Densification of Dutch postwar neighbourhoods through application of spatially efficient cooperative housing principles on gallery flats as a strategy towards enabling a sustainable and circular 2000-watt-society

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Abstract

Increasing density of housing in postwar neighbourhoods can simultaneously help in reducing housing shortages, address social-economic issues and enable a 2000-watt-society. Shifting household compositions have seen household sizes reduced and floor space usage increase, which corresponds to higher energy and material use. Reducing floor space usage per capita is a prerequisite for enabling sustainable housing. Usage of efficient principles from cooperative housing, such as sharing functions and spaces can allow for greatly reduced floor space usage per capita, without reducing quality of dwellings. To apply these principles in the postwar neighbourhood, the gallery flat is a fitting subject for transformation. By using principles of cooperative housing for top-ups on spatially inefficient gallery flats, floor space usage per capita can be greatly reduced, allowing many more people to be housed on an equal footprint. However, attention must be given to technical factors such as traffic routing, structural spans, stability and accessibility.

Keywords: *Postwar neighbourhoods, densification, cooperative housing, floor space usage, gallery flats*

1. Introduction

In the Netherlands, there is an acute shortage of housing (CBS, 2022c). Construction of new housing is proceeding slowly, and the goal of building 1 million new homes by 2030 is currently unlikely to be reached (Voermans, 2022). To reach the goal, it will not be possible to only focus on new greenfield construction. Looking inward towards existing urban areas can reveal opportunities for new housing through densification. Construction of new housing can be sped up by capitalising on existing infrastructure, amenities and even existing buildings. Furthermore, a broader spatial intervention could simultaneously address local urban issues (KAW, 2020). One such area is the postwar neighbourhood. Typical Dutch postwar neighbourhoods, built between 1945 and 1960, often suffer from problems relating to social-demographic factors (Noyon, 2008), mono-typical housing (Blom, Jansen and van der Heide, 2004) and are often simply out-dated and improperly maintained (Obbink, 2016). Despite their neglect, 68 postwar neighbourhoods in the largest 42 municipalities in the Netherlands accounted for 711.000 inhabitants in 2016 (CBS, 2017).

In light of the goal of creating a circular economy by 2050, of which the built environment is an integral part, consideration should be given to how existing environments will also be made ready for a circular economy (European Parliament, 2021). In working towards a circular economy, the first consideration to make is how to at first simply refuse or reduce a material or energetic need

(Ellen MacArthur Foundation, 2023). A method to broadly apply this principal reduction is by striving for a '2000-watt-society' (Morosini, 2010). The 2000-watt-society is a model which shows that a society, by reducing average daily primary energy usage to no more than 2000 Watt per day or 17.500 kWh per year per person, can reach a level of energy consumption which is sustainable. This goal can be attainable by 2050 without reducing the current standard of living (Jochem, 2004, 2016). Many factors influence energy consumption, of which the built environment through behaviour and lifestyle are considerable parts (table 1). The 2000-watt-society is thus not a measure of circularity, but an assessment principle which can be used to first reach a sustainable threshold of reduced energetic and material usage on which a circular economy can then be built. In what way should the built environment contribute to this goal?

Table 1. Daily energy requirements per capita in an average Swiss 4-person household in 2008 (Novatlantis, no date)

Activity	**Current daily energy requirement in watts**	**Envisioned daily requirement in a 2000-watt society**	**Difference**
Living and working environment	1500	450	-1050
Consumer goods and foodstuffs	1140	500	-640
Infrastructure	900	340	-560
Electricity consumption	570	210	-360
Mobility (automobile)	480	140	-340
Mobility (aircraft)	230	180	-50
Mobility (public transport)	140	100	-40
Total	4960	1920	-3040

2. Methodology

This paper seeks to answer the following main research question: 'How can the densification of postwar neighbourhoods using spatially efficient cooperative housing principles on gallery flats contribute towards a 2000-watt-society and the transition to a circular economy?'.

To answer it, three sub-questions are addressed in three chapters:

- How does increased density of housing relate to energy usage in urban areas, and how does it compare to housing trends in Dutch postwar neighbourhoods?
- In what way can a cooperative housing model reduce material and energetic requirements for housing in comparison to typical housing models?
- To what extent can the principles of cooperative housing be applied to gallery flats as a contribution to overall sustainable densification of postwar neighbourhoods?

This paper is structured in two halves. The first half, covered in chapter 3, uses a literature study methodology to provide a scientific framework for the second half. It explains why reduction of energy usage per capita is essential in reaching sustainable development goals by 2050, why cities should be densified to do so, and how densification relates to Dutch cities and postwar neighbourhoods. The second half, covered in chapters 4 and 5, applies a combined methodology consisting of a literature study and case study analysis. Chapter 4 uses the notion of sufficiency in housing as described by Cohen (2020) to outline sustainable targets for household sizes in square metres per inhabitant. Those targets are contextualised by contemporary Dutch housing standards.

With this literature framework, a case study is done by functionally and spatially comparing those to a number of similar cooperative housing projects, which is summarised in table 4. The most significant results of this three-way comparison are discussed in the results section, and interpreted into quantitative and qualitative design principles for further use. In chapter 5, those findings are again first considered from a scientific standpoint through literature study, and then retroactively applied to an existing gallery flat in the form of a case study.

3. Densification as an approach to sustainable postwar neighbourhoods

3.1. High density in urban areas as a prerequisite for low-energy use

In *The Weight of Cities*, it is stated that cities can be organised in such a way that they consume only 10% of their current energy demand (IRP, 2018). Creating preconditions to enable this is key in enabling this reduction. Mixing of functions can lower energy requirements by a factor of 2. Combined with attention to energy-efficient buildings, economical and renewable energy systems, behavioural/lifestyle and densification, change influenced through urban design a reduction of resource and energy usage by a factor of 10 is possible (IRP, 2018). Thus, a great deal of potential for reducing personal energy consumption towards 2000W per capita per day lies in the (design of) the built environment, both on the urban and the household scale (Lienhard, 2014).

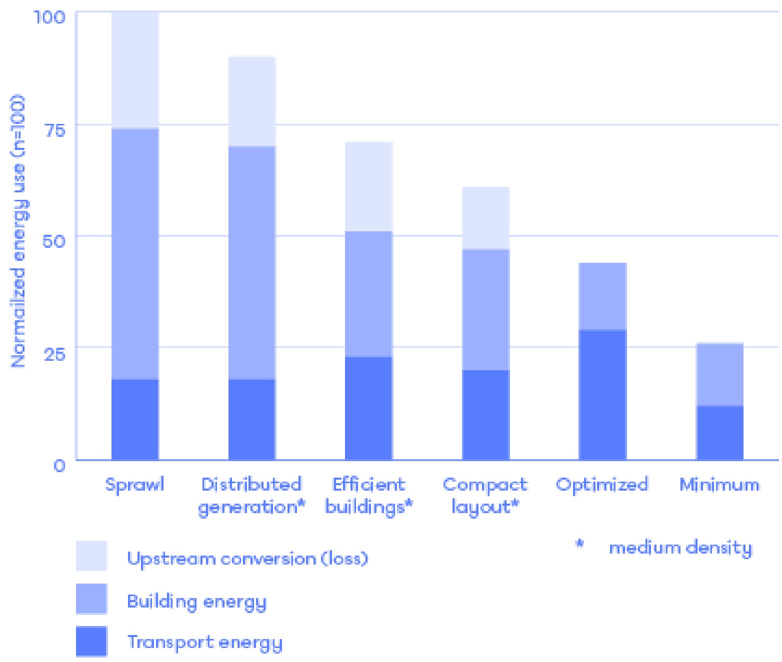


Figure 1. Energy use for five urban designs by major energy level and type (GEA, 2012)

In creating conditions for liveable, adaptable and sustainable cities, high density, though not a goal in itself, is a precondition for enabling those qualitative metrics (Sim, 2019). High density is more sustainable because it lowers energy consumption by enabling more amenities, jobs, dwellings and mobility hubs within a smaller reach (Angel, 2012). It can encourage walking, cycling and usage of public transport instead of car usage. Denser housing also allows for less material usage in construction and less energy usage for heating and utilities (IRP, 2018). Even lower consumption of energy can be reached through articulated density: a varied pattern of low and high densities is alternated with green uninhabited spaces and dense ‘nodes’ with very high density of residents, jobs, services and amenities (figure 2) (Hajer et al., 2020). According to the IRP (2018), the target density for sustainable cities lies roughly between 7.500 and 10.000 people living per km² on an average metropolitan scale, and around 15.000 per km² in the densest central areas or ‘nodes’.

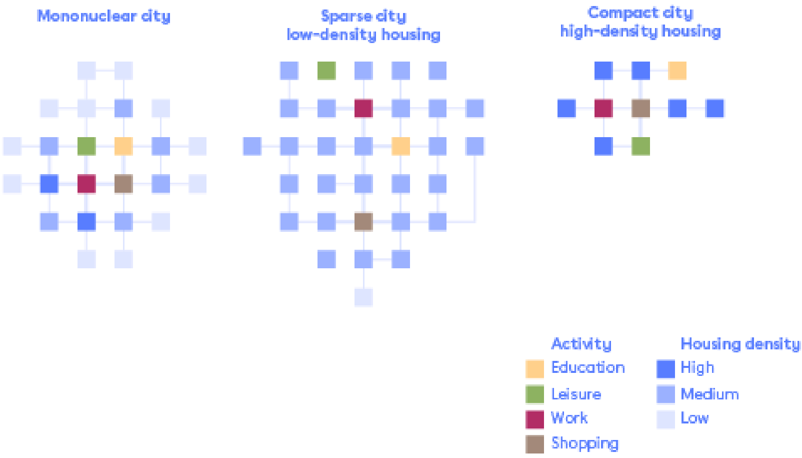


Figure 2. Schematic representation of low- and high-density urban layouts (GEA, 2020)

3.2. Trends in urban density and households in the Netherlands

While the IRP emphasises greater density as key in enabling sustainable cities, and the trend of more people living in urban areas in the Netherlands is expected to further increase towards 2050, Dutch urban areas are becoming *less* dense, due to their increasing size and inhabitants spreading out more (KAW, 2020; de Jong, 2022). This trend has continued since 1945, when a number of subsequent postwar initiatives saw many new neighbourhoods and cities built to sustain a growing population (Hereijgers and van Velzen, 2001, p. 29). A number of factors are responsible for this reduction. Average household size in the Netherlands has decreased significantly (figure 3) (Hereijgers and van Velzen, 2001, p.47; CBS, 2022b). This number is projected to remain around 2,1 until 2070 (Stoeldraijer et al., 2021).

