villa	180	8
	Man	55-64			45 000 or more			
I-10	Man	55-64	3	0	45 000 or more	Villa	~90	4
I-11	Man	55-64	2	0	30 000 - 44 999	Rental apartment	45	1,5
	Woman	45-54			45 000 or more			

1 excluding kitchen and bathroom

In Study 4, the semi-structured interviews were carried out between 2022 and 2023. Six interviews were conducted with six companies experienced in CBD (Table 7). The companies were selected through purposive sampling (Flick, 2018b). The selection criteria of the potential interview subjects were the following (as published in paper D):

- Building typology: The company's portfolio contained multi-residential buildings.
- Design approach: The multi-residential buildings were designed with CBD strategies. The building examples did not have to cover all CBD strategies (as identified by van Stijn & Gruis, 2019). However, the examples had to demonstrate the application of several CBD strategies in combination.
- Geographical location: The companies and examples were to be located in Europe. This criterion was meant to help understand design choices for similar social, cultural, technical, economic and climatic contexts.

The potential interviewees were identified through an online search and in previous literature. Additionally, interviewee C was identified as a recommendation from interviewee B. To date, only a few built examples were available due to the complexity that CBD entails (Cambier et al., 2021). Among built examples, the representation of multi-residential buildings was low (as observed during the search). Therefore, some interviewees were approached even if their circular building project was still in the conceptual phase. The search was conducted in English, which limited the identification of companies with projects reported on in other languages. The interview questions focused on three themes: (1) the professional background and CBD experience of the interviewees, (2) applied CBD strategies in their multi-residential projects and (3) the spatial configuration of dwellings with a particular focus on how adaptability is enabled (or not) in the design. Multi-residential building examples of the companies' portfolios were used as points of departure guiding the discussion. The aim was to discover the interviewees' strategies in CBD (rather than using the building examples as case studies). The interviews were used to identify the applied CBD strategies and to explore why they were chosen.

Table 7 - Overview of the participants of the interviews (based on Table 2 in Paper D)

Interviewee	Company's Profile	Interview Participant
A	design, development and realisation of construction and infrastructure projects, including maintenance, renovation and transformation	project manager, real estate developer and business administrator
B	architectural design, product development and digital production focusing on new circular solutions for housing	architect, researcher
C	design and development of circular buildings with a particular focus on adaptability	architect, real estate developer
D	CBD for the private and public sector	project leader and technical designer for building details and innovation
E	developing modular and circular housing systems for multi-residential buildings	architect
F	architectural design of buildings and cities with a focus on sustainable and circular solutions for liveable homes	architect and CEO of an architectural office

4.4.1.2. Archival documents and floorplan drawings

Floorplan drawings were collected in Studies 2 and 3. The floorplans provided a source to analyse spatial characteristics uniformly. They were suitable for documenting and comparing the different stages of the spatial design of a single case or across several cases.

In Study 2, the floorplan sample corresponded to the interviewee sample (as described in Sub-chapter 4.4.1.1). The purpose of collecting the floorplans was to document and analyse the performed alterations and identify end-user preferences connected to spatial design. The collected floorplans depicted the kitchens and dwellings before and after the spatial alterations. The 'before' floorplans were either hand-drawn based on the interviewees' descriptions or collected as digital or printed documents from the interviewees. The 'after'

floorplans were hand-drawn during the interviews performed in the participants homes. The outcome of the alterations was further documented through photographs.

In Study 3, the floorplans were collected from the archives of Gothenburg's city planning office. According to Groat & Wang (2013), using archival material as a data-collection method is a typical but less frequently used approach in quantitative research. Using the archives of Gothenburg's city planning office provided an exhaustive set of apartment floorplans. These floorplans were initially collected as part of the material published in the book Bygglov Göteborg 2017 (Granath et al., 2022). Through purposive sampling, 38 housing projects of the collected material were included in Study 3 based on the following criteria:

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

The purpose of collecting contemporary apartment floor plans was to analyse current spatial design solutions across a significant and reliable number of cases. The analysed sample comprised n=3,624 apartment units with 574 different floorplan variations. In 2017, in Sweden, 35,783 apartments were built (Statistics Sweden, 2020), which means that the studied sample represented more than 10% of the total national production. The selected building projects were located in Sweden's second-largest urban area. The sample gave a well-grounded relevance for the analysis and results regarding the number of cases and their location.

4.4.2. Data analysis

The empirical material of the qualitative studies (Studies 1, 2 and 4) was analysed through qualitative content analysis (Flick, 2018c). The analysis was carried out in the program NVivo. In Study 3, a novel spatial analytical framework and adaptive capacity criteria were developed to assess the functionality and adaptability of the floorplan drawings. The results of the assessments in Study 3 were summarised through descriptive statistics. The following sub-chapters describe these data analysis methods.

4.4.2.1. Qualitative content analysis

The analysis of the empirical material in Studies 1, 2 and 4 followed the steps of qualitative content analysis (Flick, 2018c; Schreier, 2014). These steps were (1) establishing research questions, (2) selecting material, (3) building a coding frame, (4) defining the direction of analysis guided by the research questions (segmentation), (5) trial coding, (6) evaluating and modifying the coding frame, (7) performing the analysis and (8) presenting and interpreting the findings (Schreier, 2014, pp.174-175). Qualitative content analysis enabled the assessment of rich empirical data with a thematic focus (as per Flick, 2018c). Compared to other qualitative analysis methods, qualitative content analysis focuses primarily on synthesising the material (Flick, 2018c). However, the last step of this method conveyed that this type of analysis was still sensitive to interpretations. Methodological triangulation was

used to mitigate the weaknesses of the interpretive process (as recommended by Flick, 2018c).

In Study 1, the aim was to uncover information connected to the study-specific themes: interests (of stakeholders), process map (connected to the kitchen), roles (of stakeholders) and visions (for an ideal kitchen). These themes comprised the coding frame, which was continuously expended in case sub-themes emerged (inspired by Gioia et al., 2012). The results of the analysis were further assessed by applying the value mapping tool (Bocken et al., 2015) to identify and evaluate the underlying value proposition within the themes mentioned above. The analysis followed the brainstorming process of Bocken et al. (2015): (1) identifying the stakeholders' collective purpose, (2) identifying positive values, (3) identifying negative values and (4) turning the negative values into positive ones by proposing improvements. Based on the identified aspects of the value proposition, four circular value opportunities for the built environment were highlighted in Paper A.

In Study 2, codes of the qualitative content analysis were predefined based on the research questions focusing on end-users' spatial alterations and design preferences. The codes focused on the design of spatial characteristics, the design preferences of end-users connected to those spatial characteristics and the spatial alterations the end-users performed. The codes were complemented in case new themes were discovered during the analysis.

In Study 4, the ten circular building adaptability determinants (Hamida et al., 2022) were used as a coding framework to analyse the empirical material. The determinants served as predefined codes to classify the design strategies mentioned by the interview participants. Additional codes were created in case new themes relevant to understanding the application of certain design strategies emerged. The analysis of the interviews provided a collection of design strategies enabling circular building adaptability and gave an insight into how CBD principles are considered and applied in multi-residential buildings. Based on the results of the analysis and inspired by Geldermans' (2016) inventory matrix, a conceptual design framework was developed to support a systematic implementation of circular building adaptability determinants.

4.4.2.2. Floorplan analysis

Floorplan analysis was used in Study 2 to compare the floorplans before and after the spatial alterations of the interviewees. The aim was to identify end-user processes and preferences connected to spatial design by examining which spatial characteristics they alter and how. To analyse and evaluate which important spatial aspects, it was necessary first to identify which spatial characteristics determine the spatial design of the kitchen. This identification process was part of Study 3 (explained in the next paragraph). Based on the identified spatial characteristics in Study 2, the before and after states of the dwelling floorplans were compared (as exemplified in Figure 6) and the differences were documented. Informed by the floorplan analysis and identified design preferences of the interview participants, design strategies were proposed to support circularity through the spatial design of the kitchen. It is important to highlight that the proposed design strategies emerged from the available empirical data and do not cover all possible and necessary strategies. There is a need to continue the explorations and complement the proposed strategies in further research.

Figure 6 – The floorplan of the terraced house (I-3) before (a) and after (b) the alterations (DW: dishwasher, F: fridge or freezer, O: oven, S: stove) (as published in Paper B)

In Study 3, floorplan analysis was used to assess the circular potential of spatial design. A novel spatial analytical framework and adaptive capacity criteria were developed to facilitate the analysis. The first step of the development process was to identify spatial characteristics that determined the studied dwelling function, the kitchen. The spatial characteristics were identified by studying previous literature on guidelines for kitchen design (including the results of Paper A) and Swedish building regulations and standards. The identified spatial characteristics are described in Sub-chapter 5.3.1. In total, eleven spatial characteristics were identified: room typology, open floorplan, doors, kitchen typologies, kitchen island, floor area, infrastructure, daylight and windows, dining area, accessibility and efficient work-triangle (distances between the sink, stove and fridge). Those spatial characteristics which could be assessed in floorplans were incorporated into the spatial analytical framework. Accessibility was excluded from the analysis since this feature is highly regulated and enforced by authorities in newly built residential buildings. Likewise, distances between the three workstations of the work-triangle (fridge, sink, stove) were not measured since the current trend of shrinking apartment sizes prevents unnecessarily long distances between these workstations. Additionally, characteristics (such as apartment size) and statistically relevant information (such as the number of rooms) connected to the apartments were also measured. The identified spatial characteristics were evaluated based on assessment values developed in line with design guidelines and functional requirements outlined by the literature. A detailed description of the measured spatial characteristics and the connected assessment values can be found in my Licentiate thesis (Ollár, 2021, pp.30-36) and the appended Paper C. The spatial analytical framework was tested, iterated and finally used to evaluate n=3,624 contemporary apartment floorplans. The schematic representation of and more details about the spatial analytical framework can be found in Paper C.

Study 3 took inspiration from the adaptive capacity indicators of Geraedts et al. (2014) (definition and more details in Paper C) to evaluate the adaptive capacity of the apartment

floorplans. While adaptability is a value created through design solutions (Geraedts et al., 2017), adaptive capacity is a metric for measuring a building's ability "[…] to cope with future changes with minimum demolition, cost and waste and with maximum robustness, mutability and efficiency" (Sinclair et al., 2012, p.40). The adaptive capacity indicators of Geraedts et al. (2014) assess buildings' or building units' ability to enable major and minor changes in the finishings, floorplan, room organisation, infrastructure or structural components. These indicators were adjusted to the dwelling function (kitchen) investigated in Study 3. The adjusted indicators and their definitions are presented in Table 8. As a next step, questions (means of assessment) were developed to enable the assessment of the apartment floorplans' adaptive capacity (see Table 6 of Paper C). Two indicators were not measured: Renew and Rewire. Strategies for the Renew indicator included tasks that the end-user might achieve quickly (such as repainting or exchanging the fronts of the built-in furniture) and did not require spatial changes. The Rewire indicator was studied in the context of the Relocate indicator. The relocation of the kitchen and built-in furniture would automatically require modification of the connected infrastructure outlets.

Table 8 - Overview of adapted indicators and their definitions (as published in Paper C)

Indicators*	**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	Reconfigure	Changing the kitchen's relation with other rooms in the apartment (e.g., opening, removing or relocating doors or walls)
Grain size		
Facilities	Rewire	Changing the facilities (infrastructure outlets) in the kitchen
Reallocate Internal	Relocate	Changing the location of the kitchen within the apartment
Transfer		
Expansion	Expand or reduce	Changing the kitchen's use surface, increasing or decreasing its floor area
Rejection		

* as in Geraedts et al. (2014)

4.5. Validation of results

The four studies provided insight into spatial design's contribution to circularity, which was validated through a complementary investigation. The investigation included three group interviews with architects and strategic interviews and a workshop with housing developers and managers. This investigation revolved around how housing developers and architects consider spatial design aspects in residential building projects and what processes, roles, requirements and responsibilities they had connected to it. Sub-chapter 5.5 summarises the unpublished results of this investigation.

The three semi-structured group interviews involved senior architects experienced in residential design and practising at different architectural firms. In total, ten architects

participated in the group interviews. At each session, three different firms were invited. Each firm had one representative in the first and second sessions (3 participants per session). In the third session, one of the firms was represented by two employees (4 participants per session). The discussions focused on their design processes and preferences connected to the spatial design of kitchens, influencing factors in their decision-making processes, good examples, common mistakes and their views on current building regulations.

