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Systems perspectives on transforming Swiss housing by 2040: wellbeing, shared spaces, sufficiency, and de-sprawl

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The Swiss habitat–buildings and related mobility–faces multiple interconnected problems which can only be solved together. These include high energy consumption, significant climate impact, excessive material use with low circularity, accelerating urban sprawl and ecosystem destruction, high mobility costs, low inclusion, and mixed wellbeing outcomes. Guided by values of wellbeing for all within planetary boundaries, we propose a normative scenario based on a nationwide moratorium on new construction until 2100, coupled with four simultaneous neighborhood-scale interventions: renovating buildings to achieve energy class A with high indoor environmental quality, creating flexible shared living spaces, ensuring essential daily services are available within each neighborhood, and deconstructing unneeded settlements. Action levers, coordinated efforts on multiple system leverage points, are here combined with rethinking needs satisfiers. Our model predicts that full renovation could be accomplished in 14–18years, significantly reducing labor, energy, materials, and costs both during and after the transition. Furthermore, it could reverse urban sprawl to levels seen in 1935 or even 1885, depending on deconstruction choices. These findings suggest that demand-side policies could be implemented with low risk, enhancing wellbeing, energy resilience, biodiversity, and climate action, thus providing a strong foundation for societal dialog and experimentation.

KEYWORDS

systems thinking, wellbeing, sufficiency, demand-side solutions, low energy demand, reversing urban sprawl, shared spaces, new building moratorium

1 Introduction

The Swiss human habitat, consisting of buildings, open spaces between buildings, and daily mobility induced by the position of buildings, is linked to a wide range of problematic outcomes, making it much harder to reach the goal of wellbeing for all within planetary boundaries.

Habitat-related issues encompass several critical areas. Energy use and associated GHG emissions remain significant concerns (BFE, 2023; BAFU, 2023a). Material use is high, with a low circularity rate of just 6.9% (Circle Economy, 2023). Urban sprawl has been accelerating since 2002, contributing to ecological habitat degradation (Schwick et al., 2018). High mobility use leads to various costs, including accidents (resulting in 15,200 lost life-years in 2020), air pollution, noise, and travel time (ARE, 2023). Additionally, housing-related capital accumulation is unequal, which exacerbates inequality in housing and life outcomes (Bonnet et al., 2014). Wellbeing outcomes are mixed, as reflected in the housing indicators of the OECD Better Life Index (Van Zanden et al., 2020). Similar outcomes are observed in other rich countries.

Using the 1987 definition of the Brundtland Commission, every single one of these issues is a sustainability issue, affecting both current and future generations' ability to meet their needs.

Like in any wicked problem (Rittel and Webber, 1973), the public good here is disputed and viewed from very different perspectives across the political spectrum or by main stakeholders, such as cities and communes, builders and investors, farmers and nature protection groups, companies, scientists, and the general population daily using this habitat. The main issues are also interrelated, and can be seen as symptoms of the same, larger problem. This means they can only be solved together.

In today's public discourse, housing is a prominent topic, appearing in media, political party platforms, and parliamentary debates. It is central in discussions about CO_2 emissions, climate plans, "housing shortage," low vacancies, and rising rental prices. However, a critical examination of current building practices and their effects—such as urban sprawl, car dependency, increasing floor space per capita, wellbeing, needs and satisfiers, sufficiency, and the use of public, private, or shared spaces—is largely absent. Additionally, the political economy of housing and the interconnectedness of these issues remain "hidden" from decision-makers.

In the complex housing system, it is hard to predict how, when, and which new properties will emerge from the interaction of its components: for example new roads will induce more sprawl and more mobility (Torres et al., 2016), or will cause basic services to consolidate in regional centers, thus reducing accessibility (Ferreira et al., 2012).

This paper is grounded in two core values: ensuring wellbeing for all and respecting planetary boundaries. We begin by analyzing system elements and interactions—stocks and flows, feedback loops, and leverage points—to establish the current baseline and dynamics related to these values. Next, we develop a normative scenario aimed at realizing both values. To explore the feasibility of this scenario, we model and test various quantitative assumptions regarding necessary changes in stocks and flows, as well as qualitative assumptions about modifications in feedback loops. Finally, we propose policy interventions based on identified leverage points.

Specifically, we address the following questions: What is the link between housing resource use and resulting wellbeing? What are the current dynamics? What would be the resource impact, in terms of labor, building stocks, and energy, of transforming Swiss housing? What is the potential to reverse urban sprawl?

Given the urgency of the climate and biodiversity crises, we explore low-risk system interventions that can rapidly address the main issues of Swiss housing. "Low-risk" means the transformation relies on widely available technologies, existing trained workers, and current building stocks while reducing material and energy use. Although this transformation would significantly change daily life for a majority of the Swiss population, this magnitude of change is likely necessary to stay within the boundaries set by our core values.

2 Materials and methods

2.1 Overview

Systems analysis: the interconnection of sustainability outcomes related to the Swiss built environment is analyzed using a systems approach, based on insights from literature complemented by three stakeholder workshops conducted by the author, and analysis of Swiss housing data (section 3.1, 3.2). *Modeling*: to quantify possible policy interventions identified in the system analysis, a simple renovation model is developed, simulating construction labor availability, labor productivity, neighborhood-scale renovations, city-level vacancies, and final thermal energy use for heating and hot water (section 3.3). *Calculation*: finally, the potential for urban sprawl reduction is estimated analytically, using the relative change of the Weighted Urban Proliferation (WUP) indicator, calculated on the basis of the output of the renovation model.

2.1.1 Assessing the interconnection of sustainability outcomes

We identified sustainability outcomes and feedback loops from literature, which we supplemented with insights from three stakeholder workshops focused on sufficiency and sharing. These workshops were conducted in Lausanne and Zurich between June and October 2022, each lasting 2 h and involving 21, 18, and 21 participants, respectively. Per workshop, stakeholders represented were (1) participants in a sustainability innovation conference (scientists, students, investors, startups, companies, planners, public authorities); (2) neighborhood and nature protection associations; and (3) climate communication practitioners (designers, journalists, science organizations, public authorities). While participants were representative in terms of age and gender, they were generally more educated and engaged than the general population. Each workshop followed a structured four-step process: an introduction to sufficiency, group deliberation, a plenary discussion of initial impressions, and a written report incorporating participant feedback (Nick, 2023). The results were linked to previous work on sufficiency interventions based on satisfier orders, leverage points, and action levers.

Stakeholders played a crucial role in refining and validating the feasibility and desirability of a sufficiency scenario centered on limiting and sharing housing space. However, they did not participate in the actual modeling process.

2.2 Model design, validation, parameters and assumptions

2.2.1 Model design

We developed a straightforward spreadsheet-based stock-and-flow model to simulate the effects of a potential new building moratorium. This model does not account for feedback loops or interactions between actors; these elements are included in the qualitative analysis and form the foundation for designing interventions and public policies. These policies, in turn, constrain the behavior of actors, creating the appearance of a coordinated societal effort, particularly from the perspective of modeled average behaviors.

The model follows the fundamental principles of converting causal loops into stocks, flows, auxiliaries, and system boundaries (Binder et al., 2004). It covers the period 2025–2100 and includes the availability of skilled construction workers, initial renovation productivity and the learning curve, and population growth, assuming a high growth scenario to test the moratorium under challenging conditions. The model also considers building vacancies needed for neighborhood-scale renovations, where residents temporarily relocate during renovation, and final energy consumption.

The model calculates three renovation constraints: (a) Initially, low residential vacancy rates limit the number of people who can be relocated within an agglomeration for neighborhood-scale renovations. This constraint is temporary, until renovation and shared spaces increase housing capacity. (b) The availability of qualified workers, despite improving productivity, then becomes the limiting factor. (c) Finally, when most residents live in renovated buildings, population growth dictates renovation needs. We assumed that building material availability is not a constraint, as a temporary fivefold increase in Swiss renovation material use would be negligible at the European level.

The outputs include the annual renovated area, floor space per capita, renovation worker productivity, number of years needed for full renovation, "excess" existing space not needed anymore in 2100 (as a basis for estimating the potential for urban sprawl reduction), and final energy for space heating and hot water.

The model has 22 non-redundant inputs, and 16 outputs calculated annually for 2025–2101.

2.2.2 Model validation

To gain confidence in the model, several steps were followed. First, following the Logical/Physical Theory of Spreadsheet Modeling (Isakowitz et al., 1995), the four components were separated to the extent possible: schema (logic), data (parameters and assumptions), editorial and binding (columns and logical-to-physical mapping), with the last component following causal links. Second, the initial parameters were extrapolated from the present. Third, a sensitivity analysis was performed and included in results. Fourth, a simplified manual calculation was used to check the principal results.

2.2.3 Parameters and assumptions

The state of the Swiss habitat in 2021–2022 is described in terms of stocks, flows, and feedback loops in the next section "A systems view of Swiss housing," from which the starting point of the simulation in 2025 is derived. It assumes a population of 9.05 million, a total building stock of 676 km², or 74.7 m² per capita, of which 46.5 m² of private residential space, 3.9 m² of secondary residence, 9.3 m² of access spaces, and 15.0 m² of public space. The specific assumptions are 540 km² of residential and 136 km² of public space, all estimated as an extrapolation of the trend of the last 6 years. Final energy consumption of the whole building stock (113 kWh/m²) and the class A target (37.1 kWh/m²) represent actual consumption (Cozza et al., 2020).

Population assumptions follow the FSO middle estimate for 2025, FSO high estimate for 2050 (based on the fact that longer-term, Switzerland tends to follow FSO's high estimates) with linear interpolation for 2026–2049 (FSO, 2020). To validate the feasibility of the moratorium even with high population growth, we assumed the highest plausible population in 2100 of 14 million, which is ⅓ higher than the estimate of the UN Population Division (2022) or ⅙ higher than Eurostat (2022). Again, linear interpolation is applied for 2051–2099.