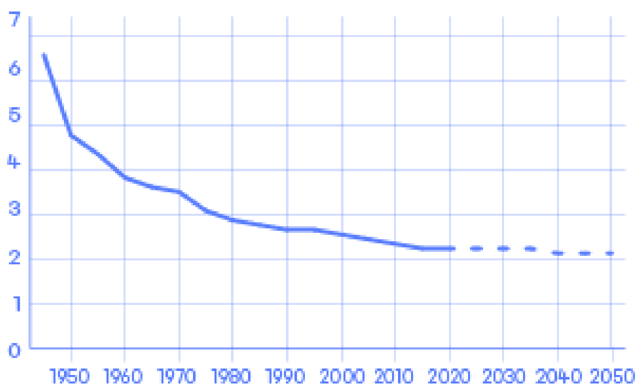


Figure 3. Average number of inhabitants per household in the Netherlands (CBS, 2022)

Simultaneously, the average number of square metres per household per person has increased greatly (figure 4) due to increasing wealth and spatial-functional requirements (CBS, 2018b). Further increase is caused by an eightfold increase since 1962 of single-person households (figure 5), today amounting to nearly 40% of all households and 18% of inhabitants (CBS, 2022b). This has been largely caused by individualisation of society and partly by widowed seniors (CBS, 2022a). 3.800.000 single person households are projected to account for 41% of all households by 2050 compared to less than 20% in 1970 when they numbered 685.000 in total. Larger households occupy more square metres on average, but per capita their requirements are lower (figure 4).

Figure 4. Average number of square metres per household and per household size (CBS, 2022)

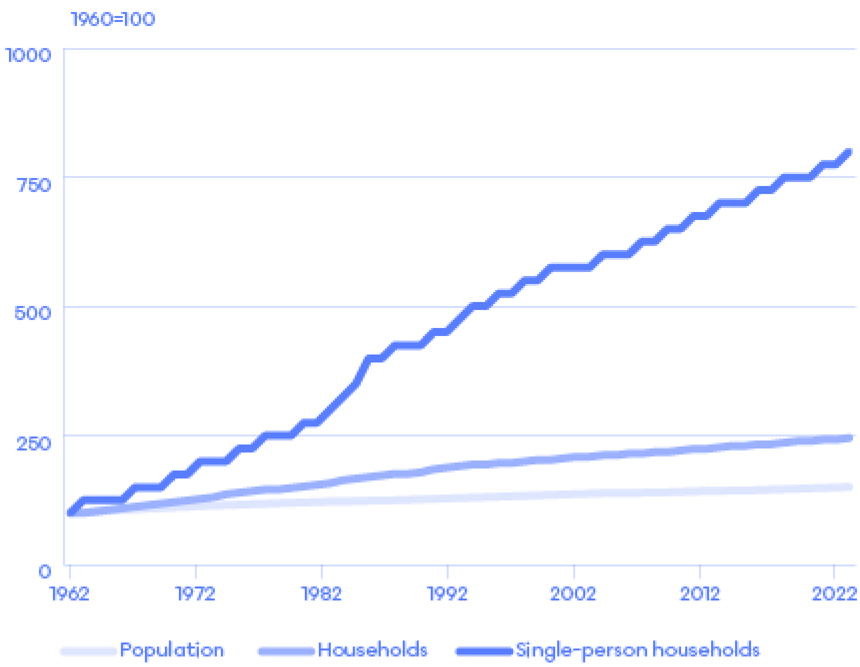


Figure 5. Relative growth of Dutch population and households (CBS, 2022)

3.3: Densifying the postwar neighbourhood for a circular economy

Postwar neighbourhoods, characterised as those built between 1945-1965, were built on a vision in which overall density was relatively low to enable wide green space, good daylight and healthy air in response to deplorable housing conditions in the old cities (de Hoop et al., 2009). Mirroring the society at that time, most dwellings were intended for families, in apartments that are today often still considered spacious. Functions and amenities for leisure, shopping and working were separated from living areas, as automobile transport was assumed to be accessible for each household, thereby greatly increasing personal mobility and mitigating downsides of greater travel distances (Hereijgers and van Velzen, 2001).

Despite finally solving the postwar shortage with sufficient housing, many postwars neighbourhoods have declined since the 1980's and 1990's. A shifting paradigm saw families that could afford doing so leaving for newer neighbourhoods with terraced houses and private gardens instead of stacked apartments. Their departure led to a drop in density and thus left less incentive and viability for public transport, services and amenities. The resulting qualitative decrease caused a negative feedback loop, leaving often only those with no alternative to remain in the postwar neighbourhood: those with low incomes, the elderly and immigrants. Inhabitants became poorer, unhealthier, lonelier and less diverse in terms of income level and education than any other Dutch neighbourhood type, and it remains the same today (CBS, 2017). The postwar neighbourhood, originally designed to house large families, now houses mostly single-person households (figure 6) (CBS, 2017).

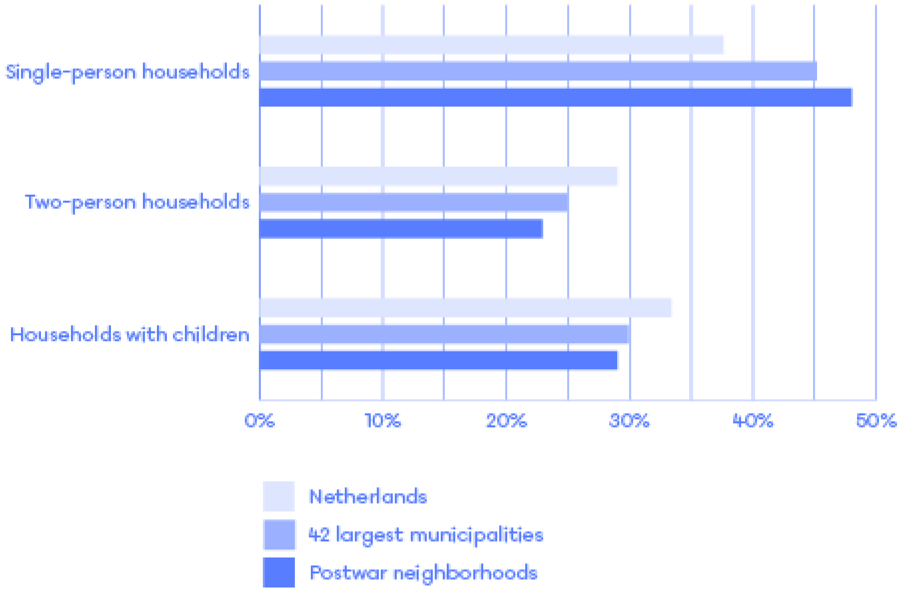


Figure 6. Percentage of household types in Dutch neighbourhoods (CBS, 2022)

A changing society has seen the postwar neighbourhood become mis-matched with the people that inhabit it. Smaller households are expected to stay the norm, while their spatial footprint is growing. In light of the goal of creating a circular and sustainable economy, *the Weight of Cities* shows that increasing density and reducing spatial requirements of cities and neighbourhoods is essential in doing so. As up to 80% of the building stock in 2050 is already built (van den Wijngaart, Folkert and van Middelkoop, 2014), today's built environment should just as well be part of a circular economy by 2050. Therefore, it is imperative to also consider in what way density, which is a precondition for urban sustainability, can be best increased in existing neighbourhoods. By doing so, an opportunity exists to also address both local and national existing issues: reduce the housing shortage, increase diversity of people and housing and mitigate the lack of mobility and amenities. Doing so can make it fit for a circular, 2000-watt-lifestyle by 2050 in which both existing and new inhabitants are included.

4: Principles for efficient floor space usage in co-operative housing

4.1. Sufficiency in Housing

Housing is responsible for significant demand for natural resources and energy in high-income countries (Cohen, 2020). High income per capita is related to greater floor space in residential dwellings, which require more material in construction and energy for heating and cooling

(Schipper, 2004; Isaac & van Vuuren, 2009). Floor space usage per capita is increasing in all of Europe in face of decreasing household size, ageing populations, and increasing complexity of domestic relationships (Lorek and Spangenberg, 2019). In turn, (embodied) energy usage is also increasing. Since housing and lifestyle is responsible for a large share of daily energy use (see table 1), reducing energy usage in housing can be a substantial step in working towards a sustainable daily consumption of 2000W or less.

In recent years, a 'sufficiency turn' has started in the field of sustainable consumption, which has shifted to encourage strategies in which absolute reductions of energy and materials are emphasised over mitigation (Gorge et al., 2015; Spengler, 2016). While some argue in favour of improving thermal efficiency and green-building techniques to reduce material and energy usage, increasing home size has caused the efficacy of those methods in comparison to their own material and energy cost to be of limited effectiveness (Huebner & Shipworth, 2017; Viggers et al. 2017). Embodied energy represents up to 52% of the life cycle energy demand over 50 years, showing that house size is a critical factor in assessing sustainable energy use (Stephan & Crawford, 2016). To meet climate and circularity targets and achieve absolute reductions in energy demand, any effective response to climate change will require new ways of living, working and relaxing (Shove, 2010). As such, it is necessary to not only slow the trend of increasing domestic spatial requirements per capita but to reverse its direction (Ellsworth-Krebs, 2019).

4.2: Minimum and maximum spatial norms for sustainable households

Determining parameters for sufficient home size is complex and nuanced. The amount of living space that residents consider to be acceptable is also affected by antecedents, culture and locality. Households can be socially complex and have specific needs. Thresholds for minimum size can ignore issues such as a two person household consisting of a couple having different requirements than two dissociated individuals. While aforementioned factors are not considered by it, the International Code Council (ICC) prescribes a 'minimum social floor' requirement of 14m² residential space for a single household occupant, and 9m² for each additional resident, based on basic needs for functionality and privacy (Cohen, 2020).

Opposing this minimum is the 'biophysical ceiling', which defines a material and energy consumption to build and sustain a certain amount of residential floor space (Tukker et al., 2016). Though again subject to caveats and exceptions, this ceiling is defined as at 20m² of floor space per capita (Cohen, 2020). A 'sustainable consumption corridor' between minimum home size and maximum energy usage can thus be calculated at 14-20m² per capita. However, it must be kept in mind that it is a general estimate, based on some subjective judgements, and can also vary depending on factors such as material usage, meaning that a limit of 20m² should serve as an ideal goal for sustainable housing while working towards a daily energy use of 2000 Watt or less.

In the Netherlands, a guideline for minimum spatial requirements for housing is the NCB. The 'Netwerk Conceptueel Bouwen' is a network between government, construction industry, educators and institutions. Together with a number of housing corporations and Aedes, the umbrella organisation of housing corporations in the Netherlands, they developed the 'Woonstandaard' in 2018 (NCB, 2018). This document prescribes minimum spatial and functional requirements based on criteria prescribed by building code and a number of additional norms (sustainability, energy usage, accessibility). Those are paired with requirements for specific households, thereby creating Product-Market-Combinations (PMC's) through which supply and demand in the construction industry can be more clearly defined. By doing so, the goal is to build affordable, sustainable and suitable housing more quickly (Oorschot & Asselbergs, 2021).

De Woonstandaard (figure 7) describes basic standards to which new housing should be built. Each function is linked to minimum spatial requirements (figure 8). Together, these can be used for qualitative and quantitative comparison to innovative housing concepts which aim to reduce floor space requirements per capita.