The group interviews were followed by individual interviews with seven housing developers and managers (a mix of organisations developing apartments for sale and rent), one procurement company and one company providing kitchen renovation services (Table 9). The questions investigated the housing developers' requirements regarding the spatial design of kitchens when procuring new multi-residential buildings, whether these requirements were formally documented, their processes evaluating finished building projects post-production, their sustainability or circularity ambitions and their views on current building regulations. Afterwards, the participants of the individual interviews were invited to a workshop where possible future requirements supporting circularity through the spatial design of kitchens were discussed.

Table 9 - Overview of the participants of the individual interviews

Interviewee	Position/Responsibility	Organisation profile
I-1	Project manager	Housing developer and manager
I-2	Responsible for building maintenance, environmental coordinator	Housing manager
I-3	Regional manager for Göteborg specialised in business development and procurement	Procurement company
I-4	Sustainability specialist	Kitchen renovation company
I-5	CEO	Housing developer and manager
I-6	Environmental coordinator	Housing manager
I-7	Project manager	
I-8	Project manager	Housing housing manager
I-9	Project manager	
I-10	Project developer	Housing developer and manager
I-11	Sustainability specialist	
I-12	CEO	Housing developer
I-13	Project developer	

4.6. Methodological considerations

This sub-chapter provides reflections on the overall methodological choices connected to the intersubjective approach and spatial theory. Additionally, it discusses strengths and limitations connected to study-specific methods with regard to sampling, data collection and data analysis. This sub-chapter also reflects on the project context's influence on the thesis work and the results' contribution to the activities of the project. This is followed by a reflection on the validity, generalisability and transferability of the results and conclusions.

4.6.1. Reflections on methodological choices

The intersubjective approach allowed to comprehensively study and synthesise the qualitative and quantitative, as well as the physical and non-physical aspects of the subject. While adopting an intersubjective approach, reflecting on the researcher's involvement in knowledge development is necessary. My professional background, knowledge, experiences and preconceptions contributed to and influenced the research. My profile as a (female) architect specialising in design for sustainable development brought knowledge of environmental, economic and social considerations to the research table. This also influenced (consciously and unconsciously) the focus of the studies. Additionally, being a foreigner in the investigated cultural context allowed me to be an external observer but limited my understanding of social codes and conventions. Furthermore, conducting empirical research in a second language (English and Swedish) where communication with the participants of the qualitative studies is at the centre of data collection put restraints on the content and depth of what the participants expressed and the nuances I could comprehend. This was mitigated by conducting the interviews in pairs with a native Swedish speaker researcher. These factors were considered while interpreting the results of this research.

The theoretical framework of spatial theory helped reflect upon the entanglement of social and material aspects of spatial design. It enabled understanding and describing how social and material aspects mutually influence one another. The application of spatial theory has proven valuable in describing these interconnected aspects, offering a deeper understanding of their components and revealing the nature of their relationships. However, the studies made limited use of the methodological grounds of spatial theory; instead, this theoretical perspective was used as an analytical tool when synthesising the study results. Incorporating the methodological grounds of spatial theory to a larger extent in the research design might have enriched the empirical evidence.

The mixed-method approach enabled both qualitative and quantitative explorations of the subject of this thesis. However, due to the nature of a PhD research (long duration, exploring complex problems, acquiring research skills), aligning the individual studies sometimes presented challenges since they were not only guided by identified research gaps but also by the project context, project partners' expectations and predetermined founding deliverables. The two-phased research design was instrumental in addressing this particular challenge. It facilitated a cohesive research design and enabled the integration of individual studies into a comprehensive research project.

The qualitative nature of Studies 1, 2 and 4 allowed to explore and summarise stakeholder processes and preferences while understanding the underlying motivations. However, the participants of the qualitative studies foremost included industry stakeholders (housing developers, housing managers, architects, a kitchen furniture producer, contractors and a real estate broker) and end-user perspectives were explored through the input of a limited number of participants. This restricted the extent of investigating end-user preferences, which meant that conclusions had to be made cautiously. Nevertheless, the studies still gave valuable indications that need further exploration in future research.

The quantitative approach in Study 3 enabled the exploration of a large sample of data, including a substantial number (n = 3,624) of contemporary apartment floorplans. This provided reliable data regarding spatial design features and their adaptive capacity in

current residential building design. However, this approach restricted the evaluation to aspects that can be measured in a two-dimensional context and excluded three-dimensional features, such as room height, window placements, artificial light positions, upper cabinets and technical installations related to plumbing and ventilation systems. An additional methodological challenge that emerged during the research design of Study 3 considered the available frameworks for assessing adaptability in the circular design context. When developing the means of assessment for the adaptive capacity apartment floorplans, no comprehensive theoretical frameworks have yet integrated the concepts of adaptability and circularity. Consequently, the study relied on existing theories related to adaptability in general, which, at that time, provided the most reliable method for the assessment. However, in hindsight, an alternative approach could be considered today to produce more coherent results. Instead of using adaptive capacity indicators, the determinants of circular building adaptability could be integrated into the proposed analytical and assessment frameworks. While there are overlaps between the adaptive capacity indicators and the circular building adaptability determinants, the latter provides a more comprehensive framework tailored for adaptability in the circular paradigm. Aligning the assessment criteria with the theoretical framework of circular building adaptability might achieve a more robust evaluation of the floorplans' adaptive capacity. This adjustment would enhance the validity of the results and contribute to the field of circular building adaptability. Looking ahead, exploring these subjects could be considered as potential future work, enriching empirical investigations into how circular building adaptability influences current housing design.

4.6.2. Reflections on the project context

The CIK project served as an excellent starting point for my research, providing me with valuable insights into the processes related to kitchen design. However, after the initial phases, my research trajectory diverged from the development of the furniture design. While the work in the project continued the prototyping and commercialisation of furniture design, my research contributed to the knowledge development within the CIK project by exploring spatial aspects of the room. This was important since a circular kitchen furniture design would not have been a freestanding artefact but an integrated part of a room. Hence, the furniture and spatial design of the room must align to facilitate CE principles in the long term. However, I encountered difficulties supporting the furniture design development with results from my research.

Recommendations derived from both the literature I reviewed and my studies were occasionally overlooked during the furniture design development due to compromises based on logistics, expectations and preferences of the project partners, aesthetical considerations, financial reasons or spatial constraints. Interestingly, this was also an issue I observed in my studies while investigating existing design processes of residential buildings. This demonstrates that merely intending to create circular products is not sufficient. Instead, there's a need for novel approaches that support the design process of circular products. It became evident that the industry's design processes still require significant transformation and a shift in priorities is necessary to transition towards circularity. The encountered difficulties also highlight the challenges in advocating for spatial design solutions supporting circularity.

4.6.3. Validity, generalisability and transferability

The validity of the qualitative investigations of the research was ensured by employing established methods and adopting methodological pathways developed for housing research. In the quantitative study, validity was aimed to be established by the large and representative sample of the floorplans. The data collection and analysis of the studies were performed in a transparent manner and conclusions were rooted in the available data. However, it is important to acknowledge that the results and knowledge development of this research were influenced by the active participation of the research team (including me). To reduce the impact of the potential bias and influence of the research team, various methods and sources for data collection were employed. Furthermore, the overall research results were validated through interviews and workshops with architects, housing developers, housing managers and some of their suppliers.

Several aspects need to be considered with regard to the generalisability of the results to a broader context. The studies were conducted with the involvement of a limited number of end-users representing a narrow part of society and a small segment of industry stakeholders in the design process. This limited the breadth of perspectives and experiences considered. Nevertheless, the studies provide valuable insights which would benefit from further research involving a broader range of stakeholders. Moreover, some stakeholder statements were context-dependent, which further impacted the generalizability of the results. It is important to remember that these results are socially grounded, meaning they are deeply intertwined with the specific Swedish socio-cultural context in which the research was conducted. This particular context may limit the generalizability of the results.

The Swedish socio-cultural context also potentially reduced the transferability of the results to other cultural or geographical contexts. However, there are commonalities in socio-cultural specificities across Western cultures. Therefore, I can reasonably infer that the results of this research can be applied to similar socio-cultural contexts, albeit with caution and consideration for the unique characteristics of each context. Additionally, focusing on the kitchen also puts certain constraints on the transferability of the generated knowledge. The investigations focusing on the kitchen resulted in insights connected to one dwelling function. The kitchen is a specific part of the dwelling due to its fixed installations (infrastructure, appliances and built-in furniture) and wide range of activities. Nevertheless, the broader results might easily be adapted to less specific spatial contexts.

5. Summary of results

This chapter is structured according to the four studies. Each sub-chapter provides a summary of the study-specific results. The sub-chapters first give an overview of the study aims, methods and research outputs (publications), followed by the key results of the study. The results of the validation study are outlined at the end of this chapter. A more detailed version of the study-specific results can be found in the corresponding papers.

5.1. Study 1: Circular value opportunities for the built environment

Aim	Exploring stakeholders' preferences and processes (with an industry focus) connected to the design, construction, utilisation and alteration of the kitchen's spatial design
Study participants	Stakeholders (n=11 participants): housing developer and manager (1 firm, 2 participants), architects (3 participants in total, 1 participant/firm), kitchen furniture producer (1 firm, 2 participants), contractor (1 firm, 2 participant), real estate broker (1 participant), end-user (1 participant)
Data collection	Semi-structured interviews, Workshop, Focus group
Data analysis	Qualitative content analysis combined with value mapping
Output	Paper A (journal paper)

5.1.1. The stakeholder network and value proposition of the Swedish kitchen

The mapping of the design and construction processes related to kitchens (which was a typical process at the time of the research) showed that usually the housing developer initiates a building project and collaborates with architects to determine the design features of the building, which include the apartment floorplan and the spatial design of the kitchen. The architect then refines the building design following the housing developer's guidelines and preferences. The kitchen furniture producer is typically involved in the development of detailed drawings. A building permit is secured once the building design, including the kitchen, is finalised. At this juncture, the architect's role in the project concludes and the contractor assumes responsibility for the architectural drawings. Prior to construction, approximately 30% of the dwellings in the housing project are typically sold based on drawings, 3D renders or showrooms. The housing developer oversees an interior design process where end-users can personalise their apartments by selecting various finishes and material options. However, end-users do not participate in determining the floorplan or spatial design. Once the interior design process is completed, the kitchen furniture is manufactured and delivered to the site fully assembled for installation.

All stakeholders, except the housing developer, participate only in specific segments of the housing development. The architect, kitchen furniture producer and contractor expressed a desire to be involved in a larger or entire portion of the development process to ensure quality, enhance collaboration and prioritise end-user satisfaction. The segmented stakeholder network has led to conflicts in stakeholders' interests, such as balancing economic and logistical priorities against design quality and end-user preferences. Despite these conflicts, the stakeholders shared common goals in their value proposition, which include (1) creating aesthetically pleasing kitchen furniture that complies with regulations and meets end-user needs, (2) designing the kitchen as a functional and livable space and

(3) developing economically viable projects with transparent processes and streamlined logistics. Study 1 further revealed that stakeholders have vast knowledge of the spatial characteristics of the kitchen and share numerous design preferences related to them. This validated the focus of this research and further studies were planned, with a greater emphasis on the spatial design of the kitchen.

5.1.2. Values captured

Study 1 identified positive values of the value proposition associated with current kitchen design (Table 10). The values expressed by the stakeholders focus on three themes: furniture and appliance design, spatial design and processes and economy. The most promising positive values are the modular design system of the built-in furniture, the established collaborations within the industry, design intentions for proper living spaces, the emphasis on spatial qualities and an increased interest in end-user preferences. These positive values could potentially be utilised as an initial foundation for developing a kitchen design that aligns with circular design principles. Connected design processes must also consider aspects such as standardisation, extended collaboration in the stakeholder network and design solutions encouraging end-users to adopt behaviours in line with CE principles. Such an approach to kitchen design could support the CE's emphasis on longevity, renewability and reduced environmental impact.