Based on the Decent Living Standards body of work (Rao and Min, 2018; Rao et al., 2019; Millward-Hopkins et al., 2020), the minimum decent living space is defined as 30 m² for the first person, and 10 m² for each additional person in the household. For a two-person household, which is slightly below the Swiss average household size, DLS requires 20 m² per person. This also corresponds to the top of the corridor of sustainable consumption (Cohen, 2021). However, if we move to shared spaces, as analyzed in section 3.2.5 and shown in Figure 1, this floor area is actually quite generous, and should provide a higher average material standard of living than today. For example, for a community with 20 residents sharing kitchens, living, play, and working spaces, DLS suggests 220 m², or 11 m² per person. Our assumption almost doubles this space.

This does not count access space like corridors and staircases, today around 20% of living space, which scales to 4 m² per person in our assumption. We assume no private secondary residences (today 3.9 m²). Public space, today around 15 m² per person, consists of offices, schools, hospitals, shops, hotels and restaurants. We assume a 25% reduction in public space, mainly due to less offices (shared spaces, automation, remote work) and less retail (lower material consumption in a sustainable society), respectively the #1 and #3 categories by space use. Including 4 m² access and 11 m² public spaces, we reach a total needed renovated space of 35 m² per person.

During the period 2013–2022, the average number of workers in construction was 315′000 (FSO, 2023c), of which we estimate 90% work in buildings (i.e., not on roads, bridges, tunnels etc.), and of those, 80% will remain in the profession in Switzerland after the moratorium (not move abroad, retire, or change profession). We also assume this number to remain constant and not grow with the population. These assumptions are all rather conservative, and we can be confident at least this number of workers will be available for renovations.

The average worker can renovate 0.06 m² per hour, corresponding to nearly 100 m² per year. This estimate is based on an average deep renovation cost of CHF 1500/m², gross construction wages of CHF 60 per hour, and labor comprising ⅔ of renovation costs. These figures were validated in November 2023 through discussions with experts at the Forum Vaudois du Logement 2023, organized by the cantonal administration. Since renovations currently occupy a small portion of workers' time, primarily filling gaps between new construction projects, we identify two main sources for potential productivity improvements: (a) better planning, organization, skills, and logistics; and (b) A 1000-fold increase in scale per construction site, shifting focus from apartment-scale to neighborhood-scale renovations. We model this learning curve as a logistic function, asymptotically approaching 150% of today's productivity, with a maximum slope of 0.8 and an inflection point after 5 years, with variations explored under sensitivity analysis (section 3.3.1).

Model inputs are summarized in the Supplementary material (New Moratorium Model, cells B21:C56).

2.3 Estimating the potential for reversing urban sprawl

The main measure of urban sprawl used for policy evaluation and planning purposes, both by the European Environment Agency, and the Swiss Federal Office for Spatial Development, is Weighted Urban Proliferation (WUP). It was developed by Jaeger et al. (2010) and Jaeger and Schwick (2014), integrating the three main effects of sprawl: built-up area, dispersion, and land use per person.

In this paper, we estimate the potential for de-sprawling Switzerland by calculating the relative change in the Weighted Urban Proportion (WUP) after renovating buildings and converting housing to shared spaces. Despite a high projected population in 2100, more efficient use

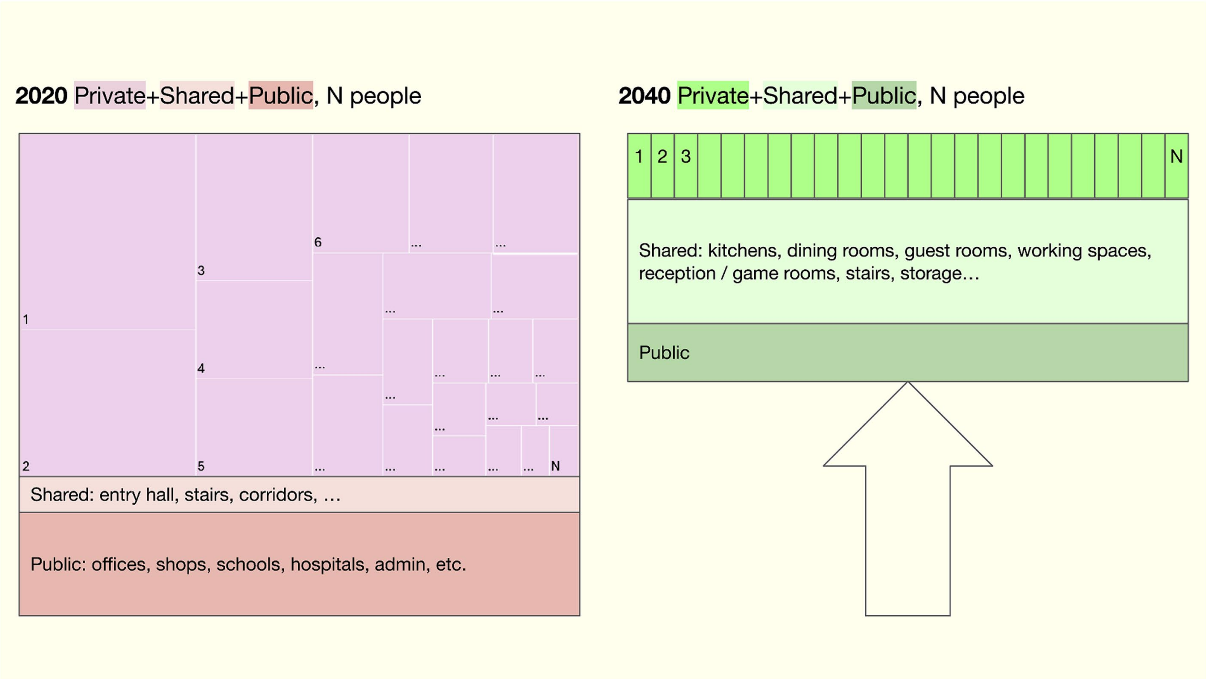

FIGURE 1
Shared spaces can be desirable for two reasons, significant reduction of needed floor space for comparable access through better use of space and lower inequality, and a contributor to wellbeing in itself, as a synergistic satisfier for multiple needs.

of space could result in approximately 27% less total floor area needed compared to 2025 (section 3.3). If buildings were randomly selected for deconstruction until the unneeded 27% floor area is reached, the built-up area would also decrease by 27%. However, optimal selection of buildings that most contribute to sprawl could significantly further reduce both the built-up area and the resulting sprawl.

Our method to calculate the relative change in WUP starts with the Equations 1–3 below, from Jaeger and Schwick (2014), but replaces the two integrals (Equations 2, 3 in the original paper) with a approximated logarithmic Equation 4 fitted to Swiss historical sprawl (Schwick et al., 2018, pp. 76 and 104). The reason for using (4) is that it allows us to estimate the relative change in WUP without the need to calculate the distance of every pair of buildings based on geodata and select buildings for deconstruction (which is a separate project proposed as future research in section 5).

$$WUP = PBA \cdot DIS \cdot w1\left(DIS\right) \cdot w2\left(LUP\right) \quad (1)$$

$$w1\left(DIS\right) = \frac{e^{0.294432 \cdot DIS - 12.955}}{1 + e^{0.294432 \cdot DIS - 12.955}} + 0.5 \quad (2)$$

$$w2\left(LUP\right) = \frac{e^{4.159 - 613.125 / LUP\left[m^2/cap\right]}}{1 + e^{4.159 - 613.125 / LUP\left[m^2/cap\right]}} \quad (3)$$

$$DIS\left[UPU / m^2\right] = 2.2179 \cdot \ln\left(total\ built\ area\left[km^2\right]\right) + 27.714 \quad (4)$$

Where Weighted Urban Proliferation (WUP) is a measure of urban sprawl, expressed in Urban Permeation Units per m^2 of land (UPU/m^2), and is the product of the Percentage of Built-up Area (PBA), Dispersion (DIS), a geometric measure of the average distance of any possible pair of built-up areas, with two weighing factors as S-curves, w1 as a function of DIS, and w2 as a function of Land Uptake per Person (LUP), where persons include both residents and workplaces. The equations are reproduced unchanged from the original references.

All variables are unitless except WUP and DIS, which are measured in UPU/m^2.

We can now estimate WUP_{2040} from the relative change to 2010 values, which are known, using (Equation 5).

$$\frac{WUP_{2040}}{WUP_{2010}} = \frac{PBA_{2040}}{PBA_{2010}} \cdot \frac{DIS_{2040}}{DIS_{2010}} \cdot \frac{w1\left(DIS_{2040}\right)}{w1\left(DIS_{2010}\right)} \cdot \frac{w2\left(LUP_{2040}\right)}{w2\left(LUP_{2010}\right)} \quad (5)$$

Known parameters are: total built area in 2010: 2571.04 km^2; WUP 2010: 2.474; WUP 1935: 0.870; WUP 1885: 0.376; population in 2010: 7.83 M; jobs in 2010: 3.36 M (Schwick et al., 2018).

The relative change in PBA serves as the input parameter for this estimate. It represents the remaining built-up area after renovations and the deconstruction of unneeded buildings, with materials reused and previously sealed ground restored. This change will range from a linear relationship (where x% of unneeded floor space results in x% less ground coverage, as would occur with a random selection) to a higher multiple if predominantly smaller buildings with relatively large ground footprints, such as single-family houses, are selected for deconstruction (section 3.3).

The remaining parameters for 2040 include a population of 10.57 million, based on the FSO high estimate (FSO, 2020), and 3.00 million FTE jobs, assuming a 10% reduction due to increased remote and flexible work.

The other components of (5) are calculated based on (2), (3), and (4).

3 Results

3.1 A systems view of Swiss housing

We propose three levels of systems analysis to better understand the Swiss habitat: (1) linking physical stocks and flows to human and non-human wellbeing outcomes, (2) understanding how positive (reinforcing) and negative (balancing) feedback loops lead to emergent properties and major housing issues, and (3) exploring how leverage points, and the more recent concept of action levers—coordinated action on multiple leverage points—could inform policy actions to simultaneously solve major housing challenges.