PMC6	PMC7	PMC8	PMC9	PMC10
Required spaces	Required spaces	Required spaces	Required spaces	Required spaces
Living room Kitchen Dining room Bedroom Bathroom WC Laundry	Living room Kitchen Dining room Bedroom (large) Bathroom WC Laundry	Living room (large) Kitchen Dining room (large) Bedroom (large) Bedroom (2x) Bathroom WC (2x) Laundry	Living room (large) Kitchen Dining room (large) Bedroom (large) Bedroom (2x) Bathroom WC (2x) Laundry	Living room (large) Kitchen Dining room (large) Bedroom (large) Bedroom (2x) Bathroom WC (2x) Laundry
42 m² minimum usable floor space	60 m² minimum usable floor space	72 m² minimum usable floor space	72 m² minimum usable floor space	72 m² minimum usable floor space
Maximum monthly rent: €452,20	Maximum monthly rent: €647,19	Maximum monthly rent: €693,60	Maximum monthly rent: €808,06	Maximum monthly rent: none

NB: Only PMC6-10 are covered in this analysis as they relate to stacked apartment typologies

Figure 7. Functional and spatial requirements for PMC's 6-10 (NCB, 2018)

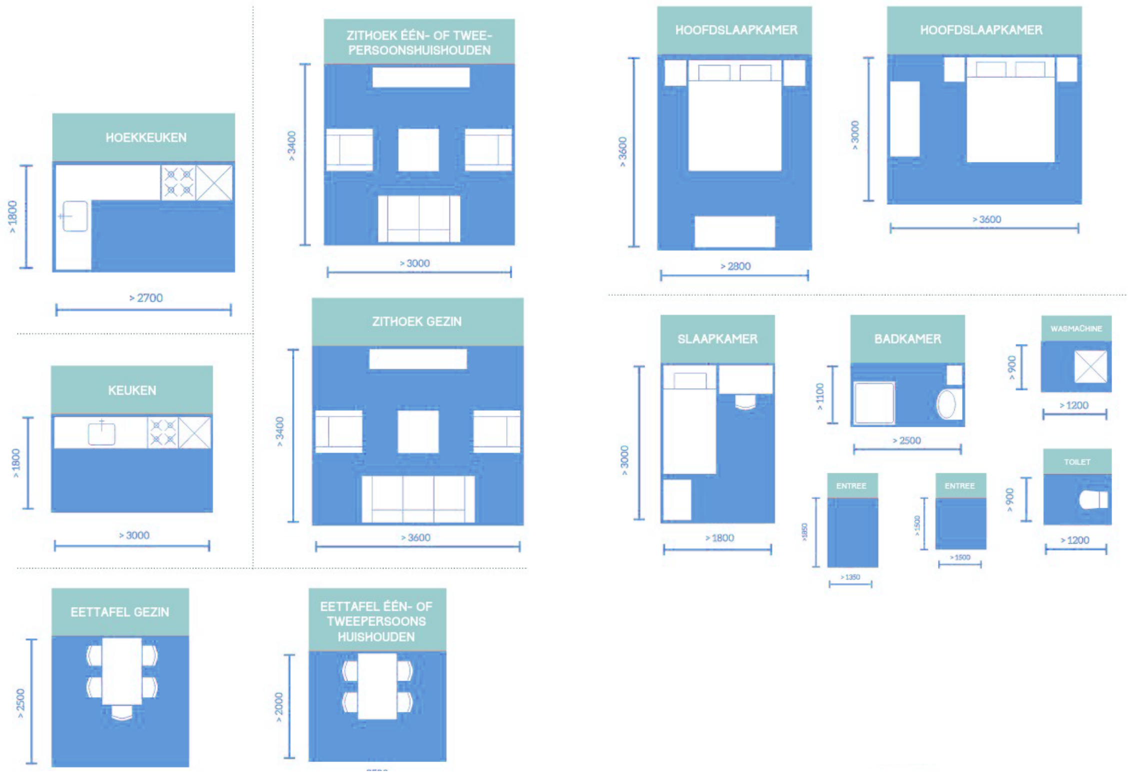


Figure 8. Minimum dimensions for standard room types in accordance with the Woonstandaard (NCB, 2018)

4.3: Quantitative assessment of cooperative housing floor space usage

A number of recent trends such as micro-apartments, tiny houses and co-operative housing have explored the physical and social minimum of housing. Of these, co-operative housing is most versatile and applicable because unlike micro-apartments or tiny houses it is not defined by spatial and functional characteristics but by organisational form. Droste (2015) defines the cooperative housing model as one in which ownership of a building is shared amongst a formalised collective of people, of which every inhabitant is a member and shareholder. Additionally, residents plan and manage their communities together and build social support networks (Droste, 2015; Nelson et al, 2016). Though not defined by it, cooperative housing often compensates for smaller private spaces by incorporating larger common rooms and spaces that are collectively designed and managed (Czischke, Carriou and Lang, 2020). By quantitatively and quantitatively comparing the norms described in those PMC's to those seen in similar cooperative housing projects (see table 2 in the appendix section), the potential reduction of floor space at similar qualitative levels is shown. By doing so, strategies for reducing floor space usage per capita can be made explicit to work towards the target of 14-20m² of floor space per capita and a 2000-watt-society.

As described in chapter 2, single-person households are currently especially demanding in per-capita floor space usage at 70m² per person on average in urban areas. In PMC6, their minimum spatial requirement is at least 42m². An example cooperative housing project similar to the prescribed norm in PMC6 is Quartiershaus in Vienna, which houses multiple dwelling types and sizes in one building. Among those are 38 small apartments for 1-2 people, housed within 6 large clusters with a total of 1,730 m2 usable floor space (figure 9) (IBA Vienna, 2022). A total of 273m² of usable floor space in a cluster is divided amongst 7 dwellings, totalling 39m² per household on average, of which ~14m² is shared amongst the cluster, or about 1⁄3 of all space per household (WaS, 2023). Total floor space per capita is quantitatively similar to the prescribed 42m² minimum from the Woonstandaard for a single-person household, and functionality of private dwellings is similar at lower floor space usage per capita (figure 10). But by sharing functions, the cluster dwelling qualitatively improves over the Woonstandaard with a second, larger kitchen, extra living room and an outdoor space. Thus, when considering the entire cluster, quantitative requirements for floor space are similar to the Woonstandaard, but with greater qualitative performance.

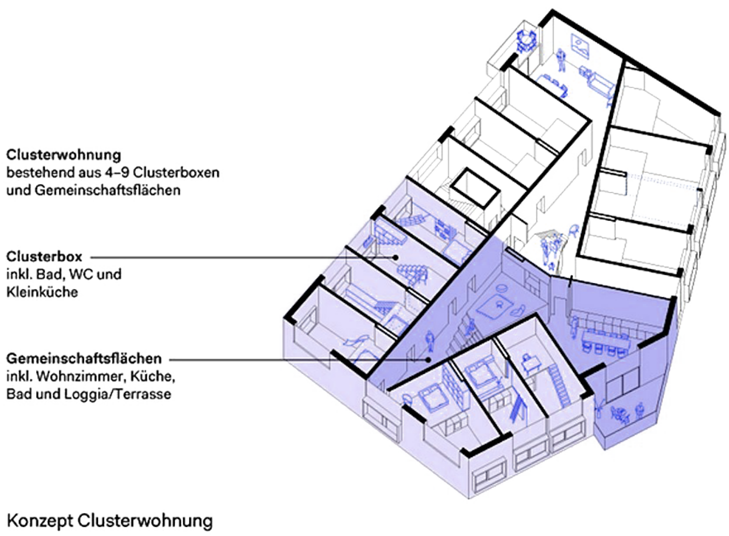


Figure 9. Quartiershaus cluster dwelling diagram (feld72 architekten, 2018)

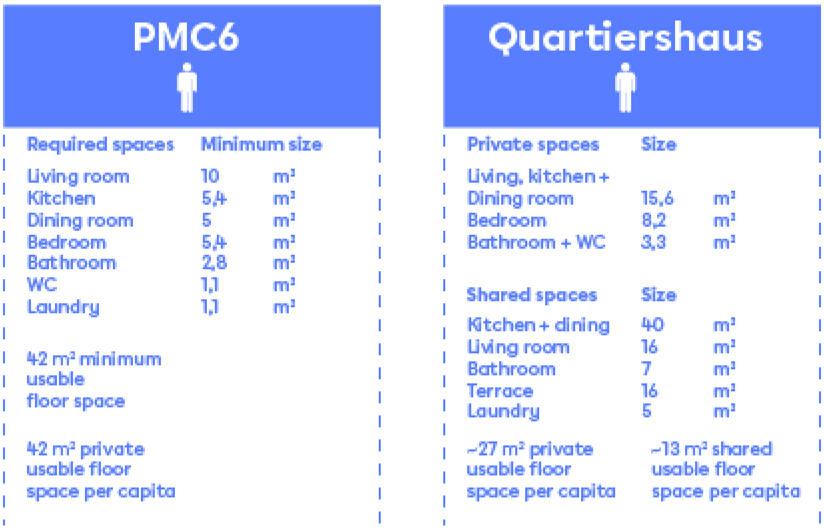


Figure 10. Spatial-functional comparison between PMC6 and Quartiershaus (own work)

While Dutch two-person households require less floor space usage per-capita than single-person households, Quartiershaus again shows further potential decrease in floor space usage, since the dwellings are suitable for 2-person households as well (WaS, 2023). Functionally, the dwellings correspond to the requirements expressed in PMC7, yet they manage to meet the ideal target of 20 m² per capita when considering collective and private space and exceeds it at 12-14m² per capita when considering only the private space.

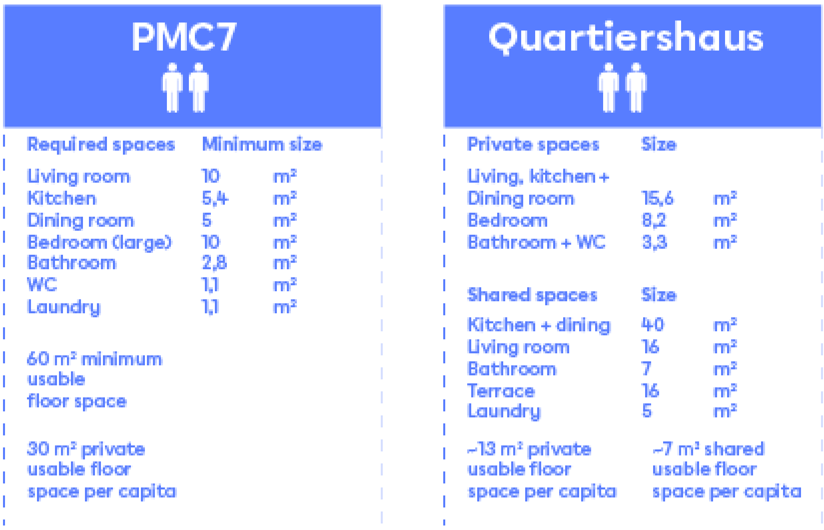


Figure 11. Spatial-functional comparison between PMC7 and Quartiershaus (own work)

Two similar examples are Haus A (figure 12) and Zwicky Süd (figure 13). Both apply the idea of cluster dwellings composed of multiple small 1-2 person households with large living shared space (Baugenossenschaft Mehr als Wohnen, 2012; Schneider Studer Primas 2016). Both provide functional equivalence to PMC6 and PMC7 with private dwelling sizes ranging between 14 and 40m² usable floor space, yet those are supplemented with 190-250m² of usable floor space which is shared amongst each cluster. In doing so, the amount of square metres per capita ranges between 30 to 40 m² per capita, yet functional and spatial quality offered is much greater than what the minimum in PMC6 and PMC7 can provide, with access to much larger kitchens, living rooms, outdoor space and more.