Table 10 - Summary of identified captured values for the Swedish kitchen (as published in paper A)

Stakeholder segments	**Value captured (positive aspects of the value proposition that can support circularity)**	
Network actors	Furniture and appliance design	Modular design
		Functional furniture
		Practical workflows for working in the kitchen
		Selected base assortment
		Demand for durable materials
		Design harmony and aesthetics.
	Spatial design	Open layouts enabling social engagement
		Specific accessibility regulations
		Preferred functional layouts
		Daylight requirements
		Intention to create liveable spatial design
		Small, compact apartments that have less environmental impact
		Dimensions of room determining furniture
		Design harmony and aesthetics
	Processes and economy	Existing partnership agreements
		Well-established collaborations aiming at effective communication
		Rising interest in end-user wishes
		Increased internal sustainability ambitions
		Similar goals and interests among stakeholders
End-user	Demand for long-lasting and energy-efficient appliances	
	Increased interest for technical solutions (e.g., connected apps)	
	Preferences for neutral colours and design	
	Options for end-user choices	
Society	Regulations and standards for good kitchen solutions	
	Extensive regulations connected to apartment design and kitchen	

5.1.3. Values missed, destroyed or wasted

Table 11 presents the identified negative values of the value proposition associated with the current kitchen design. These negative values include, for instance, the linear processes, the limited end-user involvement, the limitations of standardisation (lack of innovation, alternative solutions and adaptability), the lack of consideration for the environment and society, the more compact living spaces, the lack of product and material recovery and the strictly applied minimum dimensions of the built-in equipment mandated by regulations. These negative values hinder the uptake of circularity in residential building design by sustaining practices (e.g., environmental pollution, excessive resource use and waste generation) that go against CE principles.

Table 11 - Summary of missed, destroyed or wasted values within the value proposition of the Swedish kitchen (as published in Paper A)

Stakeholder segments	**Value missed, destroyed or wasted (negative aspects of the value proposition that can hinder circularity)**	
Network actors	Furniture and appliance design	Modular dimensions of furniture: lack of innovation opportunities
		Unsustainable material use, lack of alternatives
		Lack of correlation between standard measures of appliances and furniture
		Decreased flexibility for renovations due to built-in furniture and appliances
		Quality differences based on location of housing project and target group
	Spatial design	Lack of experimentation and innovation
		Lack of flexibility and adaptability
		Shrinking, more compact apartment sizes
		Strictly following the minimal requirements of regulations leading to inflexible apartments
		Inflexible infrastructure (electricity, plumbing, ventilation)
		Lack of simple separation options for open floorplans
	Processes and economy	Linear process
		Stakeholders are engaged in a limited part of the process, 'relay run'
		Hesitant company culture
		Complex and long value and supply chain
		Economic pressure governs (design) decisions
		Furniture usually delivered fully mounted, increased transport
		Sustainability or circularity is not a priority
		Costly repair work to refresh or refurbish furniture
		High precision for installation– increased logistics
		Complex parts of furniture (e.g., long worktops) - difficult to deliver and install
End-user	Lack of direct feedback and evaluation channels	
	Exclusion from design processes	
	Limited options for personalisation (only final finishings)	
	Increased number of electric devices in the kitchen	
	Some demands result in economic or logistical conflicts (e.g., kitchen islands, long worktops without gaps)	
Society	Lack of regulations for more circularity measures	
	Minimum requirements for design of homes (storage, m^2, etc.) being strictly applied as an upper limit	

5.1.4. Value opportunities

Value opportunities were formulated based on suggestions of the interview participants and those of the research team (Table 12). These were clustered into four groups: (1) align spatial and product design for circular economy, (2) consider end-user perspectives and demands, (3) formulate regulations based on research outcomes and (4) develop circular products and services through collaboration.

Table 12 - Summary of value opportunities (as published in paper A)

Stakeholder segment	Value opportunities (potentially supporting circularity, including improvement proposals)		Cluster
Network actors	Furniture and appliance design	Long-lasting design[1]	Align spatial and product design for circular economy
		Increased standardisation[1]	
		Practical, functional, aesthetically appealing furniture well-equipped with storage[1]	
		Flexible basic furniture arrangement to enable variety and adaptability[1]	
		Mobile furniture solutions[1]	
		Feasible, durable, sustainable alternative materials which are easy to refresh or renovate[1]	
		Energy-efficient and multifunctional appliances[2]	
		Lifecycle extension of kitchen products[2]	
		Attractive modular worktop solutions with sealed gaps[2]	
	Spatial design	More straight-kitchens and less corners[1]	
		Reasonable spatial margins (e.g., enabling flexibility or kitchen islands)[1]	
		Easy and flexible separation solutions to divide open floorplans[1]	
		Spacious dimensions for number of users and functional workflow[1]	
		Adaptable and flexible layout solutions[1]	
		More flexibility in electricity, plumbing and ventilation infrastructure and outlets[2]	
	Processes and economy	Challenging the idea of delivering kitchens fully assembled[1]	Develop circular products and services through collaboration
		Aligned standards and expand collaborations[2]	
		Understanding long-term market dynamics [2]	
		New business models[2]	
		New partnerships[2]	
		New loops and services (reuse, refurbish, recycle)[2]	
End-user	New feedback channels[1]		Consider end-user perspectives and demands
	Evaluation of user demands[1]		
	Increased user involvement[2]		
Society	New regulations demanding sustainability and circularity[1]		Formulate regulations informed by research
	Regulations possibly requiring reasonably generous dimensions to enable flexibility and adaptability[1]		

[1] Improvement proposals from stakeholders, [2] Improvement proposals from authors based on identified missed, destroyed and wasted values in line with CE goals

Regarding spatial and product design, stakeholders have proposed enhancements to existing approaches. The stakeholders valued long-lasting design solutions and the ease of

refurbishing the built-in furniture. They suggested standardised yet adaptable floorplan solutions and modular designs for the built-in furniture to optimise logistics and cater to end-user preferences. Anticipating multiple versions of the same apartment floorplan was put forth to enhance adaptability. These variations could facilitate easy modifications to the floorplan to meet the needs of future end-users. The end-user preference for separating the kitchen from the living room for privacy reasons was noted among some of the interview participants. For this reason, in one example, the architects offered various strategies to establish an open yet visually separated kitchen and living room space. It was also recommended that a spatial margin in the room should be allocated during the design phase to accommodate potential future spatial alterations. The kitchen's dimensions directly dictate the furniture's design and workflow. Therefore, the measurements of the room and the built-in furniture must be synchronised. Altogether, the stakeholders underscored the significance of the kitchen as a versatile space that should be functional, visually appealing and sufficiently dimensioned for kitchen-related activities and storage spaces.

The study participants demonstrated a limited willingness to transition towards a CE. They have only contemplated minor modifications, such as questioning the practice of delivering fully assembled kitchens or formulating sustainability strategies for their companies. These changes were devised and executed at the organisational level rather than in collaboration across the stakeholder network. This highlights the necessity for expanded collaboration among the stakeholders.

All stakeholders expressed a desire for more direct feedback mechanisms with end-users, such as interviews. Stakeholders could create new avenues for understanding end-user preferences and integrating those early in the design process. A broader assessment of end-user preferences or more comprehensive end-user involvement could result in more functional and adaptable solutions, allowing for customisation to suit the diverse preferences of end-user groups and individuals.

Despite some stakeholders expressing dissatisfaction with current building regulations, only a few potential enhancements were suggested. The kitchen furniture producer indicated that new regulations promoting sustainability and circularity could expedite the CE transition by mandating change across all stakeholders. This would mitigate the risks associated with being the first to implement CE principles in the design and production processes. Some participants also proposed that regulations could mandate larger minimal dimensions to facilitate future adaptability. However, it was pointed out that this aspiration was at odds with the economic prioritisation that currently underpins the building industry.

5.2. Study 2: Kitchen alterations and their design implications

Aim	Exploring stakeholders' preferences (with an end-user focus) and processes connected to the design, construction, utilisation and alteration of the kitchen's spatial design
Study participants	End-users (n=14 participants in total in 11 households)
Data collection	Semi-structured interviews, Floorplan drawings
Data analysis	Qualitative content analysis combined with floorplan analysis
Output	Paper B (conference paper)

5.2.1. Kitchen alterations

The interviewees shared the importance of transforming their kitchen into a space that suited their everyday habits. They additionally mentioned aesthetical and functional preferences related to kitchen design. Ten households deliberated and planned the performed alterations for a long time but eventually commenced with the changes. The interviewees expressed that they felt the alterations were necessary to create a home where they thrived. The alterations lasted between a week and 1.5 years. The significant difference in the duration of the alterations was due to several factors, such as the size of the kitchen, the extent of the alteration and whether the alterations were carried out by professionals or the owners themselves. The overview of the changes is summarised in Table 13 and the outcome of the kitchen alterations of the interview participants are shown in Figure 7.

The eleven households made diverse spatial alterations to their kitchens. The extent of the alterations seemed to be defined by the dwelling type. In villas and terraced houses - with more space to execute changes - more extensive alterations were carried out, such as constructing additional rooms, opening new doors, moving windows, removing walls or installing kitchen islands. In apartments, where such expansion of the physical boundaries of the dwelling was not possible, the interviewees worked within their limitations. They kept the layout of the built-in furniture, refrained from making structural changes to the room and focused on aesthetic improvements to the built-in furniture, appliances and finishings.

While describing the alterations, the interviewees shared enabling and hindering factors, which were further examined during the analysis of the 'before' and 'after' floorplan drawings. The primary constraint was the original design of the buildings. Spatial characteristics that were difficult or impossible to change influenced spatial alterations. For instance, as already described above, the lack of over-capacity of the free floor area often presented restrictions. Additionally, seven households had to modify the infrastructure systems (electricity, plumbing, ventilation) during the alterations. These modifications were complex and resource-intensive since accessing and altering the infrastructure systems were challenging and labour-intensive. Furthermore, the window locations and the direction and source of natural daylight were spatial pre-conditions that were almost impossible to change. Instead, the participants moved daylight-dependent functions close to existing windows or merged the kitchen with another room to create a brighter space.

The interviews and floorplan analysis revealed four main spatial design preferences of the participants. First, when possible, the participants created more free floor areas in the kitchen to enable active social use of the space. Second, half of the participants opined that they preferred a separate room for the kitchen to reduce noise disturbances or the spreading of odours resulting from cooking. Additionally, the performed spatial alterations also showed that, after the alterations, the kitchen was well-connected to other 'public' parts of the home. Third, the dining area was an important function of the kitchen; many participants ensured a prominent and well-situated place for this function (close to a natural daylight source, in or close to the kitchen). Fourth, all participants changed the built-in furniture to improve its aesthetic and functional performance. The interviewees often expressed the need for more storage space and longer work surfaces. They also highlighted the underdimensioned waste sorting spaces, typically located under the sink. To mitigate this issue, the interviewees utilised alternative areas in their homes (e.g., garage, entrance, balcony) for waste sorting.

Table 13 - Features of the interview participants' dwelling and kitchen before and after the alterations (changes marked with grey) (as published in Paper B)

Case	Dwelling type	Dwelling size (m²)	Room typology[1]		Floorplan[2]		Door[2]		Built-in furniture, storage, worksurface[3]		Kitchen typology[4]		Kitchen island		Window		Dining area[2]	
			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)

[1] A: dead-end room typology, B: pass-through room typology, C: room within an internal ring

[2] Ba: balcony, DR: dining room, H: hall, La: laundry room, LR: living room, K: kitchen, T: terrace

[3] including built-in appliances, c.: cabinets, u.: unit = 60 cm wide cabinet

[4] L: L-kitchen, S: straight-kitchen, P: parallel-kitchen, U: U-kitchen, KI: kitchen island

Figure 7 – The kitchens of the interview participants after the alterations (photos by Anita Ollár and Sofie Hagejärd)

The empirical material also provided insights into the design of the built-in furniture. In each case, the alterations led to modifications of the built-in furniture. Only one participant chose to repaint the fronts of the existing kitchen and another decided to buy second-hand cabinets. The other nine interviewees replaced the old built-in furniture with new ones. The participants expressed that they felt there were no effortless and feasible alternatives to adjust their current furniture (aesthetically or functionally). This indicates a need for a built-in furniture design and supporting business model that enables easy alterations and reduces material flows and environmental impacts (confirming the CIK project's necessity).

5.2.2. Design implications for the spatial design of the kitchen

The empirical material showed that the original design of spatial characteristics defined what type of alterations were possible. Certain spatial characteristics were more difficult to change (infrastructure, the location and distribution of windows, free floor area, room organisation and door locations) and there were some that end-users had more control over (built-in furniture, location of the dining area). This implies that it is important to implement functional and adaptable solutions in the original design, especially those related to spatial characteristics, which are more challenging to alter. Additionally, those spatial characteristics over which the end-users had more control were bound to be altered more often. Hence, design choices that enable low-impact alterations and reduce resource use and waste production are also important to implement in the original design.