3.1.1 Perspectives taken

As housing shapes societies at many levels, a systems analysis of housing could complement physical stocks and flows (spaces, energy, materials, labor) with multiple societal perspectives, such as degrowth, justice, inequality, wellbeing and human needs, or power and governance.

The transformation proposed in this paper could be considered firmly aligned with degrowth, being a "radical political and economic reorganization leading to reduced resource and energy use" (Kallis et al., 2018, p. 1), aiming to "to conceive and embody alternative ideas, explanations, practices, and institutions today," to prevent the end of growth causing "a state of continual economic depression in which islands of wealth are sustained in seas of deprivation, without pretense of democracy and social justice." (Kallis et al., 2018, p. 19).

More specifically, while historically cities have been primary enablers of growth, today's mainstream urbanism continues to reinforce this role as a driver of innovation for future green growth. This is achieved through energy-efficient housing, sustainable mobility, circular economy practices, and digitalization, fostering a collective vision of dematerialized prosperity. However, this perspective overlooks the environmental and human costs of extractivism at all scales—within cities, in surrounding areas, and across global supply chains. This post-growth view advocates for applying principles of justice, and health and wellbeing of humans and ecosystems to areas such as housing, mobility, consumption, and governance, while avoiding rigid urban blueprints (Savini et al., 2022). Following this perspective, we propose general principles to be locally developed through deliberative governance.

Housing inequality has many causes and consequences, especially other societal inequalities, and may be viewed as four partly reinforcing types: market outcome, policy consequence, situation experienced unevenly across populations, or cultural construct (James et al., 2024). While reducing inequalities is the consequence of decent minimum housing and ecological maxima, and not the premise of our approach, the cultural and policy shift to shared spaces we propose should reduce all four inequality types. Figure 1 shows space use based on actual Swiss income-based inequalities.

The primary conceptual framework developed in this paper focuses on wellbeing and human needs, providing a foundation for operationalizing and modeling space, material, and energy requirements.

3.1.2 Physical stocks and flows, and related ecosystem and human wellbeing outcomes

In 2021, Swiss housing consumed 242 PJ or 30% of Swiss territorial final energy. If ground mobility–to a large extent induced by the position of buildings–is included, the proportion rises to 62% (BFE, 2023). GHG emissions of housing were 7.95 Mt CO_2e, or 17.6% of Swiss territorial GHG emissions (BAFU, 2023a).

Over 31 years (1990–2021), GHG intensity per m^2 decreased by 55.7% due to new construction and renovation. However, total GHG emissions saw a smaller reduction of 33%. This smaller reduction is attributed to a 30% increase in population and a 16.9% growth in per capita floor surface area (BAFU, 2023a).

The sector also generated material flows of non-ore minerals of 45 Mt domestically and 64 Mt abroad, resulting in 57 Mt of additions to the (already very high levels of) building stocks, roughly estimated at 335 t per capita or 2.9 Gt, leading to a very low circularity estimated at 6.9% (Krausmann et al., 2017; Circle Economy, 2023).

There were 1.785 million fully or partially residential buildings in Switzerland at the start of 2022, of which 1.012 million (56.7%) single-family houses (FSO, 2023d). Single-family houses represent 21.4% of all dwellings, and house 29.4% of Swiss residents (FSO, 2023e).

This total building stock at the start of 2022, excluding agricultural and industrial buildings, corresponds to a heated energy reference area of about 667 km^2, of 76.3 m^2 per capita, including 46.5 m^2 of private residential space (FSO, 2023b), plus 10.4 m^2 of shared space (mostly corridors and staircases) and 3.9 m^2 of second residences, as well as 15.5 m^2 of public spaces (Wüest Partner, 2023). These average numbers hide significant inequalities, which are discussed below. The main measure of urban sprawl, the Weighted Urban Proliferation (WUP) increased 558% since 1885, the first available estimate, going from 0.376 to 2.474 UPU/m^2 or Urban Permeation Units per m^2 of land (Schwick et al., 2018).

How do these stocks and flows impact human wellbeing? Switzerland has a very high level of wellbeing, measured by WHR (Rowan, 2023), OECD (Van Zanden et al., 2020), or HDI (UNDP, 2022). Housing is generally of good quality: for example 99.98% of dwellings are equipped with an indoor flushing toilet. However, the average housing expenditure is 21.4% of disposable income, ranking Switzerland 30/41 in the OECD, with 1 being the country with most affordable housing in the OECD and 41 the least (Van Zanden et al., 2020). Given current inequalities, this means a sizable minority cannot afford decent living conditions. Beyond the dwelling itself, other indicators of wellbeing are mixed, especially in the civic engagement category, such as low voter turnout (OECD rank 41/41), gender inequality (rank 37/39), or social inequality (rank 31/35) (Van Zanden et al., 2020). We are not aware of any study exploring the links between high individualism of Swiss society, the rather private nature of Swiss housing, mixed civic engagement indicators, and the overall high wellbeing.

It is worth reflecting on the dominant driver of housing resource use, living space per capita, and its impact on wellbeing. Since 1990, housing floor area per capita grew 16.9% (BAFU, 2023a). The main

Swiss energy and climate scenarios, "Energieperspektiven 2050+," imply a further growth in all categories of housing (single-and multi-family housing, second residences) and a 10% increase of total heated area over the next 2–3 decades (Kemmler et al., 2021, p. 176). So how is this significant increase in floor area, and related material and energy resources, affecting wellbeing? The overall subjective evaluation of quality of life in Switzerland is high but stable, which is also true for the subjective evaluation of satisfaction with housing, measured since 2008 when it was 8.5, stable over time and almost unchanged in 2021 at 8.4. Satisfaction with housing is slightly lower for disadvantaged groups, such as young people (8.1), renters (8.0), or non-Swiss men (7.8), presumably related to the high housing expenditure (FSO, 2023a).

More generally, floor area affects subjective wellbeing through two pathways: space facilitates activities, and space signals wealth and reinforces social status (Foye, 2017). The first pathway shows diminishing marginal returns, which is also the basis for much of the scientific work around decent living standards, which combine basic needs from Doyal and Gough (1991) with Nussbaum's central capabilities, and generally identify a floor of 10–15 m^2/capita (Rao and Min, 2018; Rao et al., 2019; Millward-Hopkins et al., 2020). This is similar to the International Code Council (ICC) minimum of 14 m^2 for the first occupant, and 9 m^2 per additional occupant (Cohen, 2021). Exceeding this minimum may be marginally better, but not if it comes with high costs, as illustrated above, social isolation (Foye, 2017), or commuting beyond a certain distance (Ingenfeld et al., 2019).

On the other hand, status leads to hedonic wellbeing, and this has been well documented (Foye, 2017). A strong determinant of status is relative wealth, which is of course a zero-sum game. For housing, this means that the relative house size matters much more than the objective size, measured in number of rooms or floor space. If the second pathway of social status is indeed dominant for determining subjective wellbeing, as evidence suggests, public policy could achieve much better wellbeing outcomes by focusing on the more equal distribution of housing, and not minimum space standards, as is currently the case (Foye, 2017). This is also supported by evidence showing that prioritization of materialistic pursuits is robustly linked to lower wellbeing, and interventions to reduce materialism may improve wellbeing (Dittmar et al., 2014). Housing size is perceived as positional by ⅓ of respondents (who prefer bigger houses than others, regardless of absolute size), suggesting significant wellbeing benefits of policy to reduce housing inequality (Solnick and Hemenway, 2005).

If the second pathway of status competition could be limited, the total space needed for wellbeing will depend on how the space is arranged and governed, on its quality and flexibility, and on cultural expectations. Shared spaces are discussed below. Beyond a single number, it is also helpful to think of a range, or "consumption corridors," to define the minimum and maximum space, where the maximum is a consequence of the maximum acceptable aggregate consumption to stay within ecological limits, with a preliminary estimate of 20 m^2 per capita (Cohen, 2021).

Taking a historical view, even in the richest countries of the 19th century, living space was very limited: several people per 9 m^2 bedroom was the norm, and 1.5 people per room was considered an unreached ideal (Nelson, 2018). At the same time, while size increase certainly improved living conditions in the beginning, the tripling in house sizes in the US, Canada, and Australia in the last 50 years was more driven by interests of builders, architects, investors, or bankers, than wellbeing concerns (Cohen, 2021). The reason for ever-increasing floor space in rich countries is firmly rooted in the political economy of housing, and in particular the role of housing as financial assets (Cohen, 2021; Zu Ermgassen et al., 2022).

On the other hand, the wellbeing of ecosystems is clearly declining, as summarized in the latest official report, Environment Switzerland 2022: "Switzerland's biodiversity is under pressure… remains in a poor state and continues to decline. A third of all species and half of all types of habitat in Switzerland are threatened. Occasional gains are not enough to make up for the losses caused mainly by a lack of land area, soil sealing, fragmentation, intensive use, and nitrogen and pesticide inputs" (Swiss Federal Council, 2022, p. 84). It is worth noting that the Swiss habitat, i.e., settlements and roads needed to reach them, is the main contributor to fragmentation and soil sealing, i.e., the principal non-agricultural causes of biodiversity loss (BAFU, 2023b).

In summary, the stocks and flows analyzed lead to mixed wellbeing outcomes and a high pressure on ecosystems.

3.1.3 Main positive and negative feedback loops

Almost all developments analyzed in the previous section are shaped by feedback loops, mostly accelerating the underlying processes. Powerful positive feedback loops, often economic or financial in nature, play a significant role. For instance, rising house prices increase returns across the housing asset class, attracting more investment, which in turn boosts demand and drives prices even higher. Standard economic models predict that higher prices should lead to increased construction, which would then stabilize and lower prices. However, due to various restrictions and delays in permits and construction, prices remain high long enough to cause overbuilding, ultimately leading to price drops and increased volatility (Glaeser et al., 2008).