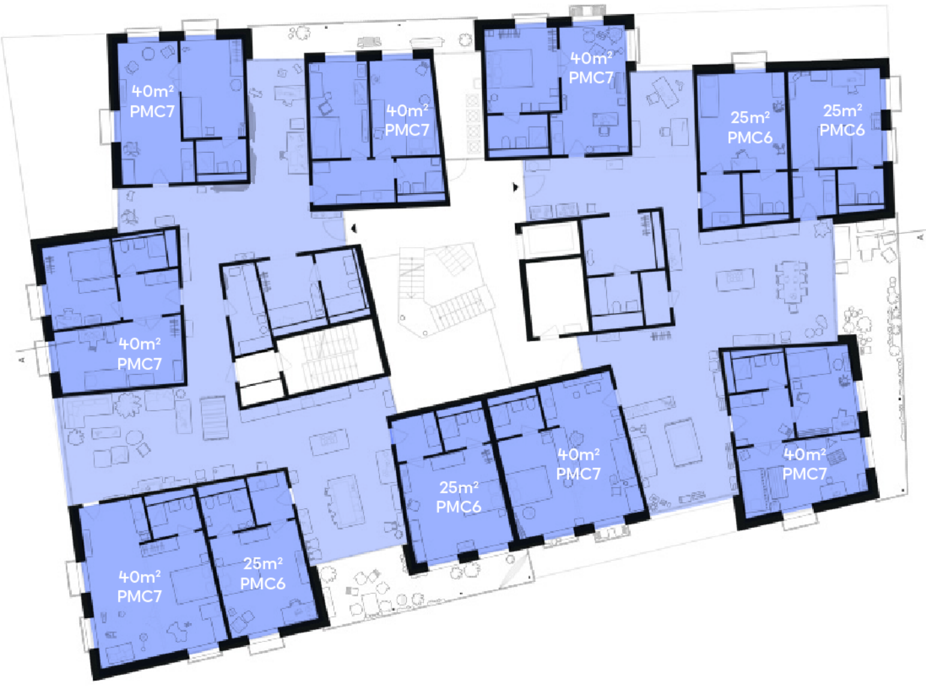


Figure 12. Haus A cluster dwelling floor plan with PMC equivalent private spaces (own work)

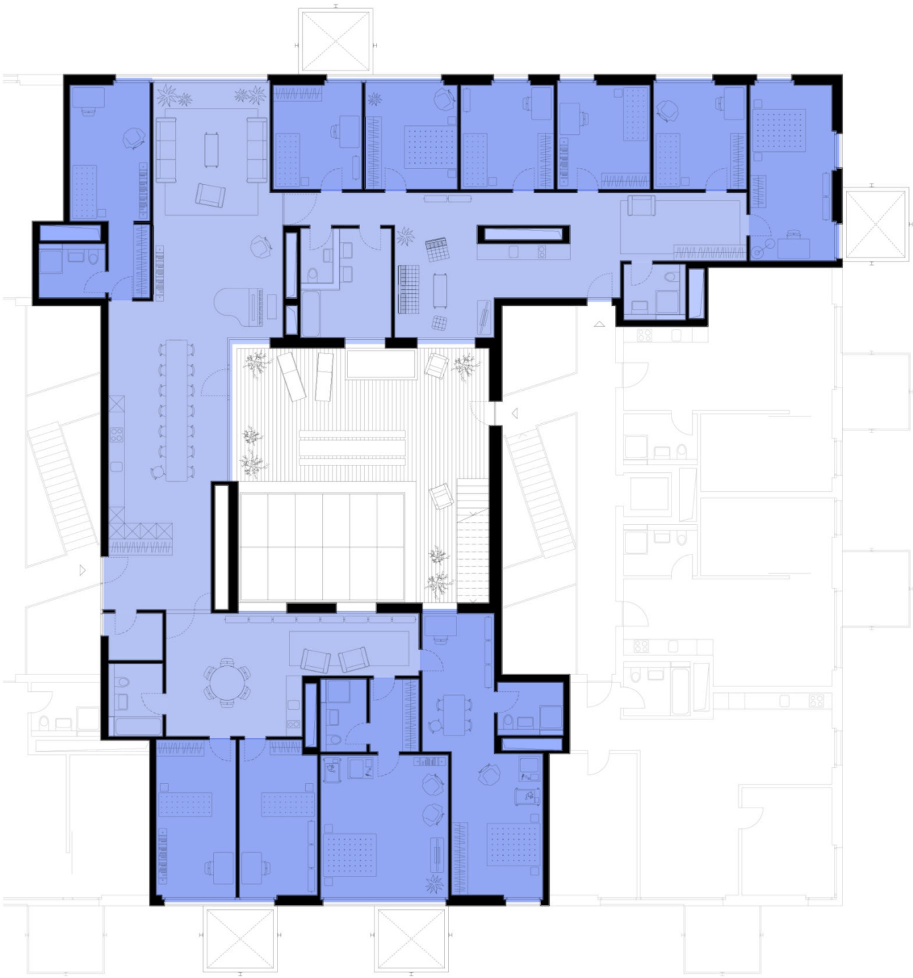


Figure 13. Zwicky Süd cluster dwelling floor plan (own work)

A Dutch family household of 3 or more inhabitants in an urban area occupies 37m² per capita on average. PMC's 8-10, apartments intended for families of 3 or more, each prescribe a minimum usable floor space of 72m². Due to greater occupancy and thereby reduced redundancy, spatial efficiency is greatly improved at 24m² per capita, already quite close to the 20m² ideal target. Though it should be noted that each room in de Woonstandaard is considered at the lowest possible size, such as two bedrooms being just 5,4m² in size and one bathroom at just 2,75m².

A case that targets similar households is San Riemo, in München. It shows how high qualitative standards, greater than PMC's 8-10 can be made possible while still meeting all functional requirements and still at low spatial requirement per capita. San Riemo makes use of a repeated standardised room of 14m² (figure 14) to enable a wide variety of dwelling types with different gradations of private versus collective space (Fischer, 2021). One such configuration is used to create a family apartment. Two of three bays are used privately by each household. A third bay is used in its entirety as one large multifunctional room, allowing for informal use by all households on that floor. A household of ≥3 inhabitants here occupies a similar amount of space per capita compared to PMC8-10 (figure 15), yet some spaces like bedrooms can be more than twice as large.

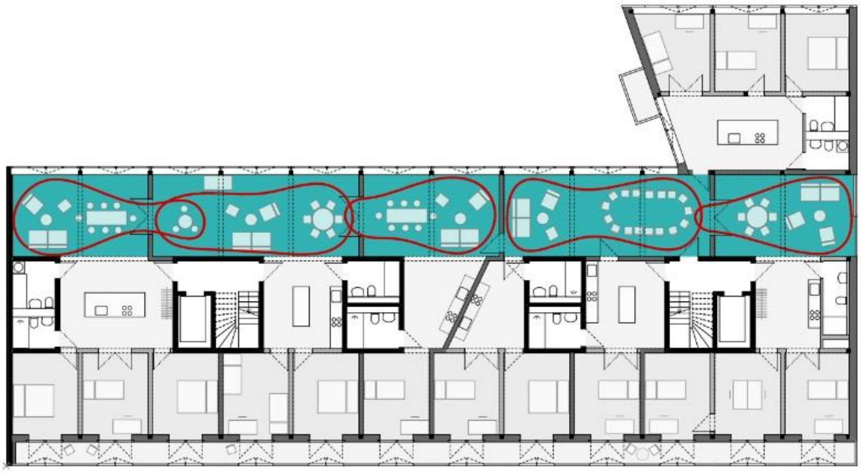


Figure 14. San Riemo family dwelling configuration (Fischer, 2021)

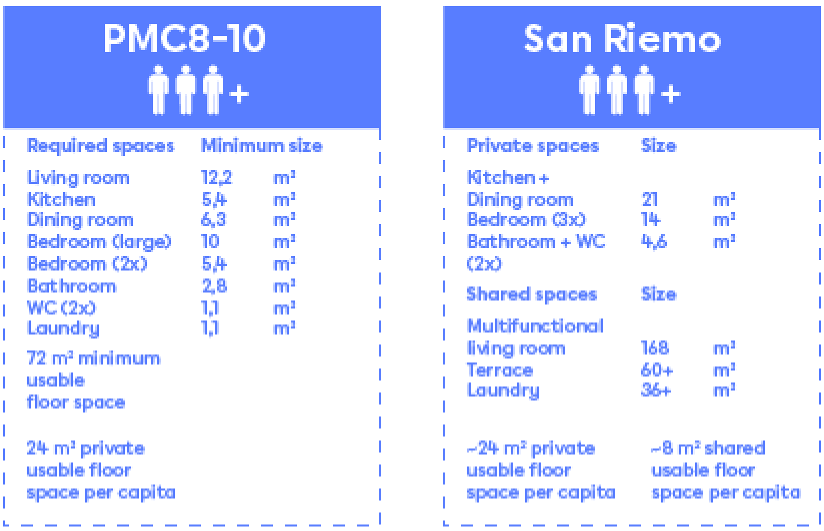


Figure 15. Spatial-functional comparison between PMC6 and Quartiershaus (own work)

Each apartment is connected to a shared ~168m² multifunctional living space, which adds 24m² of collective space per household. This raises per capita living space by about 8m² when assuming three people per household on average to ~31m² per capita. While a family dwelling in San Riemo requires somewhat greater per capita floor space usage when compared to the minimum in PMC8-10, it also demonstrates that by sharing about a part of that space — 25% of the total — much greater quality can be created in both private spaces *and* the resulting collective space.

4.4: Qualitative assessment of spatially efficient cooperative housing principles

The general spatial strategy in cooperative housing to reduce floor space usage per capita is through sharing of spaces and functions amongst more people (Czischke, Carriou and Lang, 2020). This is also evident by the fact that spatial requirements for smaller households are disproportionately large per capita compared to larger households. The level of collective use can be very limited, almost the same as normal housing, as seen in Brüggliäcker, where as little as 5% of usable floor space is shared (figure 16, see table 2). In such cases, improvements in floor space usage per capita are relatively small. In contrast, very extreme examples such as the Hallenwohnen concept as seen in Zollhaus allow for private floor space usage per capita as low as 9m² by sharing more than 60% of all spaces (Khatibi, 2022). While spatially efficient, such an extreme level of sharing does not meet standards imposed by the Woonstandaard, and is thus likely not feasible for large-scale implementation for many target groups.

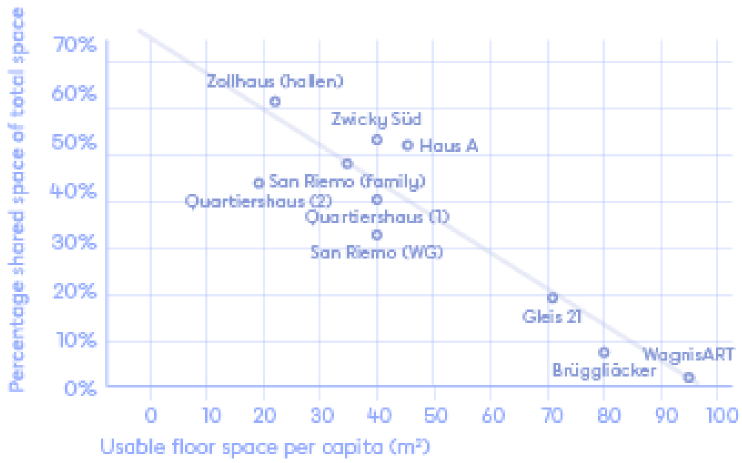


Figure 16. Relation between floor space usage per capita and percentage of shared space in analysed cooperative housing projects (own work)

Projects such as Haus A, Zwicky Süd, Gleis 21, San Riemo and Quartiershaus each comply with appropriate PMC's as dictated by the Woonstandaard by collective use of 20-50% of all usable floor space, yet do so at either higher levels of quality at the same spatial requirement or an equal level of quality at lower requirements. Generally, spaces and functions used irregularly or for utilities are first to be shared, such as storage, laundry and technical rooms. Then, private and self-sufficient dwellings can be made whose size reduction is compensated with a similar but larger alternative that is then shared amongst more dwellings, such as in Quartiershaus or Haus A. Finally, entire functions such as kitchens can be removed from the private space to only be available in collective spaces, as seen in San Riemo, Zwicky Süd or Zollhaus (figures 12-14). Doing so allows both functional compliance to appropriate PMC's, but at greatly reduced spatial requirement per capita.