Regarding the spatial design of the kitchen, the empirical material helped identify preferences of end-users, which led to design recommendations. It is important to point out that these recommendations focus on the preferences of the interviewed end-users (representing a niche of society). Additionally, spatial design is a complex exercise and more aspects than the items below must be considered. However, the results and recommendations of Study 2 showcase important end-user preferences that need to be attended to while formulating functional and adaptable (kitchen) spaces of a dwelling. The design recommendations of Study 2 are the following (as published in Paper B):

- 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 work surfaces 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.

5.3. Study 3: Current kitchen design and its circular potential

Aim	Identifying spatial characteristics (as determinants of spatial design) and assessing the circular potential of spatial design
Data collection	Archival documents – floorplan drawings of apartments in multi-residential buildings with a building permit from 2017 (n=3,624)
Data analysis	Floorplan analysis, Descriptive statistics
Output	Paper C (journal paper)

5.3.1. Spatial characteristics of kitchens

A detailed description of the spatial characteristics connected to kitchen design has been published in my Licentiate thesis (Ollár, 2021, pp.30-36). While the examined literature provides extensive guidelines regarding the functionality of the space and describes end-user preferences connected to some of the identified spatial characteristics (room typology, combined kitchen-living room, kitchen islands), it gives less input on creating solutions for enabling adaptability. An overview of the identified spatial characteristics can be found in Table 14.

Table 14 - Overview of identified spatial characteristics of kitchens (based on Table 2 of Paper C)

Characteristics	Important design trends and features	Sources/References
Room typology	The kitchen's direct connection with the living room, entrance and outdoor spaces Evolving over time (the 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 & Hanson, 1984) (Hallberg & Thiberg, 1985) (Bafna, 2003) (Manum, 2005) (Thiberg, 2007) (Manum, 2009) (Geromel, 2016) (Hillier, 2007) (Nylander, 2018) (Brkanić et al., 2018) (Caldenby et al., 2019) (Femenías & 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, kitchens must be separable (after separation: appropriate floor area for room functions with at least one window for direct daylight)	(Thiberg, 2007) (Nowakowski, 2015) (Femenías & Geromel, 2019) (Tervo & Hirvonen, 2019) (Örnhall, 2019) (Ollár et al., 2020) (BFS 2011:6)
Doors	The position of doors influences the flexibility of use and furnishability of the space The recommended number of doors in the kitchen is two It is more challenging to create new door openings than to restrict the use of existing ones	(Hallberg & Thiberg, 1985) (Nylander, 2002) (Thiberg, 2007) (Nowakowski, 2015)

Table 14 (continued)

Characteristics	Important design trends and features	Sources/References
Kitchen typologies	Straight-kitchen: the sink, work surface and stove are placed along a linear arrangement; tall additional cupboards are optional; this kitchen is most optimal when several people work simultaneously L-kitchen: angled built-in furniture with greater distances between the work units; advantageous for working alone as a disabled person in a wheelchair 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 built-in furniture connected with an extra bench; experienced as cramped and 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 & Thiberg, 1985) (Thiberg, 1994) (Nowakowski, 2015) (Geromel, 2016) (Ollár et al., 2020) (BFS 2011:6)
Kitchen island	Most common in larger apartments and open floorplans Added work surface and storage space It might include some appliances (requiring flexible infrastructure outlets) There is a lack of space to install one if the original plans were not designed for it	(Nowakowski, 2015) (Geromel, 2016) (Femenías & Geromel, 2019) (Ollár et al., 2020)
Floor area of the kitchen and apartment	Shrinking floor area – compact living Free floor areas enable accessibility, increased well-being, reduced risk of accidents, multiple user presence and the possibility of adaptability Need for enough floor area for multiple users to work at the same time	(Hallberg & Thiberg, 1985) (Thiberg, 2007)
Infrastructure (electricity, plumbing, 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 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)	(Thiberg, 2007) (Lind & Mjörnell, 2015)
Daylight and windows	Requires sufficient façade length Disadvantages of 'single-sided' apartments: poorer lighting, fewer outlooks, decreased natural ventilation At work surfaces, daylight from the side is favoured Need for complementary electrical lighting Recommended: at least one window in the kitchen (required by law in apartments larger than 55 m^2)	(Hallberg & Thiberg, 1985) (Thiberg, 2007) (Nowakowski, 2015) (BFS 2011:6)
Dining area	Important for daily life, everyday tasks (e.g., doing homework, working) and social activities It is favourable to have a spacious dining table Functions as an extension of the countertop It is recommended to be placed near work surfaces and storage spaces and in or close to the kitchen Advantageous to have a window close to the dining area	(Thiberg, 2007) (Örnhall, 2019) (Hagejärd et al., 2020)

5.3.2. Design features of contemporary kitchens and apartments

Regarding the overall characteristics of the apartments, the floorplan analysis showed that studio (39%) and one-bedroom (21%) apartments comprised more than half of the apartments in the sample. The smallest apartment was 23 m^2, the largest was 182.9 m^2 and the average floor area was 60.6 m^2. Most of the apartments were designed with a balcony or terrace (96%). The outdoor spaces were most commonly accessible from the combined kitchen-living room (80%). In apartments with separate kitchens, the outdoor spaces were more often connected to the living room. Although direct daylight in the apartments was mainly provided from two-perpendicular directions (40%), 81% of studio apartments and 30% of one-bedroom apartments received daylight only through one façade side.

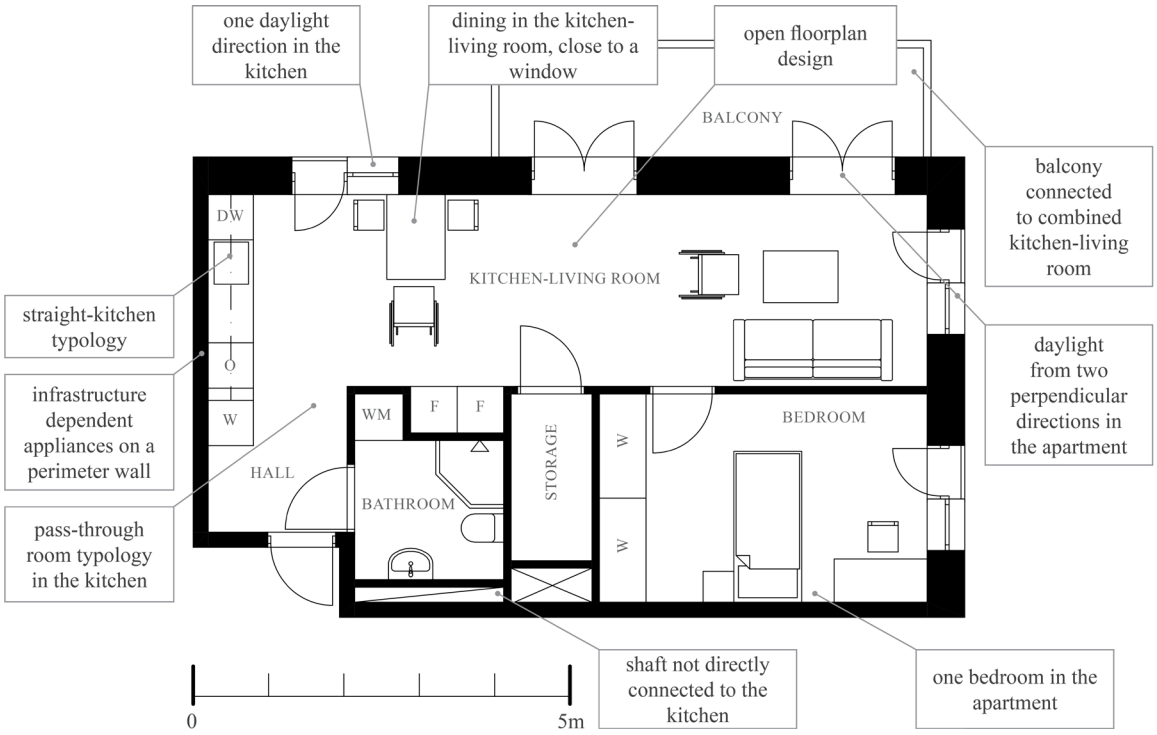


Figure 8 – Apartment floorplan from the studied sample exemplifying the most common design solutions identified during the analysis (DW-dishwasher, F-fridge and freezer, O-oven and stoves, W-wardrobe, WM-washing machine) (as published in Paper C)

Regarding the spatial characteristics of the kitchens, Figure 8 illustrates an apartment floorplan with the most typical design solutions found in the studied sample. On average, the kitchen took up 19% of the apartment's floor area. The average kitchen floor area was 11.3 m^2. The apartments in the studied sample usually had combined kitchen-living rooms (95%). 54% of the kitchens were accessible by two doors. This created mostly B (pass-through room, 55%) or C (part of one ring, 25%) room typologies. However, the internal ring in the C typology kitchens was often created by a freestanding tall cupboard unit (67% of C typology kitchens). The most common kitchen typologies were the straight-kitchen (64%) and L-kitchen (31%). U-kitchens (3%) and parallel-kitchens (2%) were seldom planned in the apartments. Straight- and L-kitchen typologies were usually designed in pass-through (B) kitchens, parallel-kitchen typologies in C typology rooms and U-kitchens in dead-end (A) rooms. 18% of the kitchens were designed with a freestanding tall cupboard unit and 3% (or 117) of the apartments were planned with a kitchen island. The dining area was most commonly located in the combined kitchen-living room (95%) and had a direct daylight

connection in 82% of the cases. The kitchens mostly received daylight from one direction (90%). Infrastructure-dependent appliances and the sink were often placed on perimeter walls between apartments (45% of all walls with infrastructure-dependent appliances) or lightweight interior walls (35% of all walls with infrastructure-dependent appliances). The shaft (including installations for electricity, plumbing and ventilation) was not directly connected to the kitchen in 36% of the apartments. In other cases, the shaft was in the kitchen (32%) or on its perimeter (22%). The drawings did not indicate the shaft in 10% of the apartments.

5.3.3. Adaptive capacity assessment

In Study 3, four adaptive capacity indicators were assessed: Rearrange, Reconfigure, Relocate and Expand or reduce. Additionally, design solutions that enabled or hindered the different indicators were explored. The results of the adaptive capacity assessment are summarised in Table 15.

Table 15 – Overview of adaptive capacity of kitchens in the sample (based on Table 9 of Paper C)

Adaptive Capacity Indicator		Adaptive capacity in the sample	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	4%	- no adjacent unconnected rooms - built-in furniture in the way	- location and number of windows (e.g. multiple windows arranged along a façade side) - room organisation - larger floor area
	Remove existing door	26%	- lack of alternative access to the adjacent room	
	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 - 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

The overall results indicate that contemporary apartment floorplans could only be partially adapted. It was possible to rearrange the kitchen in 89% of the apartments, reconfigure by separating (76%) or opening (79%) the kitchen and expand or reduce the kitchen in 76% of the apartments. However, rearranging the kitchen required major modification in 42% of the sample. Additionally, the possibility of relocating the kitchen or reconfiguring it by opening or removing door openings was rather limited. Furthermore, only in 23% of the sample were all four indicators enabled in the original floorplan design.

Adaptive capacity significantly increased in apartments larger than 55 m^2 and kitchens larger than 10 m^2. The analysis also identified design solutions which could increase the adaptive capacity of dwellings: 'squarish' enclosure of the room, continuous interior wall surfaces, larger floor area, fewer traffic zones, room organisation, shaft access from multiple rooms, multiple shafts in the apartment, location and number of windows, storage room next to the kitchen or open floorplan design. A detailed description of the results connected to the adaptive capacity of the kitchens is published in the appended Paper C.

5.4. Study 4: Circular building adaptability in multi-residential buildings

Aim	Assessing the implementation of adaptability strategies in CBD and enhancing circular building adaptability in residential architecture
Study participants	Architects (n=6 participants, 1 participant/firm)
Data collection	Semi-structured interviews
Data analysis	Qualitative content analysis with circular building adaptability determinants as a coding framework
Output	Paper D (journal paper)

5.4.1. Circular building adaptability in multi-residential building design

In the interviews of Study 4, design strategies used in current CBD were explored. The identified design strategies and their potential adaptability features are presented in Table 16. These strategies were then analysed for their contribution to circular building adaptability determinants (Hamida et al., 2022) and their possible application to the shearing layers (inspired by the inventory matrix Geldermans, 2016).

In the interviews, the participants explained their choices of design strategies for circular muti-residential building projects and the reasons for selecting those strategies. It was found that adaptability was not a primary concern in their circular multi-residential building projects for five out of six interviewees. The strategies they applied were often implemented to support other CBD strategies, such as design for disassembly, rather than explicitly promoting adaptability. The architects viewed design for adaptability as less crucial than other circular design strategies, as its impact on resource reduction was seen as less immediate or quantifiable. However, one interviewee stressed that circular buildings should be adaptable in both the short- and long-term and enable changes for the end-users.