Positive feedback loops can be techno-economic, where increased efficiency—such as in lighting, appliances, or heat pumps—leads to lower costs and various forms of rebound effects, whether embodied or income-based (Chitnis et al., 2013). The rebound effect also contributes to the thermal energy performance gap observed in Swiss buildings. For example, buildings CECB-rated G consume 40% less energy than predicted, those rated F consume 24% less, while more efficient buildings rated B consume 12% more energy per m^2 than anticipated (Cozza et al., 2020).

Techno-economical feedback loops are often structural, such as the example of car lock-in, where several interdependent processes build on each other, in this case (1) the car industry and (2) road builders reinforcing each other, enabling (3) urban sprawl and in the process creating the need for more cars and roads, with all three weakening (4) public transport by absorbing funding and creating hard-to-serve topologies; finally all four creating a (5) car culture based in advertising narratives, new daily practices, normalization of suburban car-centric lifestyles, and association of public transport with poverty (Mattioli et al., 2020).

Once car dependence is pervasive, two more things happen: for most people including decision-makers, it becomes difficult to imagine the end of car dominance, and in an individualistic society where change is first seen as individual action, any action to reduce car use such as taxing cars, road use, or fuel, is seen as socially unjust. This was the main argument used in successfully opposing the June 2021 Swiss climate law referendum, and more spectacularly, the initial spark starting the massive Gilets Jaunes protest movement in France in November 2018. Indeed, to be just, a transition would require broader intervention: wealth redistribution, dismantling the car lock-in, or probably both.

Each one of the above processes contains its own feedback loops, for example urban sprawl leads to longer travel, more transport dependency, congestion, and pressure to develop new roads. When these roads are built, they cause landscape fragmentation, but also improve accessibility to remote areas and lead to more urban sprawl. In this example, urban sprawl and landscape fragmentation are separate, not always synchronous outcomes, which strongly reinforce each other (Torres et al., 2016).

With the exception of wealth redistribution and dismantling the car lock-in, all the above examples represent positive feedback loops, leading to higher environmental degradation, lower wellbeing, or both. Once established, these processes are not easy to regulate. Building a sufficiently strong negative feedback loop generally requires political mobilization, and in the Swiss political system designed for stability, this mobilization rarely succeeds. One rare successful exception was the initiative on second homes, accepted in 2012 and signed into law in 2015, which requires communes to withhold building permits for second homes if such homes already represent 20% of all housing in the commune (Fedlex, 2015).

In summary, this analysis suggests the existing Swiss housing system structure is stable, with dominant feedback loops reinforcing environmentally and socially problematic outcomes.

3.1.4 Leverage points and action levers

Leverage points are places to intervene to change a system (Meadows, 1999). As high leverage points, like mindset (#2), system goal (#3), power to change system structure (#4), or system rules (#5), are notoriously hard to act upon, a disproportionately large part of public policy focuses on the lowest leverage point, parameters, incentives, standards (#12), often with limited results. On the three examples of sufficiency, negative emissions, and deliberative democracy, "action levers," or coordinated action on multiple leverage points, has been shown to be more effective than focusing on a single high leverage point. Action levers are effective because very small changes in high leverage points, which are feasible without too much resistance but insufficient on their own, can combine and reinforce each other to produce "positive and lasting change to society" (Nick, 2023).

Figure 2 represents Meadows (1999) leverage points, classified in four "realms of leverage" (Abson et al., 2017) indicating the type of intervention. Examples of action levers and suitable combinations of action on multiple leverage points are developed in the next section.

In housing, unsurprisingly, most policy intervention focuses on incentives and standards, such as required energy efficiency of new buildings (effective only over long periods of high construction), or minimum space requirements (ineffective when the dominant pathway to wellbeing is social status, as discussed above). Policy to limit urban sprawl, such as zoning and construction permit guidelines, failed completely, as urban sprawl accelerated after 2002 relative to the historical trend (Schwick et al., 2018).

Renovating inefficient buildings is central: only a fraction of 1% of the total heated area is in efficient buildings of class A, and a further 10% in class B. While only 35 k of 2 M buildings have been assessed for energy efficiency and given a CECB label, this is representative of all Swiss buildings. The renovation focus should be especially on categories C-D-E, together accounting for 78% of the total final energy used (Cozza et al., 2020).

Building renovation is also a major pillar of all Swiss federal and cantonal energy and climate plans, aiming to increase renovation rates from current 0.8% p.a. to at least 1.9% p.a., with some cantonal programs aiming for over 3% p.a. (Cozza et al., 2020; Kemmler et al., 2021). To the best of our knowledge, no canton is currently close to reaching this objective; even with the most favorable assumptions, in the current context, it would be hard to exceed 1.44% p.a. renovation rates (Thalmann, 2022). There are many local reasons for this gap, from lack of information, variability in return on investment, difficulty to find skilled workers, the principal-agent problem (misalignment of interest between landlord and tenant), but also systemic, large-scale reasons, such as limited workforce skilled in construction and mostly focused on new buildings, and tax incentives favoring materials (and new construction) over labor (and renovation). In other words, even if local problems are solved, renovation cannot easily be scaled to the level needed and planned.

One of the most promising approaches is a new building moratorium, which can take many forms, from a time-and-place bound policy with numerous precedents around the world, all the way to a symbolic worldwide pause to re-imagine our building and caring practices, and stop destruction at all levels and all forms of life: "Until design and planning professionals have figured out how to change their modes of engagement with the built and unbuilt environment, authorities everywhere should stop granting building permits" (Malterre-Barthes, 2025).

From a systems perspective, a new building moratorium represents a powerful system rule (leverage point #5). However, when combined with suitable policy measures designed to foster widespread cultural change, it can achieve much more. It can become a system goal (#3), which limits extraction and contributes to house-sharing, a way of reaching wellbeing for all within planetary boundaries. It can empower communities to establish rules for governing and caring for the building stock and its inhabitants (power to change system structure, #4). Additionally, it can shift stakeholders' mindset (#2) to view the world as an interdependent web of life rather than a resource for profit and growth. Neighborhood governance rules can enhance transparency by improving information flows (#6).

Overcoming obstacles to more radical sharing (Ivanova and Büchs, 2023) and allowing a reduction in total space used can activate additional leverage points. These include creating positive and negative feedback loops around the transition to a new culture of shared spaces and deconstructing urban sprawl. This can reduce the need for transport and break car dependency (#7–8). Furthermore, reusing materials from deconstructed sprawl can lead to the design of new material flows, buffer stocks, and norms of reuse (#10–11-12).

The potential for systemwide improvement is significant. The key question is: how do we design such an intervention effectively?

3.2 Designing a system intervention to solve all major housing issues

Building on the core values defined in the introduction, our proposed low-risk system intervention starts with boundaries derived from these values. The climate and biodiversity emergency necessitates achieving significant results within a decade and climate neutrality and

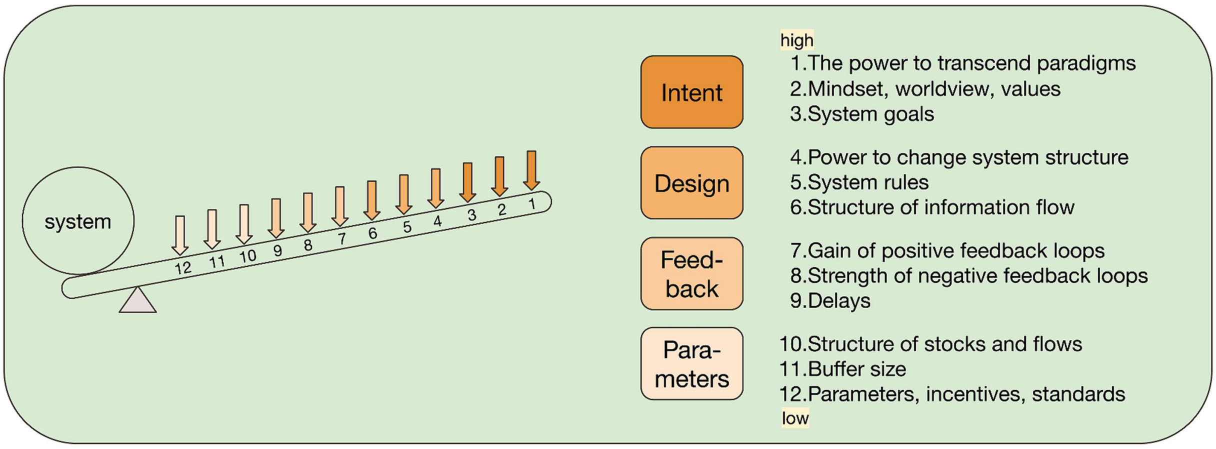

FIGURE 2
Leverage points and "realms of leverage," adapted from Abson et al. (2017) and Meadows (1999), reproduced from Nick (2023).

wide-area ecosystem restoration within two decades. This constraint limits new construction and, together with workforce limitations, directs all resources toward renovation, aiming to complete it within this timeframe. Consequently, this creates a new limit on total building space, necessitating better utilization and, in line with ensuring wellbeing for all, establishing consumption corridors for housing space (Bärnthaler and Gough, 2023). Our analysis suggests that shared spaces increase wellbeing, implying that consumption corridors could incorporate shared spaces. Additionally, to preserve ecosystems, urban sprawl must be reduced, which entails deconstructing part of the existing sprawl, a feasible approach considering needed floor space. This approach follows 'Low energy demand transformations in buildings' as a combination of socio-behavioral, infrastructural, and technological dimensions (Mastrucci et al., 2023).

In terms of interventions, we propose a specific, time-bound new building moratorium focused on Switzerland until 2100. This moratorium is complemented by additional policies to ensure coordination, renovation quality, de-sprawl and material reuse, availability of essential services, and support for people during the transition. Although our model is based on Swiss data, it is likely applicable to any affluent country with a substantial building stock.