Adaptability in housing, seen in concepts like 'open building' pioneered by John Habraken and more recent 'infill' models give users/owners the possibility of making future changes in accordance to developing needs (Habraken, 1972; Aureli, Giudici, & Issaias, 2012). Contemporary minimum housing should be at least somewhat adaptable to avoid increasing floor space usage (Montaner and Muxí, 2010). A number of cooperatives demonstrate this efficient adaptability. In San Riemo, a flexible infill system allows for walls to be removed in the course of the buildings' lifespan, different configurations can exist within the same structure (figure 17) and rooms can be traded and switched to ensure that a household inhabits a space that is appropriate to their composition (Fischer, 2021). San Riemo and Haus A both offer cluster dwellings with large spaces which are functionally undefined, but thus allow short-term adaptability. The Hallenwohnen concept in Zollhaus demonstrates a more extreme interpretation of this concept, by offering 12 inhabitants a large open room of 275m² in which moveable 9m² rooms serve as the only private spaces, easily adaptable to the needs of inhabitants (figure 18). By considering the building not as a finished product but as an adaptable and ongoing process, floor space usage can be reduced by enabling efficient long term usage (Brysch, 2019).

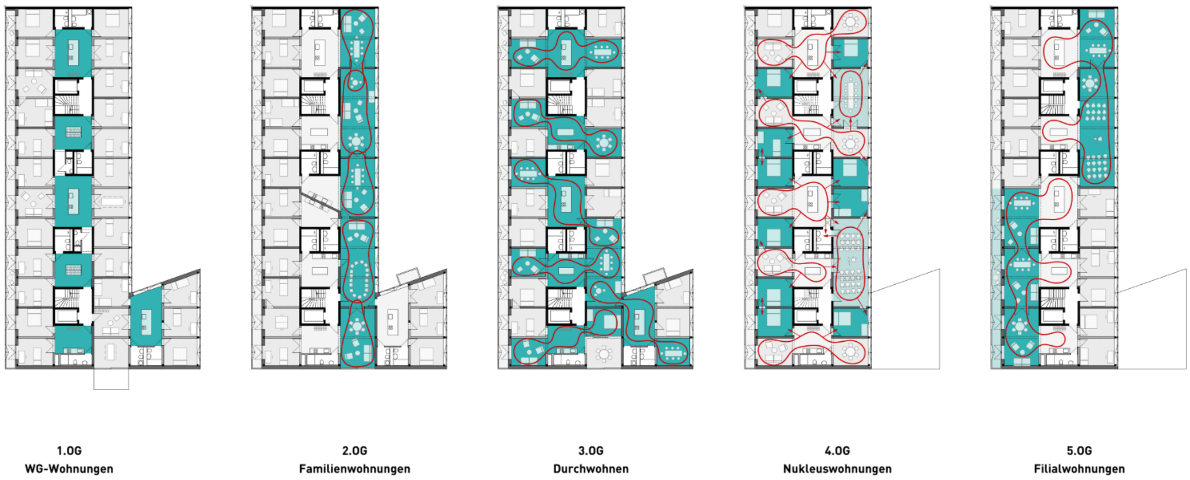


Figure 17: Floor plan configurations in San Riemo (Fischer, 2021)

Figure 18: Hallenwohnen living concept as part of the Zollhaus in Zürich (Khatibi, 2022)

Because cooperative housing is usually designed in collaboration with residents, they can define their own minimum of housing, thereby increasing spatial efficiency by reducing floor space usage per capita while retaining functional and spatial benefits of larger dwellings (Prytula et al., 2020). Design of spaces and housing can be closely attuned to precise wishes, thereby avoiding a mis-match between available housing and the eventual tenant, as might happen in traditional market-driven housing (Lengkeek & Kuenzli, 2022). Appropriate levels of sharing can be established in 'layers' with a fitting number of people to share that function or space amongst, such as some functions being shared with an entire building, one floor, one cluster or private (Francart et al., 2020). Matching requirements to levels of sharing ensures further optimisation of space.

Additionally, some cooperatives such as Coop Kalkbreite (Zollhaus & Kalkbreite) and Baugenossenschaft Grossstadt (San Riemo) have mandatory requirements for tenants to inhabit only units which fit their household composition (Fischer, 2021; Lengkeek & Kuenzli, 2022, p. 160). For example, if children move out of a family dwelling the remaining parents are required to move to a smaller dwelling (once available), thereby ensuring optimal occupation and thus use of space in the building. Because the buildings they inhabit often consist of multiple typologies (figure 19) relocation of tenants is often easy and further incentivised by reduced rental costs.

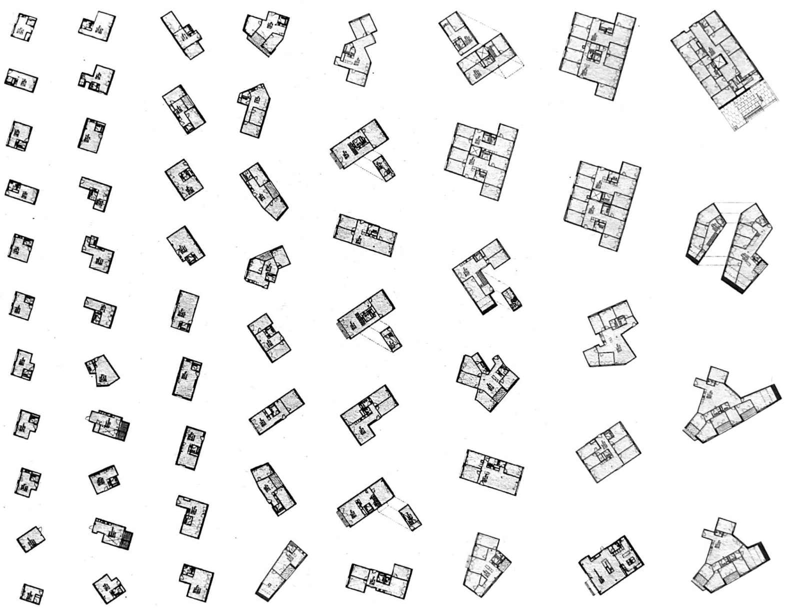


Figure 19. Floor plans of all available housing in Kalkbreite (Lengkeek & Kuenzli, 2021)

Another quality of cooperative housing is that they can reduce floor space usage per capita in ways that would simply be inherently unlikely, if not impossible in typical market-focused construction. For example, Gleis 21 in Vienna uses extra wide access galleries that can also be informally used as a collective outdoor space (figure 20). However, those spaces would not be considered rentable space for a commercial party and thus difficult to financially justify (Lengkeek & Kuenzli, 2022, p. 229). For the same reason, Gleis 21 can provide a large shared rooftop terrace as well to all inhabitants. It demonstrates the manner in which cooperatives can optimise spaces like roofs and access galleries for which there would otherwise exist little to no incentive to do so, despite the potential that those spaces can have to supply inhabitants with more and better functional spaces. By applying these measures, Gleis 21 manages to have a much higher percentage of usable floor area to gross floor area at 86% (table 2). Compared to 60% in Brüggliäcker, which is fairly similar to typical rental housing, spatial efficiency is thus much higher.

Figure 20. Access galleries and rooftop as usable outdoor space in Gleis 21 (Zilker et al., 2022)

5. Application of space-efficient cooperative housing principles on existing gallery flats

5.1: Cooperative housing in the postwar neighbourhood

Relating back to the densification of postwar neighbourhoods in the Netherlands, the question remains in what manner the principles described in chapter 3 can be beneficial for a postwar neighbourhood, and how they could be best applied there. Single-person households contribute most to high floor space usage per capita, which in typical Dutch postwar neighbourhoods consist of almost 50% of all households (figure 6) (CBS, 2017). The trend of declining household size is difficult to reverse, yet increasing spatial needs are a result of norms and policies which *can* be changed (Ellsworth-Krebs, 2019). Application of spatially efficient principles seen in cooperative housing to better match households to spatial needs, which can reduce floor space usage per capita, can be an effective first step in the densification of postwar neighbourhoods as a precondition for making it sustainable by 2050 (Balmer and Gerber, 2017).

Aside from densification, introduction of cooperative housing in postwar neighbourhoods can help address other typical prevailing issues in postwar neighbourhoods, such as loneliness, and poor health (Lubik and Kosatsky, 2019) and increase social cohesion and capital (Lang and Novy, 2013). The establishment of a cooperative can be pivotal in the establishing of a community identity (Nelson et al., 2016), and evidence suggests that cooperative housing can improve the relationship between domestic architecture and surrounding urban context by encouraging residents to socialise, care and interact with each other as well as caring, interacting, and fostering community with the neighbourhood (Williams, 2005; Fromm, 2012).

Another advantage of introducing cooperative housing in the postwar neighbourhood is the diversity of housing offered by it, the lack of which is a prevalent issue in postwar neighbourhoods that made people leave in the first place (Blom, Jansen and van der Heide, 2004; Wassenberg and Kastelijn, 2023). By appealing to a wide variety of people and households, equivalent to multiple PMC's as seen in chapter 3, cooperative housing can help in fostering a more inclusive and diverse neighbourhood. An opportunity exists to attract underrepresented target groups such as (high-income) families and highly educated people while creating a better match between housing and household for those that already reside in it.

5.2: Gallery flats as a first step towards densification in the postwar neighbourhood

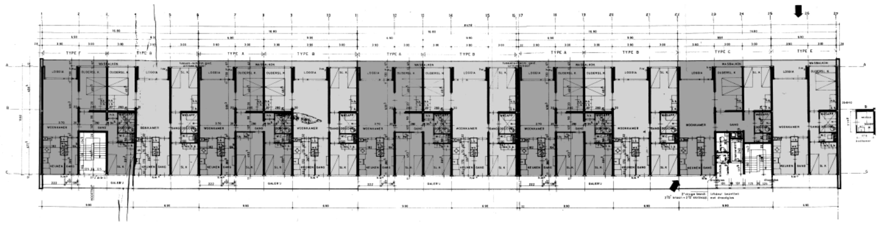
How can these principles be best applied to the postwar neighbourhood? For a number of reasons, the gallery flat is a suitable subject. First, better optimising interior space and use of existing buildings is preferable to building new ones, because it reduces energy and material usage and avoids using existing land (Höjer and Mjörnell, 2018). Second, simply by optimising and expanding existing homes, restructuring and using leftover spaces, more than plenty of new dwellings can be added. By doing so, root causes of low density in the postwar neighbourhood can be addressed, as they stem from a mismatch between available housing and contemporary household composition (KAW, 2020).