Table 16 - The design strategies and their adaptability features (based on Table 4 of Paper D)

Design Strategies	Adaptability Features
Open building concept	Flexible position of the partition walls Various floorplan solutions and room connections
Pre-cut openings in structural walls	Opening and closing entrance doors
Over-capacity	Various floorplan solutions Multiple functions for dwelling units and buildings Scalable dwelling and room sizes Space for adapting to future requirements
Demountable building components	Dismantling, relocating and re-assembling buildings Changing the physical composition of buildings Separatable components enabling future reconfiguration and maintenance of the space Scalable building and dwelling sizes
Prefabricated building components	Standardised measurements contributing to regular patterns in spatial configuration
Stackable building components	Regular patterns on the dwelling and building scale Scalable building sizes
Modular, standardised building components	Regular patterns on the dwelling and building scale Scalable building sizes
Scenario planning	Various floorplan solutions
Combined room functions	Multiple functional uses of space
Universal ceiling height	Regular dimensions for floor heights Different building functions (e.g., housing, offices)
General room sizes	Regular dimensions for rooms Interchangeable room functions
Sliding walls	Various floorplan solutions Scalable room sizes
Centralised location of infrastructure systems (infrastructure core)	Multiple locations for infrastructure-dependent dwelling units (e.g., kitchen, bathroom)
Increased floor thickness for infrastructure systems	Multiple locations for infrastructure-dependent dwelling units (e.g., kitchen, bathroom)
Removable covers or panels in the walls and floors	Access to infrastructure installations to maintain, repair or modify
Partition walls free from infrastructure installations	Possibility to move partition walls without adjusting infrastructure systems
Combined product function	Efficient space utilisation
Reversible connections	Dismantling, relocating and re-assembling buildings Separatable components and materials that enable future reconfiguration of the space
Renewable energy systems	Resilient and reduced resource use
Aligning material measurements with building units and components	Regular patterns on the dwelling and building scale
Durable materials for ease of maintenance, reuse and recycling	Adjustable interior finishings Choices for the end-users to personalise their space

Four interviewees shared that their companies developed stackable and modular building components. They created prefabricated dwelling units rather than employing a contractor to construct the buildings. These units could be delivered as individual houses or stacked to form terraced or multi-residential buildings. This strategy involved offering standardised floorplan solutions for various apartment sizes, including studio, one-bedroom, two-bedroom and three-bedroom apartments. However, these floorplan solutions were predefined and did not offer many opportunities for adaptation, making them suitable only for certain traditional household types. In contrast, another interviewee shared a different approach: developing an open floorplan solution for their building project. In this approach, the residents could purchase several dwelling units, combine them and design their own floorplan solutions. While the project's architects did provide floorplan suggestions, all the residents chose to create their own unique floorplans that best suited their household preferences. This example emphasises the crucial role of end-users in shaping their own living spaces and highlights that scenario planning alone is insufficient to address the end-users' spatial requirements.

The ownership form of the dwelling units further influenced the extent of adaptability features discussed in the examples (containing both rental and owner-occupied dwellings). In rental dwellings, the building owners' interest was to limit the potential alterations the end-users could perform to prevent damage to building components. While in owner-occupied dwellings, the end-users (owners) had the chance to be in control of their spaces and alter them according to their preferences. These preconditions resulted in the architects applying different design strategies, enabling various levels of adaptability for rental and owner-occupied dwellings. This difference would be worth exploring in future research.

A detailed description of the identified strategies' contribution to circular building adaptability determinants and their possible application to the shearing layers can be found in the appended paper D. The combined results of the interviews and the analysis of the identified circular design strategies were summarised as follows (as published in Paper D):

- The design strategies often facilitated multiple circular building adaptability determinants and could be applied on several shearing layers simultaneously.
- All ten circular building adaptability determinants were supported by design strategies applied in current CBD. However, some of the determinants were more supported than others.
- The selection process of design strategies lacked the explicit consideration of design for adaptability.
- The design strategies that enabled adaptability offered long-term solutions requiring large-scale modifications rather than facilitating low-impact adaptation by dwelling occupants.
- The design strategies were not applied in a systematic way, resulting in partial adaptability in each building example discussed.

5.4.2. The conceptual design framework

A conceptual design framework was developed based on the analysis of the identified design strategies and inspired by Geldermans' (2016) inventory matrix (Table 17). The three main components of the framework are a library of design strategies enabling circular building adaptability, the circular building adaptability determinants and the building dissected into

its parts. These three parts can be used in an iterative way. For instance, designers could take a starting point in the design program to define the shearing layers and their components. Then, they could select applicable design strategies while tracking that the circular building adaptability determinants were comprehensively addressed. In this sense, the framework can be applied not only as a design tool but also as a documentation or analytical tool.

Table 17 - Conceptual design framework for implementing circular building adaptability (based on Table 7 of Paper D)

Design strategy	Configuration flexibility	Product dismantlability	Asset multi-usability	Design regularity	Functional convertibility	Material reversibility	Building maintainability	Resource recovery	Volume scalability	Asset refit-ability	Building		
											Shearing layer	**Subcategory (Sc)**	**Part ***
DS-1											Stuff	Sc-n	Part-n
DS-2											Space plan	Sc-n	Part-n
DS-3											Service system	Sc-n	Part-n
…											Structure	Sc-n	Part-n
DS-n											Skin	Sc-n	Part-n
											Site	Sc-n	Part-n

* component, product, material, etc.

5.5. Validation study: Housing developers' and architects' considerations regarding spatial design

This sub-chapter is based on the validation study consisting of group interviews with architects and interviews and a workshop with housing developers and managers. The validation study aimed to verify some of the key results of the four studies by further investigating how housing developers and architects consider spatial design aspects in residential building projects and what processes, roles, requirements and responsibilities they have in connection to it.

The interviews revealed that housing developers and managers often did not have specific requirements for spatial design and relied on the expertise of architects. During the group interviews, the architects demonstrated a vast knowledge of and consideration for spatial design in residential building projects (including advantageous design solutions identified by the studies). However, similar to the results of Study 1, they expressed that these insights often got lost in the process of compromise, primarily driven by economic factors and resulting spatial restrictions due to the application of minimal requirements of the building regulations as upper limits (usually imposed by their clients). Architects, bound by the requirements of their clients, often had to make decisions that did not fully utilise their knowledge. Interestingly, when designing the spaces of their own homes, like their kitchens, the architects explained that they opted for different design solutions than the conventional ones in multi-residential buildings. They argued that those alternative solutions were more suitable for their needs (as end-users).

Regarding the functionality and adaptability of the residential building projects, the housing developers were asked whether they had established processes to follow up on previous projects and evaluated end-user satisfaction. The housing developers, who also managed the multi-residential buildings after production, collected some feedback through the reported maintenance needs. However, similarly to the results of Studies 1, all interviewees admitted that they did not have direct feedback loops regarding end-user satisfaction and did not incorporate potential learnings into the design of new building projects. This resulted in a lack of knowledge transfer from one project to another. Additionally, similar to the results of Study 4, adaptability features were not a priority in the housing developers' new building projects.

The housing developers did not have established circularity agendas or goals. Observed barriers included a lack of regulatory incentive, hesitant organisational culture, lack of actionable knowledge and lack of circularity processes and products within the stakeholder network. Nevertheless, while discussing the results of the four studies during the workshop, the participants showed interest in learning about designing and building for circularity and formulating new requirements.

The interviews and workshop highlight the need for housing developers and managers to take on new responsibilities as building regulations are proposed to become less detailed. These responsibilities include specifying functional requirements as well as innovating and validating design solutions. To take on these new responsibilities, housing developers must collaborate with architects and other stakeholders in the building sector to establish new processes for outlining functional requirements. The housing developers' appreciation of the architects' spatial design skills is a promising sign in establishing such collaborations.

6. Discussion

This thesis explores spatial design to contribute to the knowledge on transitioning from a linear to a circular approach in the design, construction and utilisation of residential buildings. The four studies present how spatial design and its determining characteristics could be identified, described, assessed and enhanced to support CBD. This chapter discusses the results of the studies to answer the thesis's RQs and reflect on their significance in relation to previous literature. Additionally, recommendations are made regarding spatial design solutions that could support circularity in residential building design.

6.1. Spatial design's contribution to circularity in residential buildings

RQ1: How could spatial design contribute to circularity in residential building design?

The studies indicate that implementing functional and adaptable spatial design solutions can influence residential buildings' circular potential by supporting circularity's core principle: keeping resources in place at their highest utility and value (den Hollander et al., 2017; Ellen MacArthur Foundation, 2015; Webster, 2017). In Study 1, stakeholders highlighted numerous spatial design elements while discussing preferences related to kitchen design. This underscored the significance of spatial design in supporting circularity, which was further explored in Studies 2, 3 and 4. These studies helped to understand the concepts of circularity and spatial design and their interrelation in the residential context. The results of the studies collectively suggest that functional and adaptable spatial design can aid in narrowing and slowing resource loops. This is a noteworthy contribution, especially considering that current literature primarily focuses on end-of-life scenarios (closing loops), such as recycling obsolete building materials and components (Askar et al., 2022; Dokter et al., 2021; Kozminska, 2019; Munaro et al., 2020).

It is interesting to observe that it is not only spatial design that can impact circularity. Instead, spatial design and circularity influence each other simultaneously. This provides an exemplary illustration of the socio-material entanglement observed in the subject under study. Study 4 indicates that the circular design strategies applied in CBD shape the spatial design of residential buildings. Certain design strategies (e.g., design for standardisation, modularity, prefabrication and disassembly) can lead to repetitive, minimal spaces which only support specific end-user groups. This, combined with the lack of consideration for adaptability in circular (residential) buildings, compromises the transition to circularity. Therefore, this thesis recommends that functionality and adaptability criteria must be systematically incorporated into the CBD approach.

In terms of functionality, the research studies indicate that functional spatial design solutions can contribute to circularity in residential buildings by reducing the need for alterations and connected material use (narrowing loops) and facilitating the long-term use of dwellings (slowing loops). Reducing the need for alteration and promoting the long-term use of dwellings could be achieved by implementing spatial design solutions commonly appreciated by end-users. While studying end-user behaviour and preferences, Study 2 shows that there are reoccurring, commonly appreciated spatial design solutions shared among end-users (such as the well-connected central location of the kitchen, advantageous room connections, more generous storage spaces and work surfaces, well-dimensioned and -placed dining areas and sufficient daylight). Some of these preferences are also noted in

previous literature (e.g., the works of Braide, 2019; Femenías & Geromel, 2019; Nylander, 2018; Tervo & Hirvonen, 2019). However, it is important to emphasise that not all end-user preferences align with circular behaviour patterns. Therefore, identified end-user preferences should also be evaluated for their compatibility with CE principles. As Daae et al. (2018) suggest, it is important to not only establish systems that support CE principles but also to encourage end-users to act in a way that aligns with these principles. In other words, the successful implementation of circular design solutions requires both the proper design solutions and the suitable behaviours. While this thesis advocates for studying and designing for end-user preferences, it also emphasises the need for the end-users to adopt behaviour patterns supporting circularity (e.g., reducing consumption, acceptance of pre-owned products, willingness to repair, reducing waste resulting from use or alteration of products).

Functionality, however, is a temporal phenomenon. The literature reveals a noticeable evolution over the past decade in how people, whether individuals or groups, utilise their homes and kitchens (Lee, 2018). It also highlights the changing nature of activities occurring in specific spaces of the home (Hagejärd et al., 2020; Willén, 2012). Functionality differs from end-user to end-user and changes even for a single end-user over time (Braide, 2019; Ekeblad, 1997; Werner, 2003). These differences and changes regarding functionality produce evolving spatial requirements (Braide, 2019). As a response, end-users tend to perform alterations when the original spatial design of their dwelling allows for it (Braide, 2019; Femenías & Geromel, 2019). A similar phenomenon was observed in Study 2. It was important for the interviewees to adjust the workflow in the kitchen to their specific preferences and create spatial solutions suitable for their lifestyles. The alterations were motivated by a need to create extra storage spaces and work surfaces, a wish to accommodate diverse social activities and changes in the family composition. The alterations included constructing additional rooms, opening new doors, moving windows, removing walls, installing kitchen islands and modifying the infrastructure systems. Furthermore, the alterations entailed replacing all built-in furniture cabinets with new ones in ten of the eleven cases. These alterations resulted in significant material flows and waste of resources. One explanation for this phenomenon could be the lack of adaptable solutions in the original design.