Compared to the initial goals, this intervention achieves the transformation slightly faster, with greater de-sprawl and lower energy use than strictly necessary, enhancing its robustness against imperfect implementation and external disturbances. To facilitate societal dialog, we have intentionally kept the intervention straightforward.

3.2.1 Goals of the moratorium, transition resilience

In addition to questioning today's building practice and culture, the new building moratorium serves several essential purposes: (a) refocus existing skilled labor on renovation: transition around 200 k workers, engineers, architects, city planners, etc. from new construction to renovation and remodeling, allowing an acceleration of renovation rates by almost an order of magnitude and a complete renovation to highest efficiency standards of the whole Swiss habitat in <20 years; (b) reinforce existing practices and build a new culture of sharing spaces; (c) significantly reduce the need for new materials, extraction, embodied energy, and ensure resilience under a broad range of conditions, as well as reuse materials available from the deconstruction of existing urban sprawl; (d) create a positive feedback loop of de-sprawl, where available skilled labor, culture of sharing, and widespread reuse of materials reinforce each other, and accelerate the deconstruction of car dependency, based or reversing the process described above.

The actual implementation would require several additional policies and measures beyond the moratorium, with an illustrative overview in Table 1. Here we explore one possible implementation; the actual path must be collectively negotiated. In the Swiss decentralized governance structure, communes would be required to plan renovations for each of their main neighborhoods, engaging residents in a deliberative and participatory process, ensuring essential services are developed in each neighborhood, and helping people transition to avoid any hardship. During renovation, temporary relocation would be organized. Additionally, most low density zones would be planned for deconstruction, reuse of materials, renaturation and restoring ecosystem connectivity.

At the cantonal and federal level, highly progressive taxation on space beyond 20 m^2/cap could create the consumption corridor. Cars, already unneeded following neighborhood repurposing, could be made expensive and less useful, for example by taxes, dismantling roads, repurposing parking, or discontinuing fossil fuel sale. Finally, communes can be supported to ensure they deliver on renovations.

While the framework conditions (outside Swiss housing) during the transition cannot be predicted, it is reasonable to expect further population growth, mainly through immigration, and a certain number of internal and external crises, related to climate, food production and distribution, electricity generation and distribution, health and infectious disease, geopolitical and global supply chain issues, and combinations of these and other factors which are hard to estimate or possibly even imagine today.

For these reasons, the outcome of the transition, as well as the transition itself, must be designed to be resilient: limiting the use of labor, energy, and materials; decentralizing governance and implementation; mostly using locally available resources; and reinforcing the culture of wellbeing, sharing, sufficiency, regeneration, and community. This can be achieved both by creating "quick wins," and through crisis management, should it become necessary.

TABLE 1 A systems overview of possible policy instruments combining neighborhood-scale renovation, unbuilding sprawl, and a new building moratorium.

Goal	Required outcomes	Policy examples	Leverage points
• Net zero before 2050 • Exit fossil fuels	• Reduce floor area per capita by half • Shared spaces as synergistic satisfiers • All buildings reach CECB class A • All fossil fuel heating replaced • Provide all essential services locally to minimize transport • Cars become unneeded, expensive, less useful • No-one is left behind	• New building moratorium until 2100 • Adapt renovation norms to include shared spaces, class A efficiency, local essential services • Communes must plan renovation for major neighborhoods, and include essential services • Highly progressive tax on space beyond 20 m^2/cap • Dismantling of roads, repurposing parking, tax on cars, no fossil fuel sold • Help people transition to avoid hardship	2–3–5-7-8-12 (see Figure 2)
• Reduce urban sprawl to 1935 levels or below • Restore and reconnect biodiversity	• Stop all new sprawl • Reduce total floor area needed • Deconstruct neighborhoods and roads most contributing to sprawl	Low-density zones: Communes must plan deconstruction, material reuse, renaturation and connectivity; cantons guarantee implementation	2–3–5-10
Neighborhood-scale renovation	Relocate people while deeply renovating and re-purposing each neighborhood, and locally creating all essential services	Communes grant renovation permits per neighborhood and organize temporary relocations	5–7-10
Engage population in planning	Communities deliberate and set goals for their neighborhoods, and co-create plans with architects and planners	Renovation planning must include essential local services approved in deliberative assemblies	2–3–4-5-6-7-8

3.2.2 Wellbeing for all within planetary boundaries

Wellbeing is a state of human thriving, based on full participation in society, and a sense of leading a good life. Sustainable wellbeing adds the respect of ecological constraints to extend wellbeing to future generations. Human needs are central to wellbeing and, according to the two main eudaimonic approaches to human needs (Doyal and Gough, 1991; Max-Neef, 1991), these needs are essential to avoid serious harm and deprivation. They are constant across time and cultures, finite, non-substitutable, and satiable. Both approaches differentiate between needs and satisfiers—the means to satisfy human needs. Satisfiers, which can include goods, services, activities, institutions, and relationships, are culturally specific and change over time.

This paper follows a eudaimonic perspective of wellbeing, evaluative of overall life satisfaction, as opposed to momentary happiness (Brand-Correa and Steinberger, 2017). Eudaimonic wellbeing is very different from the dominant concept of "preference satisfaction" which cannot be a good basis for wellbeing, for reasons such as imperfect knowledge, bounded rationality, adaptation, lack of moral distinction, or cultural differences (Gough, 2015, 2017). The same limitations apply to hedonic happiness, based on seeking pleasure, and avoiding fear and pain. Max-Neef (1991) distinguishes singular satisfiers (which satisfy one need), synergistic (satisfy multiple needs), pseudo-satisfiers (give the false sense of satisfying a need), inhibitors and destroyers (impair the ability to satisfy other needs).

Finally, sufficiency, as a central concept of sustainability builds on the satiability of human needs, and is the reason why wellbeing for all within planetary boundaries is possible. Thomas Princen (2005) defines sufficiency as an organizing principle of society, as opposed to today's dominant efficiency, and a basis for wellbeing within ecological constraints.

At a societal level, sufficiency can be defined following IPCC (2022): "Sufficiency policies are a set of measures and daily practices that avoid demand for energy, materials, land and water while delivering human wellbeing for all within planetary boundaries."

For housing, this includes (a) reducing activity levels while ensuring human wellbeing: building less, heating less, using less space, traveling less; (b) respecting ecological constraints, local and planetary, for example by stopping pollution, exiting fossil fuels, reversing sprawl; and (c) adapted organizing principles of society: suitable system goals, rules and policies, collective action, and especially culture.

Sufficiency is widely misunderstood, mostly absent from the public discourse, and when mentioned, often confused with efficiency. As summarized in Figure 3, sufficiency action can take place at multiple levels, with varying effectiveness, based on "satisfier orders" (Brand-Correa et al., 2020). Designing sufficiency intervention for large-scale transformation requires acting on multiple high system leverage points, corresponding to changes in socio-technical provisioning systems and socially and culturally built activities (Nick, 2023).

From the perspective of ensuring no planetary boundaries are transgressed, there is an obvious and a less obvious focus. There is obviously a need to rapidly exit fossil oil and gas for heating, significantly reduce cement use and its impact, and reverse urban sprawl to free and defragment ecosystems, as well as reduce transport energy, materials, and pollution.

Less obviously, our most important lever is cultural, as it shapes mindsets (leverage point #2): a culture of sharing, a culture of wellbeing at the community level, and a culture of regeneration (Lyle, 1994; Gibbons, 2020). Beyond culture as shared ideas, practices, and social behavior, this includes cultural and artistic creation, which to be an effective lever of regeneration, must emphasize community engagement and ownership; allowing it to contribute to physical and social regeneration (Evans, 2020).

3.2.3 Sharing and wellbeing

As we have seen above, housing cannot just be reduced to floor area, materials, CO_2 emissions, or energy use. It is above all an essential and synergistic satisfier for multiple human needs, subsistence and protection, but in ideal conditions and depending on how it is used also for affection, understanding, participation, idleness, creation, identity, and freedom (Max-Neef, 1991). In the best case, housing can contribute to satisfying all fundamental human needs and significantly improve wellbeing. But it can also be detrimental to health, create stress and tensions, alienate people, generate uncertainty, and require excessive investment in resources or travel time.

Fundamentally, most wellbeing benefits of housing center on interactions with other people, which is not surprising as this is the focus of most human needs, and even the universal societal goal of "minimally impaired social participation" (Doyal and Gough, 1991). On the other hand, most negative impacts of housing are directly or indirectly linked to high resource use.

From the perspective of human needs, shared spaces can be considered a synergistic satisfier, using the same resources to satisfy multiple needs: subsistence (place of work), understanding (setting of formative interaction), participation (setting of participative interaction), creation (productive and feedback settings, audiences, spaces for expression), identity (settings which one belongs to), building on Max-Neef (1991).

Figure 1 shows current use of habitable space per capita, including 46.5 m^2 average private space, shared spaces, and 15.5 m^2 public space per capita, for a total of 76.3 m^2. From a human needs perspective, shared spaces are a synergistic satisfier for subsistence, participation, creation, understanding, and identity. The 2040 representation illustrates what space use could look like after the transformation. By significantly reducing both average private space and its level of inequality, average floor space could be reduced perhaps by half, and most people could have access to all the space they need, most of the time, either by reserving certain spaces such as guest rooms, dining rooms, or party rooms, or by simply sharing with others present at the same time, for example in a shared kitchen or co-working space. This reduces both the time spaces are unused, and inequality of access.