Many gallery flats are often still owned by housing corporations, which means ownership is centralised and extensive projects more feasible (Brouwers, de Gunst and van Heeswijk, 2013). While often structurally sufficient for many years, gallery flats tend to be technically, functionally and aesthetically outdated (Harnack, Heger and Brunner, 2021). At least some renovation and retrofitting is a requirement to ensure that gallery flats remain technically suitable for the foreseeable future (Spoormans, 2021). Rent in cooperative housing is generally low, since it is inherently operated on a non-profit basis. However, newly built cooperative housing as shown in previous examples require members to 'buy-in' with an equity share and membership fees, which can quickly exceed >€10.000. Newly built cooperative housing is, in absence of subsidies, initially often only affordable for middle-incomes (Balmer and Gerber, 2017). However, Lengkeek & Kuenzli (2022, p220) point out that sale of real estate from housing corporations to a housing co-operation can be a feasible method to greatly reduce this cost, though the legislative systems to do so are not yet mature enough in the Netherlands.

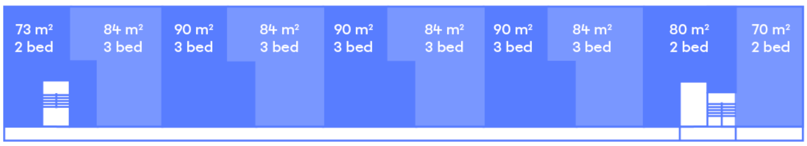
5.3: Quantitative assessment of potential for cooperative densification gallery flats

Gallery flats tend to house many dwellings on a small footprint, which means further densification can have great impact towards creating articulated density. For example, a generic flat of 10 floors, each housing 10 dwellings. Using the average household size in 1965 of 3,5, an average flat of 80m² would be quite efficient at 23m² per capita, and capable of housing ~350. However, when considering today's average household size of 2,1 floor space usage per capita would be 38m² per capita at best, housing ~210 people.

Using principles from cooperative housing to once again achieve high densities in an existing gallery flat is not straightforward, as it was never designed as such. Shared amenities were never considered in their design, as living was considered strictly individual. An easier and more affordable initial strategy is by vertical extension with new building layers, or ‘top-ups’ (KAW, 2020; Wassenberg and Kastelijn, 2023). By doing so, more flexibility in construction is allowed by not being limited to existing walls, structures, etc. An example of a generic gallery flat is the Ekamaflat in Haarlem (figure 21). Currently, one floor houses 10 dwellings in 5 types, similar to PMC8-10. In total, one such floor offers 1092m² of gross floor area for a vertical extension to build upon. When using 2,1 as a guideline for average household size, the average (usable) floor space usage per capita is quite high at 42,8m² per capita for 21 inhabitants per floor.



Current configuration of Ekamaflat



Household sizes of Ekamaflat

Figure 21. Ekamaflat floor plan and diagrammatic rendition (Noord-Hollands Archief, 2022)

Both the Ekamaflat and San Riemo can house 21 people on one floor in family-type dwellings. However, in the latter the inhabitants occupy 664m² of usable floor area, of which about 25% is shared (table 2). Considering that one floor in the Ekamaflat offers ~900m² of usable floor area, and the ratio of gross to usable floor area is similar in both, application of a floor plan like San Riemo could house up to 25% more inhabitants at ~26 on the same footprint, while also offering access to a much larger kitchen and communal living room (figure 22).

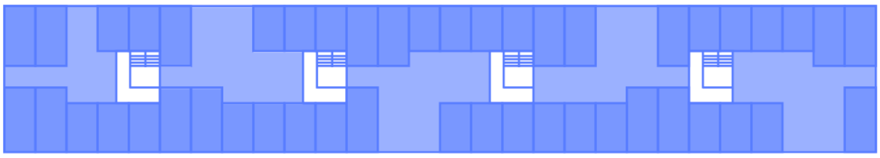
Current configuration of Ekamaflat

Footprint of Ekamaflat combined with San Riemo floorplan. Up to 25% more inhabitants possible per floor

Figure 22. Possible spatial configuration in Ekamaflat based on San Riemo (own work)

Since smaller households are especially prevalent in the postwar neighbourhood, the potential for reduction of floor space per capita is greater when considering an efficient spatial configuration from cooperative housing suited for such small households. The cluster dwelling in Quartiershaus is one such example. In it, 7 private dwellings of 23-26 m² can house 14 occupants at most, requiring as little as 11,5m² of private floor space usage per capita (figure 11). When considering ~900m² of available floor space available in the Ekamaflat, up to 46 inhabitants could be housed on the same footprint which now houses 21 (figure 23). Though doing so would require smaller private spaces, those are compensated by larger and qualitative shared spaces. By comparing current and potential inhabitant density of gallery flats, it is clear that large gains could be made, both quantitatively and qualitatively, by application of typologies and principles which are found in cooperative housing.

Current configuration of Ekamaflat



Footprint of Ekamaflat combined with Quartiershaus floorplan. More than twice as many inhabitants possible per floor

Figure 23. Possible spatial configuration in Ekamaflat based on Quartiershaus (own work)

5.4: Comparison between qualitative metrics of gallery flats and cooperative housing

Despite considering the application of cooperative housing principles only as a ‘top-up’ on a gallery flat, a number of technical characteristics, both those inherent to the gallery flat and those seen in cooperative housing, can either enable or inhibit the application thereof to the gallery flat. Many specific structural systems exist, though postwar gallery flats were generally built using similar concrete structures. As a general rule, existing high-rise structures can allow for 15 to 25% extra load-bearing capacity by ensuring new loads are placed directly on existing structural members, while even more is possible when using new reinforcements or secondary structures (Maas and van Manen, 2021). In general, stability of vertical extensions through greater wind loads is a limiting factor before load-bearing capacity becomes so (De Bouwcampus, 2022).

Furthermore, by definition the gallery flat makes use of some type of vertical connection to connect multiple floors together and external galleries to connect those to housing on each floor. While the horizontal connection is always the same, the vertical can be either internal or external. The cooperative housing cases previously discussed are all multi-storey apartment type dwellings as well, since that type is spatially most efficient (Viggers et al., 2017). Therefore both use similar vertical connections. However, most do not use galleries and instead use internal corridors to access each dwelling. One advantage of such a system is that space that would normally be used for traffic only can also become a usable space. A notable exception is Gleis 21, which is also a gallery type, but which uses widened galleries (figure 20) as informal outdoor space for all inhabitants, and additionally allows extra vertical connections between galleries to allow easier access to other levels and neighbours.

Despite the similarity, galleries on gallery flats are designed strictly as utilitarian space and as such are generally too narrow to be used as anything other than access. As such, a cooperative housing top-up will be limited to using existing vertical connections like stairways and elevators, though depending on whether those are internal or external those could use the same, possibly widened gallery system or a new, alternative internal traffic access. By reducing traffic space to a minimum and/or making it more usable, spaces can be more efficiently utilised.

6. Conclusions

This paper sought to answer the main research question; 'How can the densification of postwar neighbourhoods using spatially efficient cooperative housing principles on gallery flats contribute towards a 2000-watt-society and the transition to a circular economy?' by answering three sub-questions:

- How does increased density of housing relate to energy usage in urban areas, and how does it compare to housing trends in Dutch postwar neighbourhoods?
- In what way can a cooperative housing model reduce material and energetic requirements for housing in comparison to typical housing models?
- To what extent can the principles of cooperative housing be applied to gallery flats as a contribution to overall sustainable densification of postwar neighbourhoods?

The principal requirement of a circular economy lies in refusing and reducing unnecessary material and energetic needs in the first place (Ellen MacArthur Foundation, 2023). The 2000-watt-society is a model which defines the boundaries of the circle that is the entire circular economy: it serves as a threshold from which a circular economy should be established. Since current energetic usage in the Netherlands is still above this threshold, energetic needs per capita must be reduced to establish a circular economy. A major energetic reduction can come from the built environment. Increased density of housing can reduce energy usage in urban areas because it is a precondition for other factors which reduce energy usage (IRP, 2018).

High urban density decreases travel distances, material for infrastructure and enables sustainable methods of travel amongst other things. Despite this, the trend in the Netherlands has been of reducing density due to demographic changes and shifting household sizes and compositions. Cooperative housing projects have demonstrated that it is possible to still meet functional requirements for Dutch housing but with lower spatial needs. Reduction of floor space usage per capita is not an end goal in itself, but a strategy which can enable the necessary energetic reduction to enable a sustainable 2000-Watt-society (Francart et al., 2020). The main strategy in doing so is the reduction of redundant space and optimization thereof, usually by sharing certain functions with other households (Czischke, Carriou and Lang, 2020). Furthermore, the model demonstrates a number of other optimisation methods such as adaptable structures and diverse typologies.

In general, the densification of postwar neighbourhoods can be a realistic strategy for lowering its energetic needs per capita. Gallery flats can be a fitting subject for a transformation to a cooperative, but the application of specific design principles seen in cooperatives can be limited by the possibilities of existing flats. Top-ups can be a feasible first application of these principles, but substantial internal change to existing housing to conform to these principles can be costly, both financially and energetically, and thus less realistic. Thus, the densification of postwar neighbourhoods with cooperative principles on gallery flat contributes towards a circular economy because it can bring energetic needs down to a sustainable level by directly addressing a number of fundamental issues which were responsible for its reduced density in the first place while simultaneously beginning to increase density to a suitable level for sustainable living with new housing.

The cases that have been analysed have demonstrated that the main approach to reducing floor space usage per capita, the optimization of spatial usage through sharing, is effective. However, the social and cultural acceptance of doing so is historically much greater. Despite Dutch housing corporations originally fulfilling the same role as today's housing cooperatives, cooperative housing ownership is today a largely unknown concept. The Dutch housing market has developed itself strongly towards market-based private ownership, with a smaller role for housing corporations and even less so for the free-market rental sector. The introduction of the cooperative model as a 'third option', as described by Lengkeek & Kuenzli (2022), is currently ongoing yet will require the proper legislation before it will become truly feasible. Despite this, a number of municipalities, including Amsterdam, have taken initiative to allow for the first new Dutch cooperatives to establish themselves. For the foreseeable future, the cooperative model can be a small-scale yet effective housing model for those to which it appeals. In general, the prospect of sharing spaces is not something which can currently be expected to simply enter mainstream housing. Indeed what little cooperative housing is currently being built is being done with new construction, thereby consisting of those people that themselves took the initiative to form a cooperative. It is unclear whether it is feasible to expect an existing group of people, in this case living in a gallery flat, to agree to form a cooperative together.

To that extent, Cohen (2020) states that the success of efforts to achieve meaningful reductions in home size hinges on two transitions: a shift in cultural values that reduces the primacy of houses as consumer goods and a transformation in political and economic priorities that enables the pursuit of less ownership-centric lifestyles. Thus, a question to ask in further research could be *how* those transitions could be realised in an ownership-centric housing market as is present in the Netherlands. Similarly, since the necessity of decreasing home sizes has been underlined by energetic and material requirements, the question could be asked to what extent new methods and technologies to simply reduce those requirements could be equally if not more feasible than the reduction of housing sizes. Therefore, the role of efficient (prefabricated) construction methods, CO^2-neutral construction, bio-based materials and circular re-use of material are just as worthy of consideration individually and perhaps in combination with the efficient reduction of home size as well.