In terms of adaptability, spatial design could ensure that, when imperative, change is possible without generating unnecessary material flows and waste (narrowing loops), just as emphasised in the literature (Hamida et al., 2022). Additionally, adaptable spatial solutions could enable spatial solutions responsive to evolving end-user needs. As Braide, (2019) highlights, this is imperative to prolong the longevity and utilisation of the housing stock (slowing loops). The studies of this research contribute to the discussion on circularity in the residential context by demonstrating spatial design’s importance in achieving adaptability. As shown in Study 3, the design of the determining spatial characteristics establishes the dwellings' adaptive capacity already at the construction of residential buildings. In Study 2, the examples of end-user alterations also reveal that the buildings' original design put certain restraints on the alterations they could perform. However, Study 4 confirms the findings of the literature (Askar et al., 2022; Hamida et al., 2022; Tarpio et al., 2021): adaptability is still not considered in current multi-residential building design. One explanation - that one of the interviewees of Study 4 shared - is that adaptability has a

seemingly less immediate effect and urgency than other circular design strategies. Nevertheless, adaptability's importance for circularity is extensively underscored in the literature (e.g., Askar et al., 2022; Hamida et al., 2022) and this thesis further emphasises the necessity of incorporating adaptability in CBD approaches.

In conclusion, on the one hand, the functionality of spatial design should be promoted by implementing design solutions that are commonly appreciated by end-users and are in line with CE principles. On the other hand, these standardised design solutions must incorporate opportunities for future adaptation. Combining the concepts of functionality and adaptability would lead to design solutions that are standardised yet adaptable. This thesis argues that such adaptable standard design requirements are vital in CBD and, hence, for transitioning to a circular built environment.

6.2. Social and material aspects of spatial design for circularity

As a starting point, the case of the kitchen provided a suitable example for studying the social and material aspects of spatial design. On the one hand, how the kitchen is designed and built affects the processes of the industry stakeholders and how end-users utilise and alter the space. On the other hand, the processes and preferences of the stakeholders connected to the kitchen shape how it is designed and utilised today. The studies highlight that aligning spatial design's social and material aspects is crucial to supporting circularity in residential buildings. This is exemplified in Sub-chapter 6.2.1, which discusses gaps identified within the materiality of current spatial design solutions of kitchens and presents recommendations for mending those gaps. Additionally, social aspects leading to these gaps are explained. Furthermore, 6.2.2 discusses stakeholder processes (social aspects) of spatial design that could promote more circularity in residential building design.

6.2.1. The gaps in the current spatial design solutions of residential kitchens

RQ2: What are the gaps in the current spatial design solutions of residential kitchens when assessing their circular potential?

Studies 1, 2 and 3 explored social and material aspects related to the circular potential of current spatial design solutions for residential kitchens. Studies 1 and 2 (identifying stakeholder preferences), compared with Study 3 (assessing contemporary apartment floorplans), show that current residential building design has shortcomings. This results in gaps in the spatial design solutions with regard to functionality, adaptability and, ultimately, circularity. To bridge these gaps, Study 3 identified advantageous spatial design solutions such as numerous and well-distributed windows in the apartment, a limited number of door openings in the kitchen, strategically placed traffic zones, centrally located shafts accessible from multiple rooms with windows, advantageous room typologies 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). The identified gaps and connected recommendations for advantageous design solutions are discussed in the following sub-chapters. These gaps are further illustrated in Paper C through apartment floorplan examples assessed in Study 3.

6.2.1.1. GAP 1 - Room organisation: the lack of diverse floorplan solutions and practical room organisations

Study 3 reveals that contemporary apartments are almost exclusively built with a combined kitchen-living room. Previous research has indicated a divided preference among occupants for a separate kitchen or a combined kitchen-living room design (Femenías & Geromel, 2019; Tervo & Hirvonen, 2019). In line with the literature, in Study 2, six households (of young couples, families with children and older couples) expressed a preference for a separate kitchen. They argued that combined kitchen-living room solutions might result in noise disturbances, spreading of unwanted odours and loss of storage space. On the contrary, other households have expressed that a combined kitchen-living room is preferable for hosting guests, cooking and watching the kids simultaneously and creating a spacious feeling.

Study 2 shows that end-users often prefer kitchens positioned in a central location that is well-integrated with other functions of the dwelling. According to the literature, the most important room connections from the kitchen are to the living room, entrance and outdoor areas (Thiberg, 2007). Study 3 found that these room connections are often present in the floorplan of multi-residential dwellings. However, how the rooms of the dwelling were arranged in the floorplan solution usually resulted in a fragmented room organisation, creating unfurnishable traffic zones and reducing free floor areas (further discussed in Sub-chapters 6.2.1.3 and 6.2.1.4).

Another recurring design solution that Study 3 reveals is narrow pass-through kitchens spilling over from the entrance of the dwelling, with a limited free floor area in front of the built-in furniture. Such a design solution limits the functionality of both the entrance and the kitchen. On the one hand, there is often insufficient space to change, greet guests or store outdoor clothing and equipment in such an entrance. On the other hand, in such a design solution, the entire kitchen becomes a traffic zone, creating collisions when someone uses the built-in furniture. Study 3 found that this design solution also reduces the possibilities for rearrangement, reconfiguration and expansion of the kitchen.

In conclusion, it would be advantageous to design combined kitchen-living rooms with the potential for easy partitioning. While the Swedish building regulations mandate that the kitchen and living room should be separable in apartments larger than 55 m^2, the separation is only indicated with a dashed line on the floorplan and there are no feasible, easily realisable or built-in solutions to separate the two rooms in case the end-users would wish to do so. Furthermore, a balance should be struck between apartments with separate kitchens and combined kitchen-living rooms in new residential buildings. Additionally, creating less fragmented floorplans in which the kitchen is placed in an area with limited traffic zones and close to the living room, dining spaces and windows enhances functionality, potentially increasing occupant satisfaction and reducing the need for future alterations.

6.2.1.2. GAP 2 - Kitchen furniture: the lack of space for storage, work surfaces and favourable kitchen typologies

As observed in the studies, some features of the built-in furniture influence the spatial design of the kitchen. For instance, the kitchen typology is interdependent with the room dimensions. Study 1 shows that industry stakeholders favour straight- and L-kitchen typologies. This aligns with the findings of the literature (Geromel, 2016; Thiberg, 2007). In

accordance, Study 3 shows that straight and L-shaped kitchens are the most prevalent typologies in contemporary apartments. However, it is important to mention that during the alterations examined in Study 2, the end-users prioritised creating sufficient work surfaces and storage spaces, even if they had to build a parallel or U-kitchen. They utilised the room dimensions and the available free wall surfaces to accommodate this preference for adequate work surfaces and storage space.

As the literature emphasises (Marco, 2022), there has been an increase in the volume of storage space that a household would need. Yet, contemporary residential designs have not adapted to meet this demand (Hand et al., 2007; Marco et al., 2021). This is also evidenced in the case of the kitchen. In the kitchen, the need for more storage space is driven not only by the accumulated material possessions but also by new activities performed in the kitchen. For instance, it was often discussed during the interviews of Studies 1 and 2 that waste sorting - a relatively new domestic task - is supposed to be carried out in the kitchen. However, the space allocated for this task, typically under the sink, was perceived as insufficient for sorting various waste types effectively. Consequently, the interviewees reported utilising alternative areas in their homes (e.g., garage, entrance, balcony) for waste sorting. The literature has also noted that contemporary kitchen design does not accommodate the necessary space required for waste sorting, failing to meet the demands of this new task performed in the kitchen (Sjöstrand, 2018).

The results indicate that contemporary apartment designs do not typically include kitchen islands. However, earlier research (Femenías & Geromel, 2019) has shown that kitchen islands are a favoured addition to the built-in furniture. In contrast, only two of the eleven households participating in Study 2 installed a kitchen island. It is worth noting that this might be due to limitations of free floor area rather than end-user preferences. Further investigations into understanding end-user preferences related to kitchen islands could result in more informed recommendations on related spatial requirements.

In conclusion, the results suggest that the dimensions of the kitchen should provide adequate space to accommodate both straight- or L-kitchen typologies. For reduced material use and ease of installation, it could also be advantageous to design kitchens with one open end rather than enclosed by two walls on the sides. Moreover, both the built-in furniture and the room must offer enough space to include adequate storage, ample work surfaces and effective waste-sorting solutions.

6.2.1.3. GAP 3 - Free floor area: the lack of excess space

Free floor areas play a significant role in apartments' furnishability, utilisations and adaptive capacity (Thiberg, 2007). Study 3 shows that apartments with a floor area exceeding 35 m^2 have an increase in adaptive capacity and those larger than 55 m^2 demonstrate significantly higher adaptability. Kitchens with a floor area greater than 10 m^2 also show enhanced adaptive capacity. This can be explained by the regulations requiring the possibility of separating the kitchen and the living room in apartments larger than 55m^2. To facilitate this, an adequate number of windows are necessary. This requirement for a sufficient number of windows also supports two of the adaptive capacity indicators, namely, Reconfigure and Relocate.

In line with previous literature (Femenías & Geromel, 2019; Hagejärd et al., 2020), Study 3 shows that larger apartments could more likely be designed with the identified

advantageous spatial design solutions (as demonstrated in Paper C) and, hence, cater to the preferences of diverse households, as the free floor area in those apartments allows for diverse spatial utilisations and adaptations. On the other hand, the results show that apartments smaller than 35 m^2 face challenges in implementing advantageous spatial design solutions due to spatial constraints. In such apartments, daylight access is limited, all dwelling functions (except for the bathroom) are confined to one room, there is no distinction between private and public room functions, the kitchen is cramped, traffic zones occupy all the free floor area, and there are no possibilities for adaptation. These apartments are usually suitable for a single occupant, are highly specific regarding arrangements for furnishing and utilisation and lack the possibility to adapt to changing household compositions.

Study 2 also shows that larger dwellings enable a more comprehensive range of possible alterations. The extent of the alterations also seems to be influenced by the dwelling type and ownership model. More extensive alterations were carried out in villas and terraced houses, which were inhabited by their owners. One possible explanation is that in these dwelling types, there is usually a more generous free floor area compared to apartments and the owners have more freedom to perform spatial alterations than in rental dwellings. Additionally, it could be argued that the middle- to high-income of the households is a key facilitator of the alterations and households with lower incomes would not be able to perform such extensive alterations. Therefore, designing rental dwellings with the identified advantageous design solutions is increasingly important. It is important to note that this does not imply building excessively large apartments, which could lead to increased construction costs and sales prices (as also discussed by Marco et al., 2021 and Saarimaa & Pelsmakers, 2020). Instead, this thesis highlights the potential for implementing advantageous design solutions within the same dwelling size. This approach can enhance the dwelling's quality, functionality and adaptability, offering practical and cost-effective solutions. For instance, practical room organisation, built-in solutions for partitioning, functional built-in furniture, strategically placed windows and doors and separating free floor areas and traffic zones can all contribute to a more functional and adaptable dwelling environment.

The identified relationship between the floor area and adaptive capacity aligns with the findings of previous studies. Larger apartments undergo alterations more frequently than smaller ones (Femenías & Geromel, 2019), likely due to the increased possibilities their space offers. Thiberg (2007) has noted the importance of reasonably large kitchens with adequate free floor areas for ensuring a high quality of life for end-users, including possible alterations according to their changing preferences. However, the results of Study 3 indicate a trend towards smaller newly produced apartments and kitchens. The average apartment floor area reported in Study 3 is 60.6 m^2, which is less than the averages found in the literature (e.g., 83 m^2, as in Femenías & Geromel, 2019) or what end-users consider a desirable apartment size (minimum of 69 m^2, as in Tervo & Hirvonen (2019). Additionally, 60% of the sample in Study 3 consists of studio and one-bedroom apartments. These smaller apartments primarily accommodate individuals or couples, as their size limits the types of end-users that would thrive in such dwellings. This increasing trend of constructing smaller apartments is concerning. Tervo & Hirvonen (2019) have observed that small housing units do not meet end-user needs and that the mass production of small apartments is primarily

driven by “the makers and executors of housing policy that allow the housing markets to determine apartment sizes and prices” (p.15). However, a conflict exists between apartments' floor area and affordability (Heidrich et al., 2017; Marco et al., 2021). As discussed earlier, the production of larger dwellings (with larger kitchens) incurs higher costs, which many households cannot afford. Additionally, the extra resource use associated with larger dwellings and the energy required for heating larger spaces are crucial considerations for a circular built environment. However, current discourse highlights a debate about the pros and cons of reducing apartment sizes versus providing alternative housing solutions such as collective or shared living (Braide, 2019; Tarpio et al., 2021). Further research is needed to identify suitable free floor areas for different housing and apartment types in relation to different end-user types, economic factors and environmental impacts.