Many forms of shared spaces exist at all scales, from co-living, cooperatives, ecovillages, communes, co-housing, kibbutzim, intentional communities, pocket neighborhoods, and others. Each shared form has its good and bad sides, and most likely this large diversity will continue and expand in the future. While the ecological constraint imposes that average housing should be small, and wellbeing considerations suggest shared spaces, the key question could be formulated as "How compact and how communal?" (Nelson, 2018, p. 7). Of course, the space is just the beginning; just as important is the culture, the shared practices, ideas, values, and learning to live together. As conflict is inherent to sharing, these practices must include conflict resolution. Conflict reduces wellbeing, but overcoming conflict builds trust, shared norms, and social capital, improving wellbeing. This is nothing new; it has been the norm throughout much of human history. It is today's oversized and standardized living arrangements in the Global North that represent the historical exception (Nelson, 2018).

Additionally, and less obviously, shared spaces are one of the most effective ways of rapidly reducing inequalities, which is in itself desirable for wellbeing and trust in society, but is also indispensable for behavior change leading to net zero, which could otherwise cause hardship for disadvantaged people, for example when acting to break the car lock-in (Kukowski and Garnett, 2023). Additionally, empirical evidence from Barcelona shows that willingness to share houses or objects is one of the strongest predictors of life satisfaction (Sekulova and van Den Bergh, 2013).

Sharing spaces could be supplemented by tiny apartments, for people who cannot or do not wish to share, while maintaining similar space per capita. Ensuring equitable access to quality and quantity of living space is crucial for the acceptability and overall success of the transformation.

3.2.4 Supply-side vs. demand-side interventions

While the moratorium is a supply-side policy, its main effect could be as an enabler of demand-side solutions, which are policies, interventions, and measures designed to reduce demand and improve wellbeing at the same time (Creutzig et al., 2022). In addition to decent living standards described under stocks and flows above, it includes scenarios like "High with Low" (HwL), focused on high wellbeing and low energy and material demand, and makes building a decarbonized and resilient energy system, economy, and by extension society feasible, while limiting reliance on unproven technologies like large-scale carbon removal (Sugiyama et al., 2024). This improved (or degraded) resilience is locked-in early through path dependency, with low energy demand leading to multiple benefits such as healthy humans and ecosystems, wellbeing, equity, and resilience. On the other hand, high energy demand would lead to multiple risks such as environmental destruction, pollution, delays, competition for land, or fragile energy systems (Sugiyama et al., 2024). The reason why demand-side solutions work so effectively for wellbeing is that they target not only provisioning systems, as supply-side measures do, but also act on satisfiers, i.e., means through which we satisfy our needs, in effect transforming culture (which can be viewed as the sum of all satisfiers).

While demand-side interventions are highly desirable, they do not materialize automatically by changes in supply. Rather, supply-side transformations may create the conditions for additional policies which would be much more difficult to enact without such transformation. For example, sharing spaces (demand-side) is much easier if dwellings are designed for sharing, where private and shared spaces can easily be separated and reconfigured as needed, and when many people are living in housing designed for sharing, and when large private spaces are culturally seen as unusual and are heavily taxed, therefore expensive. All this needs critical mass, which can only be developed (supply-side) within a decade or two when most construction workers move from new construction to renovation. This can be achieved with a moratorium, which also makes progressive taxation of space to reduce inequality both necessary and more acceptable.

Illustrative policy instruments are developed in section 4.2 and Table 1.

3.3 Renovation modeling results

Our simple model suggests that the main interrelated problems of Swiss housing can indeed be solved together in less than 20 years, using less resources (workers, energy, materials, money) than business-as-usual, every year during and especially after the transition. This holds all four main outcomes of the transformation: housing availability, wellbeing, energy use, and urban de-sprawl.

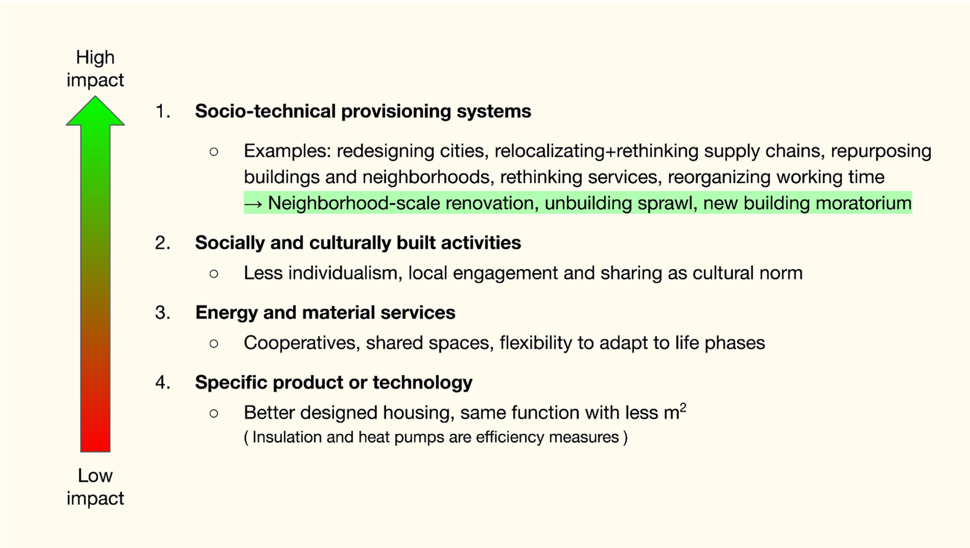

FIGURE 3
Effectiveness of sufficiency action; "satisfier orders" adapted from Brand-Correa et al. (2020).

The proposed transition begins with a nationwide moratorium on new building construction until 2100, redirecting all available construction workers to four coordinated neighborhood-scale renovations: (a) Achieving energy efficiency equivalent to CECB rating A, while ensuring high indoor environmental quality; (b) Repurposing existing residential, office, retail, and other spaces to create neighborhoods where all essential daily services are within short walking distance; (c) Transforming buildings to accommodate shared living and working spaces, reducing private areas, and allowing flexible access to spaces as needed; and (d) Deconstructing neighborhoods that most contribute to urban sprawl and are difficult to repurpose, to reduce overall space to the necessary level and substantially decrease urban sprawl, while reusing materials, removing access roads, and restoring ecosystems. Further assumptions are detailed in the methods section.

Counterintuitively, opposing the dominant public discourse on residential space shortages, a new building moratorium can rapidly and significantly improve housing availability. The current lack of availability, which leads to high housing prices and low affordability, is primarily due to prevailing usage patterns—such as housing inequality and the frequent vacancy of many apartments and most rooms—exacerbated by the treatment of housing as an investment asset class, rather than an actual shortage of space. This perspective aligns with recent systems-based research, such as the study on social housing availability in the United Kingdom by Pagani et al. (2024).

New construction gradually increases the stock of available space, but it can also perpetuate inefficient use patterns. For example, it may increase floor space per person or the number of secondary residences, resulting in either a slow increase or decrease in overall availability, depending on which effect is dominant.

On the other hand, a new building moratorium liberates the large existing skilled workforce to start transforming the existing building stock at an accelerated rate enabling a much more efficient use of space. If coupled with suitable public policy, the physical transformation (systems leverage point #10), incentives to discourage high space use (#12), system rules (#5), and a new culture of sharing space (#2) can create a powerful action lever, and transform the whole built environment and its use in 15–20 years. Under such conditions, Switzerland has more than enough space in existing buildings for its growing population until well beyond 2100, even after deconstructing 20–30% of existing space.

3.3.1 Housing and space availability, wellbeing

In our central estimate, the whole transformation can be completed in 14 years (2025–2039), providing each of the 10.37 million Swiss residents in 2039 with 35 m^2 of highest indoor environmental quality space, energy class A, as a combination of private, shared, and public space, with little residual inequality.

Figure 4 presents the main results of the simulation. The annual renovated floor area (light green) increases as the obstacle of low vacancies in Swiss cities is overcome. Worker productivity (black stars) rises as the sector focuses on renovation, eventually renovating 53% of the initial stock to meet the population's needs (dark green). As a result, floor area per person decreases and stabilizes (brown dotted line), which together with better efficiency reduces final energy consumption by 82% (orange).

Of the initial total 676 km^2 of floor space, 360 km^2 (53.2%) have been renovated by 2039, 130 km^2 (19.3%) have been identified and reserved for future renovations, one neighborhood at at time, to accommodate the growing population until 2100, and a further 186 km^2 (27.5%) have been identified as unneeded, progressively deconstructed to reuse materials, as well as liberate and defragment ecosystems.

Today's trained construction workforce in Switzerland is sufficient to renovate the whole needed building stock in 14 years, in the central estimate. This finding is robust and depends little on model assumptions. This period is also the shortest meaningful duration for a new building moratorium. However, given the numerous uncertainties of such an ambitious program, a 5-year buffer, covering a wide range of parameters, would be meaningful, defining the shortest meaningful initial building moratorium of around 20 years. The moratorium could later be extended, perhaps as an easier political decision than immediately aiming for 2100.

The current annual renovation rate of 0.8% can be accelerated by a factor of five to 3.8% p.a. on average over the 14-year period, with a peak rate exceeding 5% p.a.

3.3.2 Robustness and sensitivity analysis

The main outputs, especially time needed for full renovation and repurposing of the Swiss building stock, change only very little with assumptions. For example, limiting labor productivity increase to 10% extends renovation by 4 years, whereas allowing +100% productivity accelerates by 2 years: range 12–18 years, central estimate 14 years. Changing the number of workers who stay after the moratorium from 80% changes a year or two: 16 years for full renovation with 70% worker retention; 13 years with 90%. Reducing population growth from the high to the central 2050 scenario makes little difference: 14 years, unchanged. Finally, increasing private + shared space requirement by 25% adds 3 years. The main reason for high robustness is that, other than the system goal and moratorium, most assumptions are derived from today's existing best practices.

While wellbeing is not directly modeled, it is highly likely to improve, based on four factors: (a) Availability and affordability of living space, an area where Switzerland is in the bottom third of the OECD ranking, creating stress for disadvantaged groups; (b) Highest indoor environmental quality of living space after renovation; (c) Shared spaces as a synergistic satisfier for participation, creation, understanding, identity, combined with a culture of sharing; and (d) Lower transport stress, time, cost, and pollution. From the perspective of Doyal and Gough (1991), the stronger community, more involvement in local governance, healthier living and less polluted transport environment, and easy access to all essential daily services is likely to improve all three main wellbeing dimensions: participation, health, autonomy.