The analysed case studies demonstrate the manner in which floor space usage per capita can be reduced and show how cooperative models enable a 2000-watt-society: by maintaining well-defined and collectively agreed upon sustainability goals in its policy, rules and social norms (Francart et al., 2020; Agriantoni, 2022). The value of this approach thus lies not just in quantitative comparisons but also in the explicit review of qualitative aspects of cooperative housing which embody the cultural values which Cohen (2020) emphasises as being required for meaningful energetic reductions. In that sense, the methods that have been examined in this paper can be applicable to cooperative models and to some extent to traditional models as well. Similarly, despite it being the focus of this paper, the gallery flat and the postwar neighbourhood consist of only one example where the application of these principles can be greatly beneficial. In light of the general need for densification for sustainability, a wider evaluation of densification potential in *all* of the Netherlands is worthy of further research.

References

Agriantoni, M. (2022) *Towards sufficiency in housing: Agent-based model and transition scenarios*. PhD-thesis. École polytechnique fédérale de Lausanne.

Angel, S. (2012) *Planet of Cities*. Illustrated. Lincoln Institute of Land Policy.

Aureli, P., Giudici, M. and Issaias, P. (2012) "From Dom-ino to Polykatoikia," *Domus*, 31 October. Available at: https://www.domusweb.it/en/architecture/2012/10/31/from-dom-ino-to-em-polykatoikia-em-.html.

Balmer, I. and Gerber, J.-D. (2017) "Why are housing cooperatives successful? Insights from Swiss affordable housing policy," *Housing Studies*, 33(3), pp. 361–385. Available at: https://doi.org/10.1080/02673037.2017.1344958.

Baugenossenschaft Mehr als Wohnen (2012) *Planheft Haus A | Hunziker Areal | Zürich Leutschenbach*, *Mehr Als Wohnen*. Available at: https://www.mehralswohnen.ch/fileadmin/downloads/Hunziker_Areal/maw_Hunziker_Areal_A_Planheft.pdf.

Baumberger & Stegmeier AG (2014) *Brüggliäcker standard floor plan*, *Swiss-architects*. Available at: https://www.swiss-architects.com/en/baumberger-and-stegmeier-ag-zurich/project/bruggliacker-housing-estate.

Blom, A., Jansen, B. and van der Heide, M. (2004) *De typologie van de vroeg-naoorlogse woonwijken*, *Rijksdienst Voor Het Cultureel Erfgoed*. Zeist, Netherlands. Available at: https://www.cultureelerfgoed.nl/publicaties/publicaties/2014/01/01/de-typologie-van-de-vroeg-naoorlogse-woonwijken.

Brouwers, R., de Gunst, D. and van Heeswijk, H. (2013) *Nieuwe kansen voor de galerijflat: Ideeën en aanbevelingen voor de komende vijftig jaar*. NDCC.

Brysch, S. (2019) "Reinterpreting Existenzminimum in Contemporary Affordable Housing Solutions," *Urban Planning*, 4(3), pp. 326–345. Available at: https://doi.org/10.17645/up.v4i3.2121.

Centraal Bureau voor de Statistiek (2017) "Veel naoorlogse stadswijken sociaaleconomisch zwak," *Centraal Bureau Voor De Statistiek*, 18 November. Available at: https://www.cbs.nl/nl-nl/nieuws/2017/46/veel-naoorlogse-stadswijken-sociaaleconomisch-zwak.

Centraal Bureau voor de Statistiek (2018a) *Woonoppervlakte in Nederland*. Available at: https://www.cbs.nl/nl-nl/achtergrond/2018/22/woonoppervlakte-in-nederland (Accessed: December 5, 2022).

Centraal Bureau voor de Statistiek (2018b) "Woonoppervlakte in Nederland," *Centraal Bureau Voor De Statistiek*, 2 June. Available at: https://www.cbs.nl/nl-nl/achtergrond/2018/22/woonoppervlakte-in-nederland.

Centraal Bureau voor de Statistiek (2022a) *Alleenstaande oudere vrouwen wonen het grootst*. Available at: https://www.cbs.nl/nl-nl/nieuws/2022/48/alleenstaande-oudere-vrouwen-wonen-het-grootst.

Centraal Bureau voor de Statistiek (2022b) "Huishoudens nu," *Centraal Bureau Voor De Statistiek*, 25 February. Available at: https://www.cbs.nl/nl-nl/visualisaties/dashboard-bevolking/woonsituatie/huishoudens-nu.

Centraal Bureau voor de Statistiek (2022c) "Meer mensen willen verhuizen maar kunnen geen woning vinden," *Centraal Bureau Voor De Statistiek*, 23 November. Available at: https://www.cbs.nl/nl-nl/nieuws/2022/47/meer-mensen-willen-verhuizen-maar-kunnen-geen-woning-vinden.

Cohen, M.J. (2020) "New Conceptions of Sufficient Home Size in High-Income Countries: Are We Approaching a Sustainable Consumption Transition?," *Housing, Theory and Society*, 38(2), pp. 173–203. Available at: https://doi.org/10.1080/14036096.2020.1722218.

Czischke, D., Carriou, C. and Lang, R. (2020) "Collaborative Housing in Europe: Conceptualizing the Field," *Housing, Theory and Society*, 37(1), pp. 1–9. Available at: https://doi.org/10.1080/14036096.2020.1703611.

De Bouwcampus (2022) *Inspiratiesessie en Workshop SUM "Renoveren als Nieuwe Norm," De Bouwcampus*. Available at:

https://debouwcampus.nl/bestanden/transitietrajecten/Industrialisatie_Woningbouw/documenten/20102022_Inspiratiesessie_en_workshop_renoveren_als_de_nieuwe_norm_.pdf.

Di Giulio, A. and Fuchs, D. (2014) “Sustainable Consumption Corridors: Concept, Objections, and Responses,” *GAIA - Ecological Perspectives for Science and Society*, 23(3), pp. 184–192. Available at: https://doi.org/10.14512/gaia.23.s1.6.

Ellsworth-Krebs, K. (2019) “Implications of declining household sizes and expectations of home comfort for domestic energy demand,” *Nature Energy*, 5(1), pp. 20–25. Available at: https://doi.org/10.1038/s41560-019-0512-1.

European Parliament (2021) “Hoe wil de EU uiterlijk in 2050 een circulaire economie tot stand brengen?,” *European Parliament*, 22 February. Available at: https://www.europarl.europa.eu/news/nl/headlines/society/20210128STO96607/hoe-wil-de-eu-uiterlijk-in-2050-een-circulaire-economie-tot-stand-brengen.

Fischer, F. (2021) *SUMMACUMFEMMER, Büro Juliane Greb · San Riemo*. Available at: https://divisare.com/projects/445152-summacumfemmer-buro-juliane-greb-san-riemo.

Francart, N. *et al.* (2020) “Sharing indoor space: stakeholders’ perspectives and energy metrics,” *Buildings and Cities*, 1(1), pp. 70–85. Available at: https://doi.org/10.5334/bc.34.

Fromm, D. (2010) “Seeding community: Collaborative housing as a strategy for social and neighbourhood repair,” *Built Environment*, 38(3), pp. 364–394. Available at: https://www.jstor.org/stable/23290269.

Gorge, H. *et al.* (2014) “What Do We Really Need? Questioning Consumption Through Sufficiency,” *Journal of Macromarketing*, 35(1), pp. 11–22. Available at: https://doi.org/10.1177/0276146714553935.

Habraken, J. (1972) *De dragers en de mensen: het einde van de massawoningbouw*. Nederland.

Hajer, M. *et al.* (2020) *Neighbourhoods for the Future: A Plea for a Social and Ecological Urbanism*. trancityxvaliz.

Harnack, M., Heger, N. and Brunner, M. (2021) *Adaptive Re-Use: Strategies for Post-War Modernist Housing*. JOVIS.

Hereijgers, A. and van Velzen, E. (2001) *De naoorlogse stad: een hedendaagse ontwerpopgave*. Rotterdam, Netherlands: NAi Uitgevers.

Höjer, M. and Mjörnell, K. (2018) “Measures and Steps for More Efficient Use of Buildings,” *Sustainability*, 10(6), p. 1949. Available at: https://doi.org/10.3390/su10061949.

de Hoop, A. *et al.* (2009) *Tussen Park en Stad: naoorlogse stadswijken : leidraad voor ruimtelijke ontwikkeling*. Wageningen: Uitgeverij Blauwdruk.

Huebner, G.M. and Shipworth, D. (2017) “All about size? – The potential of downsizing in reducing energy demand,” *Applied Energy*, 186, pp. 226–233. Available at: https://doi.org/10.1016/j.apenergy.2016.02.066.

IBA Vienna (2022) *Wogen Quartiershaus*. Available at: https://www.iba-wien.at/en/projekte/projekt-detail/project/wogen-quartiershaus-am-hbf.

IRP (2018) *The Weight of Cities: Resource Requirements of Future Urbanization*, *https://www.resourcepanel.org/reports/weight-cities*. Nairobi, Kenya: United Nations Environment Programme. Available at: https://www.resourcepanel.org/reports/weight-cities (Accessed: December 19, 2022).

Isaac, M. and van Vuuren, D.P. (2009) “Modeling global residential sector energy demand for heating and air conditioning in the context of climate change,” *Energy Policy*, 37(2), pp. 507–521. Available at: https://doi.org/10.1016/j.enpol.2008.09.051.

Jochem, E. (ed.) (2004) *Steps towards a sustainable Development: A White Book for R&D of energy-efficient technologies*. ETH Zürich. Available at: https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cce/2004/white_book_energy-efficient_technologies.pdf.

Jochem, E. (2016) “R&D and Innovation Policy — Preconditions for Making Steps towards a 2000 Watt Society,” *Energy & Environment*, 15(2), pp. 283–296. Available at: https://doi.org/10.1260/095830504323153478.

de Jong, A. (2022) “PBL/CBS regionale bevolkings- en huishoudensprognose 2022,” *Planbureau Voor De Leefomgeving*, 6 July. Available at: https://www.pbl.nl/publicaties/pblcbs-regionale-bevolkings-en-huishoudensprognose-2022.

Khatibi, M. (2022) “A socio-spatial approach to the first legal hall dwelling setting in Switzerland: the case study of Hallenwohnen in Zurich,” *Journal of Housing and the Built Environment* [Preprint]. Available at: https://doi.org/10.1007/s10901-022-09980-y.

Koöperatieve Architekten Werkplaats (2020) *Ruimte Zat In De Stad*. Available at: https://www.kaw.nl/wp-content/uploads/2020/06/KAW_RUIMTE_ZAT20200623.pdf.

Lang, R., Carriou, C. and Czischke, D. (2018) “Collaborative Housing Research (1990–2017): A Systematic Review and Thematic Analysis of the Field,” *Housing, Theory and Society*, 37(1), pp. 10–39. Available at: https://doi.org/10.1080/14036096.2018.1536077.

Lang, R. and Novy, A. (2013) “Cooperative Housing and Social Cohesion : The Role of Linking Social Capital,” *European Planning Studies*, 22(8), pp. 1744–1764. Available at: https://doi.org/10.1080/09654313.2013.800025.