In conclusion, the research shows that the available free floor area influences both functionality and adaptability. Hence, reasonable over-capacity of the free floor area is recommended in the original design of the building. However, it must be noted that this recommendation does not encourage building large dwellings with increased environmental impacts (resource use, heating, cooling, etc.). Instead, architects’ expertise is crucial in accommodating this recommendation by balancing over-capacity with well-selected spatial design solutions (as demonstrated in Paper C). Additionally, the results indicate that it is increasingly important to apply design solutions that align with end-user preferences and provide solutions that enable easy alterations in all types of dwellings, independent of the households’ dwelling type, ownership model or economic situation.

6.2.1.4. GAP 4 - Window and door openings: the lack of strategical placement and dimensioning

The presence, location and distribution of windows have been identified as crucial elements in enhancing the adaptability of apartment designs. Despite kitchens commonly having a window in many smaller apartments, Swedish building regulations permit the construction of kitchens in apartments with an area of less than 55 m^2 without direct daylight (BFS 2011:6). As seen in Study 3, when kitchens are designed without a window, the adaptive capacity of the apartment is reduced compared to apartments that incorporate a window in the kitchen. Additionally, the location and distribution of windows significantly affect both the reconfiguration and relocation of the kitchen. Study 2 further shows that this spatial characteristic is rather difficult and resource-intensive to modify during alterations. The studies reveal that besides windows, doors also influence the spatial design of kitchens by defining wall openings, room connections, traffic zones and disruptions in continuous wall surfaces. As observed in Study 3, in smaller apartments, the free floor area typically coincides with the traffic zones, thereby limiting the apartment’s usability, furnishability and adaptability.

In conclusion, even in apartments where daylight is provided solely from one direction, it may be advantageous to design windows evenly distributed along the façade, with at least one connected to the kitchen. This arrangement would also facilitate the placement of the dining area near a window, which is currently more challenging in smaller apartments. Additionally, providing multiple windows instead of large window surfaces enables the possibility to subdivide the room in the future. Regarding spatial design solutions related to

doors, a less fragmented room organisation and optimised room connections can reduce the overlap between traffic zones and free floor areas. Furthermore, a reduced number of door openings could provide continuous wall surfaces for additional built-in furniture for storage spaces, work surfaces and waste sorting.

6.2.1.5. GAP 5 – Infrastructure: the lack of adaptable infrastructure outlets and accessible shafts

As observed in Study 3, the location, adaptive capacity and accessibility of infrastructure systems can influence the circular potential of the kitchen design. Low-impact alterations rely on easy modification of the electrical, plumbing and ventilation outlets, which would also enable ease of maintenance in the long term. In Study 1, the industry stakeholders remarked that the spatial design of the kitchen depends on the plumbing, ventilation ducts and, to a lesser extent, electrical outlets. This dependency is in line with prior research, such as that conducted by Lind & Mjörnell (2015). Their work suggests that renovations of plumbing and ventilation systems are frequently accompanied by kitchen renovations, which typically involve the replacement of all built-in furniture. Visa versa, in Study 2, it was observed that alterations in the kitchens often resulted in modifications to the infrastructure systems. It was important for the participants of Study 2 to create a suitable workflow in their kitchens. Consequently, they often replaced all the built-in furniture, resulting in modifications to the infrastructure system. Study 3 further shows that the relocation of a kitchen is directly linked to the existence of multiple shafts within the apartment, typically one associated with the kitchen and another with the bathroom. This arrangement facilitates multiple access points, often from different rooms.

In conclusion, the more adaptable infrastructure outlets are, the less extensive the spatial alterations could be. This could potentially reduce waste generated during kitchen alterations. Additionally, having multiple shafts in or connected to an apartment could offer various floorplan solutions catering to diverse end-user preferences. However, it is important to note that such design solutions should not trigger unnecessarily extensive construction work leading to significant material flows. As emphasised earlier, end-users must adopt behaviour patterns aligning with CE principles.

6.2.1.6. Overall remarks on the spatial design of residential kitchens

The studies highlight the sociomaterial entanglement across several shearing layers. The results of Study 2 indicate that end-user preferences (as part of the social layer) related to the utilisation and alteration of their home directly impact the design of the space plan layer. Additionally, the dimensions of the space plan layer predefine the arrangement and possible modification of the built-in and mobile furnishing (stuff). Vice versa, the requirements regarding the built-in and mobile furnishing dictate the minimum dimensions of the space plan layer. Furthermore, as the spatial alterations in Study 2 and the adaptive capacity assessment in Study 3 show, the infrastructure systems (service layer) can influence possibilities for furnishing the room and future alterations. Moreover, the original design of the façade (skin layer) and elements of the structure layer define possible future alterations. This indicates that the identified advantageous spatial design solutions supporting circularity must be aligned across the shearing layers with attention paid to their varying lifespan and opportunities for dis- and reassembly (as also suggested by Schmidt & Austin, 2016).

Regarding functionality, the studies show that the findings of the end-user studies performed by HFI between the 1940s and 1980s are still broadly applicable. For instance, design guidelines for adequate daylight, free floor areas, room connections, accessibility, workflows and furnishing solutions (Thiberg, 2007) still provide good functionality. However, implementing these design guidelines has shortcomings in current residential building design. This shortcoming could be amended by adopting the recommendations of this thesis. These recommendations are straightforward to implement, requiring minimal specialised technical solutions. They can be realised using currently available technologies and should not necessarily impose any additional financial burdens.

Regarding adaptability, the results suggest a need to implement design solutions on different scales related to the different shearing layers. Currently, there is a lack of design solutions that enable the end-users to perform easy modifications. Adaptability solutions should facilitate short- and long-term alterations; however, altering different shearing layers might need to be authorised for specific stakeholders. While the end-users should be able to easily modify the built-in and mobile furnishing (stuff) or the space plan, the housing manager should look over the more extensive alterations involving the service system, skin or structure.

6.2.2. Stakeholder processes supporting circular residential building design

RQ3: How could stakeholder processes related to spatial design enhance circularity in residential buildings?

The results of mapping the processes of the stakeholders in Study 1 show two main value opportunities that are currently overlooked: (1) the lack of attention to gathering evidence on and implementing end-user preferences and (2) the segmented stakeholder network where different stakeholders are only part of a short section of building development. Additionally, in Study 2, the participants demonstrated behaviour patterns that do not align with CE principles and their spatial alterations did not include considerations of sustainability or circularity. This was partly due to the lack of products or services that could enable sustainable or circular choices. Furthermore, Study 4 shows that the implementation of CBD in residential buildings is still fragmented and requires a more holistic and systematic application.

A growing body of literature underscores the significance of end-user preferences (Daae et al., 2018; Lofthouse & Prendeville, 2018; Pomponi & Moncaster, 2017; Selvefors et al., 2019). This research observes that end-user preferences are frequently overlooked in practical implementations of CBD. Study 1 reveals that end-users' involvement in the design processes of multi-residential buildings is currently limited. In multi-residential projects, the housing developer, not the end-user, is the primary client; they have an important role in shaping residential environments for the end-users. As a result, the objectives and interests of housing developers often overshadow those of the end-users. One explanation is that economic and regulatory considerations usually supersede user preferences. While end-users may not be involved in the design process of multi-residential housing, their preferences should be considered to a larger extent, as also advocated by previous literature (Braide, 2019; Werner & Grange, 2011). As Study 2 shows, end-users have strong preferences regarding their living environment and given the resources (spatial preconditions, financial means), they perform spatial alterations, which often result in

generating waste and using virgin resources. Hence, understanding end-user preferences is increasingly important for realising a circular built environment. A design approach for multi-residential buildings based on end-user preferences might enable better functionality and adaptability, prolong the lifespan of dwellings, reduce the impacts of spatial alterations and decrease resource exploitation (as outlined in Sub-chapter 6.1). In summary, end-user considerations must be more thoroughly integrated into CBD's theories and practical applications. This is in line with the observations of Pomponi & Moncaster (2017), advocating for a more thorough investigation of the societal and behavioural dimensions of the built environment.

In Study 1, the housing developers and the architects recognised their limited capacity to gather evidence-based input on current end-user preferences. The empirical data of the validation study further shows that end-user perspectives in building projects are not evaluated and observations on (in)adequate design solutions are not documented, limiting the potential for design improvement in future projects (as also found by (Werner & Grange, 2011). In this regard, collaboration between academia and practice could be a potential resource in identifying end-user preferences and supporting spatial design solutions. Such collaboration has proven advantageous before, as demonstrated in the state-funded kitchen research performed by HFI between 1940s and 1980s (Lee, 2018). Many of the recommendations of that research remain relevant and are still a foundation of housing qualities today (e.g., functional requirements of kitchens).

While specific to the design and construction process of kitchens within a particular cultural context (Sweden), the stakeholder network under investigation has revealed issues also discussed in the international literature. The results of the studies unfold a lengthy and intricate stakeholder network with stakeholders participating only in segments of the design and construction processes (as also identified by Eberhardt et al., 2019). Study 1 identifies currently overlooked values (such as current linear processes, limited end-user involvement, lack of consideration for the environment and society, more compact living spaces, lack of product and material recovery and strictly applied minimum regulations) that could be harnessed through improved and expanded collaboration, a strategy highlighted by several authors (e.g., Dokter, 2023; Eberhardt et al., 2019). Strengthening existing collaborations and establishing new ones throughout the stakeholder network could exploit these untapped circular values. These partnerships could promote circular design solutions for building components and material innovations. Stakeholders are also urged to reevaluate their value-creation approach to facilitate a circular built environment (Nußholz, 2017). The prevailing business model associated with kitchens, which is linear and economically driven, requires restructuring to incorporate environmental and social factors, as also suggested by prior research (Bocken et al., 2013). Regarding the stakeholder network, this thesis emphasises that to achieve circularity in the building industry, it is essential to improve the involvement of the different stakeholders in building developments and enhance their collaborative efforts throughout the design, construction and post-production processes.

The roles of various stakeholders also need to be reevaluated. For instance, in the face of loosening building regulations (Boverket, 2020), housing developers may need to take on more responsibility for advocating for sustainable and circular alternatives and working towards improving the spatial quality of living environments. As Study 1 demonstrates, architects possess vast knowledge and understanding of functional and adaptable spatial

design. Although this expertise is currently underutilised, the validation study reveals that housing developers value and trust the design knowledge of architects. Additionally, multitudes of design strategies are available to facilitate functionality and adaptability. The studies show that some of these strategies (such as advantageous room connections, well-dimensioned and -placed dining areas and sufficient daylight) are already applied in current residential building design. However, they are not explicitly considered for enabling functionality and adaptability. What needs to be improved is systematically considering design strategies and purposefully designing for functionality and adaptability. Housing developers and architects could play an important role in synthesising and incorporating the available knowledge into CBD.

In terms of current building regulations, Study 1 reveals a generally positive perception of the functional requirements of residential building design. These regulations are seen as beneficial in guiding the creation of quality homes and averting unsuitable solutions. However, with the proposed changes to the building regulations - reducing functional requirements - there is a concerning trend of treating these minimum requirements as the maximum standards. Rather than reducing functional requirements, this thesis advocates for a new line of research to provide contemporary evidence-based data for revising building regulations. The ways people use their homes, for instance, which individuals or groups are active in the kitchen, has evolved over the past decade. These changes must be mapped and studied to provide relevant information for regulatory changes.

The proposed changes to the building regulations also seem to neglect considerations of sustainability and circularity despite existing national regulations and policies - like the Swedish Climate Act (SFS 2017:720) and Sweden's National Strategy for a Circular Economy (Regeringskansliet, 2020) - aiming to promote sustainability and CE principles. Study 1 highlights the lack of policy and regulatory support for circularity demands, a point also emphasised by Hart et al. (2019) and Kirchherr et al. (2018). The interviewees demonstrated a good understanding of the issues associated with current linear production and consumption models. However, some industry stakeholders suggested that without regulatory requirements for circularity, they would not alter their production processes and business models due to the perceived high costs of adopting circular models. This underscores the need to bridge the gap between academic knowledge in the field of CE, its practical implementation and the supporting regulations.