3.3.3 Energy and material use

Total operational final energy use after the transformation in 2040 is reduced by 82%, relative to 2025, going from 275 PJ to 49 PJ, as a result of sufficiency (−46% used living space based on shared spaces) and efficiency (−67% final thermal energy per m^2 based on renovating the while used building stock to efficiency A).

The total environmental impact of renovation is significantly lower than that of new construction per m^2, typically accounting for only 11% of the materials mass, 25% of the global warming potential, and 30% of the non-renewable energy demand (Hasik et al., 2019). In our central scenario, over a 14-year transition period, the average renovated floor area is projected to be about five times greater than current new construction rates (26 km^2 vs. 5 km^2 annually). Despite providing five times more high-quality floor area annually, accelerated renovation would use only 55% of today's annual new construction material mass. Over this 14-year period, based solely on the embodied energy in materials, this approach would generate 125% of today's GHG emissions and use 150% of today's non-renewable energy. However, final energy consumption would decrease sharply (Figure 4).

Moreover, large-scale utilization of materials from the 27% of floor space that is no longer needed could significantly reduce this impact, likely bringing it below the levels of business-as-usual, even at peak times. After this transformation, the environmental impact of annual renovations to keep up with population growth and necessary maintenance would be a small fraction of today's impact.

Finally, after reducing final operating energy by 82%, the remaining energy demand would be easy to cover entirely with heat pumps, eliminating virtually all residual CO_2 emissions. In 2021, heat pumps generated 4.6 TWh or 17 PJ of thermal energy, almost 35% of the needed 49 PJ (Link, 2022).

3.3.4 Urban de-sprawl

Many good proposals aim to slow urban sprawl, restricting or even blocking new built-up areas, for example the Swiss perspective analyzed in Schwick et al. (2018). Yet proposals to reverse sprawl to a past, much lower level, while improving wellbeing of a growing population are lacking.

Our model enables us to examine which spaces are required to accommodate both the current and expected future populations, as well as which spaces will not be needed until 2100, even with high population growth. In our central scenario, deconstructing the 27% of floor space that is not needed can free significant land for food production and ecosystems, defragment landscapes by removing access roads, reduce energy consumption, and provide materials to renovate the remaining buildings. Furthermore, deconstructing the most sprawled settlements would significantly reduce the costs and impacts of transportation, truly solving together the most intractable problems of housing, territorial planning, and transport.

The effect of such deconstruction on Weighted Urban Proliferation (WUP) can be analytically determined from its definition. WUP depends on three parameters, built-up area, dispersion, and land use per person, which are all much less favorable in single-family zones, especially when linked to a minimum plot size requirement (Wegmann, 2020).

Figure 5 presents an analytical calculation of the potential reduction in the Weighted Urban Proliferation (WUP) indicator of urban sprawl, as a function of remaining built-up area after deconstruction. If 27% of unneeded floor space were randomly distributed and deconstructed, the built-up area would decrease to 73%. Alternatively, deconstructing predominantly dispersed settlements could reduce the built-up area by at least 40%, leaving only 60% of the current built area. These two approaches would reduce Swiss urban sprawl to levels observed in 1935 and 1885, respectively. Exact calculations and mobility reduction modeling are planned for future research, but it is likely that the optimal strategy may involve deconstructing most single-family houses.

4 Discussion

4.1 A holistic view, sufficiency, and wellbeing

We have seen that from a systems perspective, the multiple issues of the Swiss habitat (energy, CO_2, materials, circularity, mobility impacts, inequalities, mixed wellbeing outcomes) all result from the same systems structure, and dominant culture or

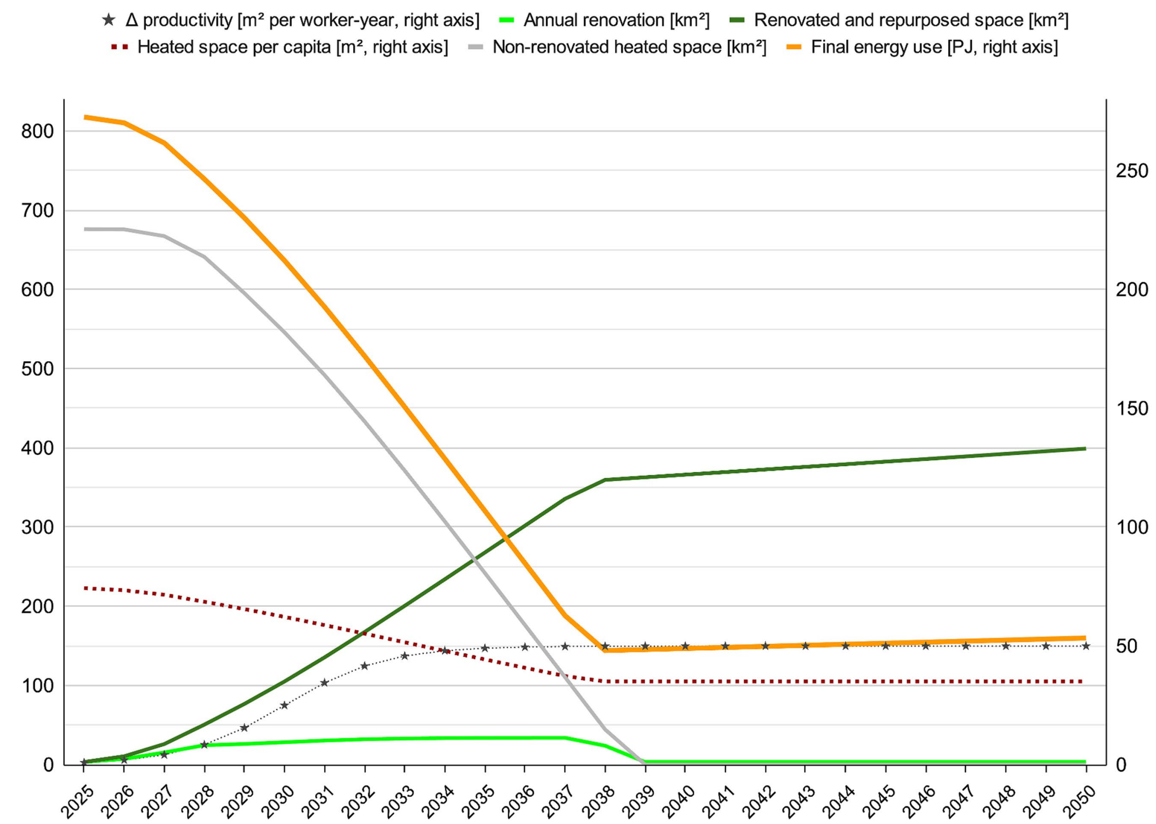

FIGURE 4
Simulation results for the Swiss new building moratorium until 2100, refocusing all available construction workers on four coordinated neighborhood-scale renovations, indicating full transformation can be achieved in 14 years in the central scenario.

mindset (individualism, land and housing ownership structure, power structures around the car lock-in, the imaginaries around single-family houses, profit motivation and housing as a financial asset class, zoning rules, minimum size standards), consistently with the systems iceberg model (Monat and Gannon, 2015). This is especially pertinent if systems structure is primarily viewed as the "cause-and-effect manner in which system components interrelate to yield the system behavior," as recently suggested by Monat and Gannon (2023).

Additionally, the public good is mostly missing from the public discourse, and when discussed, is disputed, as illustrated in the case of sufficiency or biodiversity, making housing issues a wicked problem. Typically, mobility and housing are analyzed separately, and policy is developed independently, but car lock-in and urban sprawl feedback loops show they can only be solved together, or not at all.

Effective climate and energy action requires a mix of sufficiency, efficiency, clean energy, and some CCUS and negative emissions. Such removals being limited to around 10% of current emissions, reaching net zero requires sufficiency, efficiency, and clean energy to cover at least 90% (Thalmann, 2021). When time is short, much of this reduction must come from sufficiency, today completely absent in housing policy, incentives, or public discourse. Yet sufficiency is closely related to the satiability of human needs, and our three stakeholder workshops showed that effective engagement with the topic is seen by participants as both possible and desirable.

Our model shows sufficiency is essential, given the available workforce and the need to de-sprawl, with a new building moratorium as a possible central leverage point. Extrapolating the current renovation rate of 0.8%, it would take 125 years to renovate the whole building stock, often to less than CECB efficiency A: renovating class F or G to C, D, or E is common. The moratorium forces society and building actors to re-think the value of housing, materials, and labor, as a scarce resource and satisfier of essential human needs, going beyond today's financial reasoning. Refocusing those scarce resources on more valuable outcomes allows to increase renovation peak rates to 5%, and renovate all needed buildings in 14 years to CECB efficiency A.

From the perspective of career planning, a long moratorium has the benefit of engaging construction workers, architects, engineers, and planners to fundamentally rethink their role around caring for the built environment and hopefully its inhabitants.

Wellbeing is a state of thriving, full participation in society, strongly dependent on meeting all fundamental human needs (Doyal and Gough, 1991; Max-Neef, 1991). Consumption levels poorly measure wellbeing, as they ignore the moral distinction of who consumes what and for which purpose, bounded rationality, and cultural differences (Gough, 2015, 2017). In a sustainable society, the needs of all must be met using less resources, making synergistic satisfiers essential. Limiting total living space by stopping new construction creates conditions for widespread adoption of shared spaces, a powerful synergistic satisfier.

Spaces can be shared simultaneously, facilitating participation, as in shared kitchens or children playrooms, or sequentially, by reserving rooms for exclusive use, for example guest or meeting rooms. High levels of access to space while reducing total floor area is possible by reducing the number of empty rooms, which is today a large majority of 16.7 million rooms, or 1.9 average per capita for 8.8 million people (Van Zanden et al., 2020) - i.e. today most rooms are empty most of the time.