Lengkeek, A. and Kuenzli, P. (2022) *Operatie wooncoöperatie: Uit de wooncrisis door gemeenschappelijk bezit*. Trancityxvaliz. Available at: https://valiz.nl/publicaties/operatie-wooncooperatie.

Lienhard, M. (ed.) (2014) *Implications of the 2000 watt society for urban planning and economics*, *ERSA 2014 - 54th Congress of the European Regional Science Association*. European Regional Science Association. Available at: http://hdl.handle.net/10419/124224.

Lorek, S. and Spangenberg, J.H. (2019) “Energy sufficiency through social innovation in housing,” *Energy Policy*, 126, pp. 287–294. Available at: https://doi.org/10.1016/j.enpol.2018.11.026.

Lubik, A. and Kosatsky, T. (2019) “Public health should promote co-operative housing and cohousing,” *Canadian Journal of Public Health*, 110(2), pp. 121–126. Available at: https://doi.org/10.17269/s41997-018-0163-1.

Maas, W. and van Manen, S. (2021) *Rooftop Catalogue: Dakencatalogus*. Rotterdamse Dakendagen. Available at: https://rotterdamsedakendagen.nl/dakencatalogus/.

McMaster, J. (2016) *Mehr als Wohnen*, *Arc Space*. Available at: https://www.researchgate.net/deref/https%3A%2F%2Farcspace.com%2Ffeature%2Fmehr-als-wohnen.

Montaner, J. and Muxí, Z. (2010) “Reflexiones para proyectar viviendas del siglo XXI,” *Dearq*, 6, pp. 82–99. Available at: https://revistas.uniandes.edu.co/doi/10.18389/dearq6.2010.09.

Morosini, M. (2010) “A 2000-Watt Society In 2050: A Realistic Vision?,” in M. Mascia and L. Mariani (eds) *Ethics and Climate Change : Scenarios for Justice and Sustainability*. Fondazione Lanza, pp. 57–72. Available at: https://www.researchgate.net/publication/317539631_A_2000-WATT_SOCIETY_IN_2050_A_REALISTIC_VISION.

NCB (2018) *De Woonstandaard*. Available at: https://www.conceptueelbouwen.nl/dewoonstandaard (Accessed: January 3, 2023).

Nelson, T. *et al.* (2016) “Emergent identity formation and the co-operative: theory building in relation to alternative organizational forms,” *Entrepreneurship &Amp; Regional Development*, 28(3–4), pp. 286–309. Available at: https://doi.org/10.1080/08985626.2016.1155744.

Noord-Hollands Archief (1967) *Plattegrond 1e t/m 6e woonlaag, blok C*, *Noord-Hollands Archief | Bouwtekeningen*.

Novatlantis (no date) *Smarter living: Generating a new understanding for natural resources as the key to sustainable development – the 2000-watt society*, *Novatlantis*. Available at: https://web.archive.org/web/20070927040640/http://www.novatlantis.ch/pdf/leichterleben_eng.pdf (Accessed: January 3, 2023).

Noyon, R. (2008) “De sloop van naoorlogse wijken in historisch perspectief | NUL20,” *Nul20*, March. Available at: https://www.nul20.nl/dossiers/sloop-van-naoorlogse-wijken-historisch-perspectief (Accessed: December 19, 2022).

Obbink, H. (2016) “Naoorlogse woonwijken niet meer van deze tijd,” *Trouw*, 4 December. Available at: https://www.trouw.nl/nieuws/naoorlogse-woonwijken-niet-meer-van-deze-tijd~bfb94c99/.

Oorschot, L. and Asselbergs, T. (2021) “New Housing Concepts: Modular, Circular, Biobased, Reproducible, and Affordable,” *Sustainability*, 13(24), p. 13772. Available at: https://doi.org/10.3390/su132413772.

Prytula, M. *et al.* (2020) *Cluster-Wohnungen für baulich und sozial anpassungsfähige Wohnkonzepte einer resilienten Stadtentwicklung: Abschlussbericht, Dezember 2019*. Weinheim, Duitsland: Beltz Verlag.

Schipper (2004) “International Comparisons of Energy End Use: Benefits and Risks,” *Encyclopedia of Energy*. Edited by Cleveland, 3, pp. 529–555.

Schneider Studer Primas (2016) *Haus 5: 1. Obergeschoss*, *Swiss-architects*. Available at: https://www.swiss-architects.com/de/schneider-studer-primas-zurich/project/zwicky-sud.

Shove, E. (2010) “Beyond the ABC: Climate Change Policy and Theories of Social Change,” *Environment and Planning A: Economy and Space*, 42(6), pp. 1273–1285. Available at: https://doi.org/10.1068/a42282.

Sim, D. (2019) *Soft City: Building Density for Everyday Life*. Amsterdam, Nederland: Amsterdam University Press.

Spengler, L. (2016) “Two types of ‘enough’: sufficiency as minimum and maximum,” *Environmental Politics*, 25(5), pp. 921–940. Available at: https://doi.org/10.1080/09644016.2016.1164355.

Spoormans, L. (2021) *Renoveren met Respect*. Available at: https://www.tudelft.nl/2021/bk/renoveren-met-respect-1.

Stephan, A. and Crawford, R.H. (2016) “The relationship between house size and life cycle energy demand: Implications for energy efficiency regulations for buildings,” *Energy*, 116, pp. 1158–1171. Available at: https://doi.org/10.1016/j.energy.2016.10.038.

Stoeldraijer, L. *et al.* (2021) “Huishoudensprognose 2021-2070 : Groei aantal huishoudens houdt aan,” *Centraal Bureau Voor De Statistiek*, 16 December. Available at: https://www.cbs.nl/nl-nl/longread/statistische-trends/2021/huishoudensprognose-2021-2070-groei-aantal-huishoudens-houdt-aan?onepage=true.

Sundling, R., Blomsterberg, Å. and Landin, A. (2019) “Enabling energy-efficient renovation: the case of vertical extension to buildings,” *Construction Innovation*, 19(1), pp. 2–14. Available at: https://doi.org/10.1108/ci-04-2018-0034.

Tukker, A. *et al.* (2016) “Environmental and resource footprints in a global context: Europe’s structural deficit in resource endowments,” *Global Environmental Change*, 40, pp. 171–181. Available at: https://doi.org/10.1016/j.gloenvcha.2016.07.002.

Viggers, H. *et al.* (2017) “Increased house size can cancel out the effect of improved insulation on overall heating energy requirements,” *Energy Policy*, 107, pp. 248–257. Available at: https://doi.org/10.1016/j.enpol.2017.04.045.

Voermans, T. (2022) “Harde afspraken nodig voor aanpak woningtekort: ‘Eén miljoen extra huizen in tien jaar gaat niet lukken,’” *AD.nl*, 11 March. Available at: https://www.ad.nl/wonen/harde-afspraken-nodig-voor-aanpak-woningtekort-een-miljoen-extra-huizen-in-tien-jaar-gaat-niet-lukken~a9707f10/.

WaS (2023) *Das Haus*. Available at: https://amstadtbalkon.wien/.

Wassenberg, F. and Kastelijn, M. (2023) “Wijken verdichten of de bevolking aanvullen?,” *Platform31*, 10 January. Available at: https://www.platform31.nl/blogs/blogs-platform31/wijken-verdichten-of-de-bevolking-aanvullen (Accessed: January 10, 2023).

van den Wijngaart, R., Folkert, R. and van Middelkoop, M. (2014) *Op weg naar een klimaatneutrale woningvoorraad in 2050: Investeringsopties voor een kosteneffectieve energievoorziening*, *Planbureau Voor De Leefomgeving*. 738. Den Haag, Netherlands: PBL. Available at: https://www.pbl.nl/publicaties/op-weg-naar-een-klimaatneutrale-woningvoorraad-in-2050.

Williams, J. (2005) “Designing Neighbourhoods for Social Interaction: The Case of Cohousing,” *Journal of Urban Design*, 10(2), pp. 195–227. Available at: https://doi.org/10.1080/13574800500086998.

Zilker, M. *et al.* (2022) *Gleis 21 Standard Floor*, *Miesarch*. Available at: https://www.miesarch.com/work/4301.

Appendix

Case	Location	Dwellings	Inhabitants	Typologies	Gross floor area (GFA)	Usable Floor Area (UFA) total	UFA / GFA	UFA private	UFA collective	UFA commercial	Outdoor space (collective)	% collective of total UFA	Average private UFA per inhabitant	Average total UFA per inhabitant	Outdoor space per dwelling	Outdoor space per inhabitant	Average total space per inhabitant
					m²	m²		m²	m²	m²	m²		m²	m²	m²	m²	m²
Brüggliäcker	Zürich	30	60	3	6089	3752	61,62%	3445	307	0	1083	8,18%	57,4	62,5	36,1	18,1	80,6
Gleis 21	Vienna	35	70	multiple	4804	4126	85,89%	2761	650	715	1689	19,06%	39,4	48,7	48,3	24,1	72,9
Gleis 21 (1 floor)	Vienna	8	12	multiple	-	-	-%	-	-	-	-		-	-	-	-	
Haus A	Zürich	11	98	2	6875	5310	77,24%	2846	1999	465	381	41,26%	29,0	49,4	34,6	3,9	53,3
Haus A (Großwohnung)	Zürich	2	18	2	1000	840	84,00%	390	430	0	0	52,44%	21,7	45,6	0,0	0,0	45,6
Quartiershaus	Vienna	51	90	multiple	8853	5380	60,77%	3155	1282	943	1884	28,89%	35,1	49,3	36,9	20,9	70,2
Quartiershaus (2p-wohnen)	Vienna	7	14	1	310	273	88,06%	161	112	0	16	41,03%	11,5	19,5	2,3	1,1	20,6
Quartiershaus (Clusterwohnen)	Vienna	7	7	1	310	273	88,06%	161	112	0	16	41,03%	23,0	39,0	2,3	2,3	41,3
San Riemo	München	29	80	multiple	4118	3333	80,94%	2253	716	364	267	24,12%	28,2	37,1	9,2	3,3	40,5
San Riemo (Familienwohnen)	München	7	21	multiple	850	664	78,12%	496	168	0	56	25,30%	23,6	31,6	8,0	2,7	34,3
San Riemo (WG-wohnen)	München	6	19	multple	850	664	78,12%	496	168	0	56	41,03%	23,0	39,0	2,3	2,3	41,3
wagnisART	München	136	200	5	24431	14589	59,72%	12718	1131	740	5187	8,17%	63,6	69,2	38,1	25,9	95,2
Zollhaus	Zürich	55	230	multiple	15838	9413	59,43%	5074	661	3678	2763	11,53%	22,1	24,9	50,2	12,0	36,9
Zollhaus (Hallenwohnen)	Zürich	12	12	1	300	275	91,67%	108	167	0	0	60,73%	9,0	22,9	0,0	0,0	22,9
Zwicky Süd (Clusterwohnen)	Zürich	1	11	2	530	410	77,36%	200	210	0	40	51,22%	18,2	37,3	40,0	3,6	40,9
Zwicky Süd	Zürich	125	350	13	-	16885	-	12750	285	3850	0	2,19%	36,4	37,2	0,0	0,0	37,2

Table 2: Quantitative comparison of cooperative housing projects (own work)