In conclusion, this thesis identifies several stakeholder processes related to spatial design that could support more circularity in residential buildings. These processes include:

- stakeholders establishing extended collaborations in the stakeholder network,
- housing developers and architects studying, evaluating and implementing end-user preferences that align with circularity,
- housing developers incorporating circularity in their (design) requirements,
- housing developers valorising architects' spatial design knowledge,
- architects designing and advocating for functionality and adaptability as an integral part of CBD,
- end-users adopting behaviour patterns that align with circularity and
- policy-makers formulating regulations promoting circularity in the built environment supported by evidence-based research.

While these processes are vital to supporting circularity in residential buildings, it is important to acknowledge that the list of these processes is not exhaustive and could benefit from further investigation.

6.3. Limitations

As outlined in connection to the methodological considerations, this thesis needs to be understood while reflecting on six types of limitations: the socio-cultural (Swedish) context, the focus on the spatial design of kitchens, the limited number and representation of participants in the studies, the foremost qualitative nature of the research, the researcher's contribution to the knowledge development and the available methods assessing spatial design in the circularity context. These limitations are briefly summarised in the following and a more profound reflection in connection to them can be found in Sub-chapter 4.6.

The research results are embedded in the Swedish socio-cultural context. This context-specific nature of the research could potentially limit the interpretation of the results in other cultural or geographical contexts. However, given the similarities in socio-cultural aspects across Western cultures, the results of this research could be cautiously extrapolated to similar socio-cultural contexts.

The studies' focus on kitchens may also impose certain constraints on the knowledge generated. However, the more general results of the study, which are not specific to the kitchen context, could be adapted to other less specific spatial settings. Nevertheless, in-depth research on the dwelling and building level is necessary to comprehend spatial design's implications for circularity.

The qualitative studies primarily involved industry stakeholders, such as housing developers, housing managers, architects, kitchen furniture producers, contractors and real estate brokers. The end-user perspectives were explored through a limited number of participants, restraining the breadth of perspectives and experiences considered in the studies. Despite this limitation of the number of stakeholders involved in the studies, the results provide valuable insights that could benefit from further research involving a broader range of stakeholders, especially a more diverse representation of end-user groups.

The research team's active participation also influenced the research outcome. To mitigate the potential bias and influence of the research team, various methods and sources for data collection were employed and the results were validated through interviews and a workshop with architects, housing developers, housing managers and some of their suppliers.

An additional methodological challenge emerged during the research design of Study 3, which considered the available frameworks for assessing adaptability in the circular design context. At the time of developing the means of assessment for the adaptive capacity evaluation of apartment floorplans, no comprehensive theoretical frameworks integrated the concepts of adaptability and circularity. Consequently, the study relied on existing theories related to adaptability in general. However, an alternative approach could be considered today to produce more coherent results, namely, integrating the determinants of circular building adaptability in the analytical and assessment frameworks developed in this thesis.

7. Conclusions

The overall aim of this PhD research is to contribute to the knowledge development and the discussion on transitioning from a linear to a circular approach in the design, construction and utilisation of residential buildings. In this thesis, four studies unfold spatial designs' contribution to circularity through exploring stakeholder processes and preferences (Studies 1 and 2), analysing the circular potential of the physical manifestation of spatial design (Study 3) and investigating the integration of adaptability (as one of the key factors of spatial design's contribution to circularity) into CBD processes (Study 4). The following sub-chapters summarise the contributions of this thesis, implications for practice and recommendations for future research pathways.

7.1. Contributions

The novelty of this thesis is highlighting spatial design's importance and contribution to circularity in residential buildings. The studies reveal that spatial design could contribute to circularity by slowing and narrowing resource loops. This can be achieved through functional and adaptable spatial design. Much research and knowledge exists concerning design guidelines for the functionality and adaptability of residential buildings and dwellings. However, the studies of this research show that the practical implementation of this knowledge has shortcomings.

Regarding functionality, this thesis highlights that more emphasis needs to be placed on end-user perspectives, evaluation of building projects post-production and implementation of the learnings. The studies show that end-users commonly prefer certain spatial design solutions. Implementing these design solutions could facilitate the long-term use of dwellings and reduce the need for alterations. Continuous evaluation and implementation of end-users' design preferences are crucial to creating evidence-based functional spatial design of dwellings.

Regarding adaptability, a comprehensive application of the concept must be facilitated and encouraged in practice. The studies show that adaptability is down-prioritised in the design process in current design practice. Adaptability must be incorporated holistically into CBD throughout all shearing layers and with regard to short-term and long-term solutions so resource-efficient alterations can be easily carried out. As previous literature also emphasised, this thesis concludes that adaptability is a key component of CBD. To facilitate the implementation of adaptability features in CBD, this thesis provides methodological pathways, frameworks and examples of spatial design solutions that could support circularity in residential buildings.

Study 1 shows that stakeholders wish to be part of a larger segment of building projects. The complex and lengthy stakeholder network currently involves stakeholders in only parts of the process. The results also expose that despite architects possessing a vast knowledge of spatial design solutions facilitating functionality and adaptability, they sometimes implement less suitable design solutions due to compromises made based on the requirements and budgetary constraints of the housing developers. Study 4 further reveals that architects' conventional knowledge and skills have evolved in the new circular paradigm. However, currently, there is a significant emphasis on technical aspects concerning the selection of materials and the adoption of technologies that foster

circularity. Despite demonstrating a novel skill set and understanding of circular design approaches, the architects did not sufficiently consider the end-users' perspectives in Study 4. Additionally, the implemented design strategies' impact on the dwellings' spatial design was not evaluated. Architects' knowledge of advantageous spatial design solutions should be better valorised in CBD processes.

The case-specific results connected to the kitchen's spatial design show that the research of HFI performed between the 1940s and 1980s is still applicable to a large extent. However, this thesis identifies a need to reintroduce end-user-focused research to evaluate the preferences of a broader range of end-user profiles, investigate previously non-dominant kitchen activities and expand the research subjects to sustainability and circularity demands. Such research is also important with regard to the proposed changes to Swedish building regulations. Instead of prioritising short-term benefits, policymakers should address the long-term implications of circularity.

Table 18 – Overview of the contributions of the four studies of the thesis

Study	Contributions
Study 1	Pinpoints four circular value opportunities for the built environment Identifies the potential significance of spatial design for circularity Reveals some of the spatial characteristics of the kitchen Provides insight into stakeholder preferences regarding the spatial design of kitchens Highlights design preferences of stakeholders regarding the built-in furniture of the kitchen Exemplifies the segmented stakeholder network within the building industry Identifies the need for increased collaboration among stakeholders Highlights the need for evaluating and implementing end-user needs
Study 2	Exemplifies spatial alterations performed in the kitchen Provides insight into end-user preferences regarding the spatial design of kitchens Provides insight into motivations behind end-user-driven alterations of kitchens Highlights design preferences of end-users regarding the built-in furniture of the kitchen Outlines advantageous spatial design solutions supporting circularity in residential buildings
Study 3	Identifies spatial characteristics of the kitchens Develops a spatial analytical framework to assess the spatial design of kitchens in apartment floorplans Develops an assessment criteria to evaluate the adaptive capacity of kitchens in apartment floorplans Presents a descriptive overview of contemporary design solutions for kitchens and evaluates the functionality of those solutions Provides an assessment of the adaptive capacity of contemporary apartment floorplans Outlines spatial design solutions that can support circularity in residential buildings
Study 4	Identifies design strategies applied in current CBD in the multi-residential context Presents an overview of architects' design approaches and connected reasonings regarding circular design strategies Provides an evaluation of the identified design strategies in terms of their support of circular building adaptability determinants Provides an overview of the identified design strategies' application to various shearing layers Develops a conceptual design framework to support the implementation of circular building adaptability determinants Identifies the lack of consideration for adaptable design solutions in current CBD Identifies the lack of consideration for diverse end-user preferences Exemplifies the changing role of architects in the new circular paradigm

This thesis complements the research in the field of CBD with several methodological contributions. Currently, there is a lack of assessment tools to evaluate the circular potential of spatial design solutions. My work contributes to bridging this gap by adopting and developing frameworks and assessment tools through the spatial analytical framework and the adaptive assessment criteria presented in Paper C and the conceptual design framework for implementing circular building adaptability presented in Paper D. Additionally, the four studies of this thesis collectively provide methodological pathways for assessing the circular potential of spatial design. An overview of the study-specific contributions can be found in Table 18.

In conclusion, this thesis advocates incorporating functionality and adaptability requirements in CBD approaches. Combining the concepts of functionality and adaptability would lead to design solutions that are standardised yet adaptable. This thesis argues that such adaptable standard design requirements are vital in CBD and, hence, for transitioning to a circular built environment. Additionally, this thesis highlights the need for enhanced collaboration among stakeholders in the building industry and expanded evaluation and implementation of end-user preferences related to the design of their dwellings.

7.2. Implications for practice

The role of architects is pivotal in shaping the future of sustainable living spaces. Their knowledge and skills are instrumental in designing functional and adaptable spaces. The implications of this research underscore the importance of spatial design for circularity in residential buildings. Architects are encouraged to consider these aspects in their designs, advocate for and promote functional and adaptable spaces and support end-user behaviour that aligns with circularity.

This thesis emphasises the importance of integrating CE principles into residential building design, which extends beyond material reuse and waste management. It advocates for the design of adaptable, functional residential buildings that support circularity. With the impending changes in Swedish building regulations, housing developers face new challenges. They must embrace new responsibilities, particularly in defining and enforcing functional requirements in residential design. Aligning these functional requirements with circularity demands and end-user preferences is a difficult task. Successful execution of this task requires industry-wide collaboration; housing developers, architects, researchers and other stakeholders must be engaged and take an active role in it. This thesis provides valuable insights by identifying spatial design solutions that align with CE principles and end-user preferences. Furthermore, this thesis highlights the need to establish evaluation channels and foster collaboration, moving away from siloed operations.

The shift in governmental regulations over the past century reveals two significant concerns: (1) a lack of guidance from evidence-based research and (2) a lack of prioritising housing qualities supporting end-users' preferences and needs. My research provides evidence-based design recommendations, particularly regarding the spatial design of kitchens. These recommendations could inform upcoming changes in the building regulations. By incorporating these results into the regulations, it would be possible to promote design solutions that are more functional, adaptable and in line with the CE principles. This would ultimately contribute to creating living spaces better suited to the needs of the end-users and the environment.

7.3. Further research

While this thesis presents insights into spatial designs' contribution to circularity, it also identifies pathways for future research. Firstly, the explorations initiated in connection with the kitchen could be applied to other spaces of the home. Future research might investigate which spatial characteristics define other spaces (e.g., bathroom, entrance, bedrooms, balconies) and how those spaces may be designed based on CE principles. This could lead to a holistic overview of functional requirements for CBD in the residential building context.

Second, while this thesis acknowledges and advocates for a comprehensive exploration and integration of end-user preferences in CBD, it does not provide exhaustive input on such preferences. There is a need for further research to comprehend the design preferences of a broader range of household types and end-user profiles, going beyond the traditional categories of singles, couples, families and the elderly. The research should also delve into the evolving activities conducted in the kitchen and other home areas. For instance, the kitchen has seen a shift in its utilisation, including changes in cooking habits, food choices and social interactions. Although the CIK project explored some of these changes, it maintained a somewhat traditional perspective on kitchen use. There is a need to investigate more innovative approaches and lifestyles that align with CE principles. The findings from such research could assist architects and housing developers in devising spatial design solutions that align with circularity. Additionally, it could guide policymakers in formulating regulations that promote the transition to a circular model in the building industry.

Third, within the emerging field of circular building adaptability, there is still a need for further investigation regarding design strategies, tools and frameworks that support the application of the concept. My work contributes to the field of circular building adaptability by identifying and analysing supporting design strategies and proposing a conceptual design framework. In its current form, the framework's main objective is to illustrate the fundamental reasoning necessary for the systematic application of circular building adaptability. However, there is a need to refine and evolve this framework into a user-friendly tool that can guide designers through the complexities of circular building adaptability. Testing, iterating and validating this framework in real-world design situations involving architects is crucial. This step is critical to ensure that the framework aids the architects' design process rather than complicating it.

Lastly, currently, there is a lack of investigations on how applied circular design strategies influence the spatial design of dwellings. A potential future research subject could be investigating the spatial manifestation of CBD and its impact on end-users and their living environment. Analysing and comparing end-user preferences and floorplan drawings of circular building projects could be an interesting future research pathway. Additionally, a more comprehensive use of spatial theory could contribute to a more robust understanding of the social and material aspects of the spatial design of residential buildings.

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