Finally, it is important to think of the flexibility of people, not only spaces: as life circumstances change, with births, deaths, recomposed families, or adult children moving in or out, how can people remodel their space use without the disruption of moving?

In summary, we have identified and to a certain extent quantified the main elements needed to solve the wicked problems of housing, with its interrelated symptoms: a systems understanding of the main interactions, the key measures and dimensions of the ecological constraint, housing-related drivers of wellbeing, and promising feedback loops, leverage points, and action levers upon which to build the proposed transition. Two simple models, of the building moratorium and of deconstructing urban sprawl, provide a first test of the feasibility of the approach.

4.2 Policy implications and examples

So far we mainly analyzed one policy measure, the new building moratorium, and discussed system goals and outcomes related to others, such as renovation, governance, or de-sprawl. Table 1 summarizes examples how goals, policies, and outcomes could form an "action lever," i.e., simultaneously action on multiple system leverage points, reinforcing each other (Nick, 2023). This table is just an illustration of possible public policies and a starting point for discussion, not a detailed analysis.

Several combinations of policy instruments could potentially reach the desired outcomes to support the goals. Table 1 covers regulation, incentives, and public investment; it is implicitly assumed culture will follow. But cultural change could also lead the way. For example, will a rich owner of a 1,000 m^2 palace willingly share it with 50 people (cultural change), or just pay a high tax to avoid sharing, thereby subsidizing many poorer people (no change in culture, but new incentives)?

Whichever path is ultimately chosen, sharing-related policies must be designed democratically and equitably, both supply-side (moratorium, renovation policy) and demand-side (culture, sharing, incentives, resource use restrictions).

5 Conclusions, limitations, and a proposed research agenda

This paper addresses a significant challenge: defining, understanding, and simultaneously solving all major issues related to Swiss habitat—particularly energy, climate, biodiversity, accessibility, and wellbeing—well before 2050. Using systems analysis, a simple model of space, renovation effectiveness, labor, an analytical model of de-sprawl, and an initial discussion of potential public policies, we present a comprehensive approach.

5.1 Conclusions

The conclusions are highly promising. Shared spaces emerge as synergistic satisfiers for subsistence, participation, creativity, understanding, and identity. They are deemed acceptable and desirable based on insights from three stakeholder workshops and allow a significant reduction in floor space per capita. This reduction facilitates a nationwide new building moratorium, reallocating the existing skilled workforce to renovations and accelerating these efforts by a factor of five. Additionally, it supports the deconstruction of unneeded buildings, which account for almost 30% of floor space. By wisely selecting neighborhoods for deconstruction, we can reduce Swiss

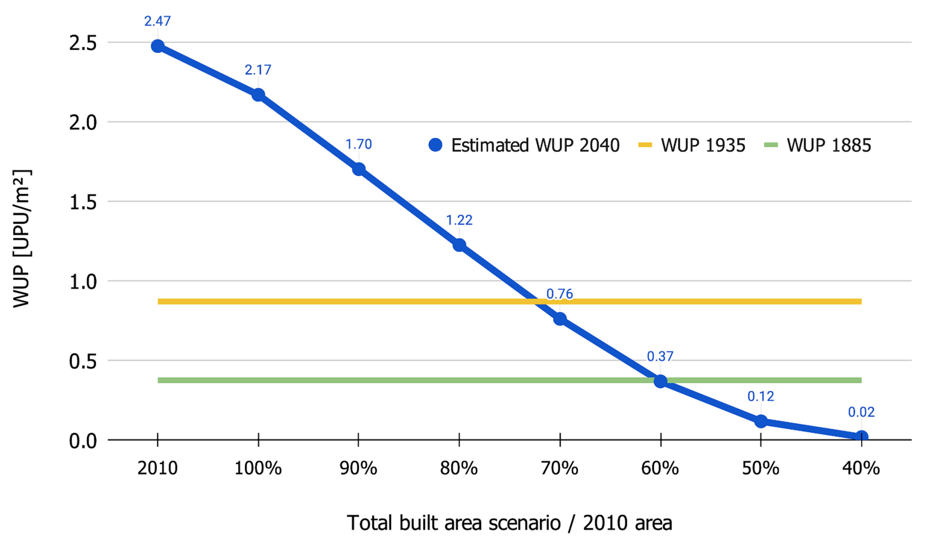

FIGURE 5
Analytical calculation of possible reduction in urban sprawl, expressed as Weighted Urban Proliferation (WUP). Depending on deconstruction choices, the total built area needed is min 60%, max 73%, corresponding to urban sprawl levels in 1885 and 1935, respectively.

10.3389/frsus.2024.1375271

urban sprawl to levels seen 100–150 years ago, break the car lock-in, simultaneously solving daily mobility challenges, and provide valuable materials for renovation, significantly enhancing circularity.

Our model indicates that a moratorium on new construction would significantly reduce all necessary building-related resources. Specifically, labor requirements would decrease by 20%, with 80% of workers remaining in the construction sector. Material use would drop by 45% during the 14-year renovation period and by 90% thereafter, while energy consumption would be reduced by 82%.

This resource efficiency suggests that costs per square meter should not increase, and average rental costs could potentially halve due to shared spaces reducing per capita space needs. Operating costs could drop by 80%, significantly enhancing accessibility—a current weak point in OECD comparisons. The 82% reduction in energy use will make oil and gas heating easily replaceable with heat pumps powered by clean electricity, thereby eliminating most CO_2 emissions from heating and greatly improving energy resilience.

Furthermore, reductions in transport time, costs, pollution, and stress, coupled with healthier ecosystems, lower housing costs, better access to shared spaces, and greatly improved indoor environmental quality, should collectively contribute to higher overall wellbeing.

5.2 Limitations

While the systems logic is solid, only space, labor, energy, and sprawl have been quantified using a simple model, and other aspects have only been discussed. They need to be properly analyzed and are here proposed as a research agenda.

Even within the scope of this paper, several limitations exist. The potential of shared spaces is based on literature, three stakeholder workshops, and examples from intentional communities. However, there are few architectural designs of shared spaces for the general population, limiting the generalizability of these findings. The assumed quantity of heated space needed, 35 m^2 per capita, is derived from literature and has not been validated in Switzerland. The analysis adopts a territorial perspective, excluding embodied energy, materials, and emissions from imports. The conversion of final energy to useful heat uses today's efficiency and prevalence of heat pumps, both of which can be significantly improved.

Furthermore, only stocks and flows have been modeled, with much of the systems analysis being qualitative. The nonlinear feedback loops dynamics have not been modeled or quantified. For instance, the question "how much de-sprawling is needed to break the car lock-in?" remains unanswered.

5.3 Proposed research agenda

Beyond the scope of this paper, but important for implementation, there are several key areas or research needed, here proposed as a research agenda:

5.3.1 People

How acceptable are various aspects of a system-wide transformation of the Swiss habitat? Which conditions are needed to increase acceptance? How does this vary by population subgroups? What are the labor and skill implications, beyond the construction workers we analyzed? Which special considerations are needed for rural communities producing food? Will the transformation temporarily cause hardship for some people, and how can this be overcome? How to preserve community links in much-transformed neighborhoods? How to create new social connections? How to best engage communities in deliberation, planning, and governance?

5.3.2 Neighborhoods

Based on spatial analysis and geodata, which criteria and priorities should be used to select neighborhoods for deconstruction? How much de-sprawl, ecosystem defragmentation, car dependency reduction, and material reuse can be achieved? Which regulatory and legal changes are needed? When does property structure need to change, and when is a different governance with existing property structures more beneficial? How to preserve architectural quality and character? Which areas will become vulnerable due to climate change?

5.3.3 Mobility

How can the transformation of the Swiss habitat affect mobility requirements and policies, as well as related policies such as energy, climate, land-use? How can these policies reinforce each other? How can leisure, today's biggest cause of mobility, be transformed to best support high wellbeing with low resource use? Which implications on neighborhoods could this have?

5.3.4 Materials

How suitable are deconstruction materials for renovation, as opposed to new construction, a much more researched area? Which materials, in which quality and quantity, could be reused from the likely main deconstructed neighborhoods, such as single-family houses built after 1960, or shopping malls? Which organizational, legal, economic, informational, or skill and practice obstacles need to be overcome, and how?

5.3.5 Energy resilience

While the habitat transformation will strongly benefit the Swiss energy system, alone it will not solve today's two main issues: crisis resilience and closing the winter electricity gap between high consumption and low generation. What other measures are needed? What will be the impact on the electricity grid of more people living in renovated buildings, with more heat pumps, but also local PV and much higher efficiency?

5.4 Implementation

How to best test, improve, and validate the proposed transformation in real-life neighborhoods? Which conditions are needed for neighborhood-scale tests to happen and succeed? Beyond a successful test neighborhood, how to scale to the needed level in communes, cantons, and nationally? Which policies are needed when?

As often, the solution to complex or wicked problems is not a product, technology, or method. Instead, it begins with dialog and deliberation, perceiving the problem differently, rethinking goals and constraints, and adopting a holistic approach that considers the interactions between parts. This process involves empowering and engaging communities to develop their own solutions guided by the overarching goals of wellbeing for all within ecological limits. This approach has proven effective at small scales, like in ecovillages or citizens' assemblies. Humanity's future collective wellbeing, and possibly survival, depend on our ability to extend this approach to all. Especially for rich countries extracting resources from abroad, it means including the perspective of all affected communities and ecosystems.

The primary goal of this paper is to initiate this much-needed societal dialog. A systems perspective reveals the extent of change required in habitats and behaviors, with the actual path forward to be collectively negotiated.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

SN: Conceptualization, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing, Funding acquisition, Investigation, Project administration, Software, Supervision.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frsus.2024.1375271/full#supplementary-material

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