Health & Place 87 (2024) 103218

Contents lists available at ScienceDirect

Health and Place

journal homepage: www.elsevier.com/locate/healthplace

Urban densification in the Netherlands and its impact on mental health: An expert-based causal loop diagram

Mariëlle A. Beenackers [a,*], Hanneke Kruize [b,c], Lisa Barsties [b], Annelies Acda [d], Ingrid Bakker [e], Mariël Droomers [f], Carlijn B.M. Kamphuis [g], Eric Koomen [h], Jeannette E. Nijkamp [i], Lenneke Vaandrager [j], Beate Völker [k,l], Guus Luijben [b], Annemarie Ruijsbroek [b]

[a] Department of Public Health, Erasmus MC, University Medical Center Rotterdam, Rotterdam, the Netherlands
[b] National Institute for Public Health and the Environment (RIVM), Bilthoven, the Netherlands
[c] HU University of Applied Sciences Utrecht, Utrecht, the Netherlands
[d] Annelies Acda Advies – public health, policy and the built environment, Bussum, the Netherlands
[e] Department of Urban Innovation, Research Centre of Social Innovations Flevoland, Windesheim University of Applied Sciences, Almere, the Netherlands
[f] Department of Public Health, City of Utrecht, Utrecht, the Netherlands
[g] Department of Interdisciplinary Social Science, Utrecht University, Utrecht, the Netherlands
[h] Department of Spatial Economics, Vrije Universiteit Amsterdam, Amsterdam, the Netherlands
[i] Department of Healthy Cities, Research Centre for Built Environment NoorderRuimte, Hanze University of Applied Sciences Groningen, Groningen, the Netherlands
[j] Health and Society, Wageningen University and Research, Wageningen, the Netherlands
[k] Department Human Geography and Spatial Planning, Utrecht University, Utrecht, the Netherlands
[l] Netherlands Centre for the Study of Crime and Law Enforcement (NSCR), Amsterdam, the Netherlands

ARTICLE INFO

Keywords:
Population density
Inequality
Mental health
Complex systems approach
Group model building

ABSTRACT

Urban densification is a key strategy to accommodate rapid urban population growth, but emerging evidence suggests serious risks of urban densification for individuals' mental health. To better understand the complex pathways from urban densification to mental health, we integrated interdisciplinary expert knowledge in a causal loop diagram via group model building techniques. Six subsystems were identified: five subsystems describing mechanisms on how changes in the urban system caused by urban densification may impact mental health, and one showing how changes in mental health may alter urban densification. The new insights can help to develop resilient, healthier cities for all.

1. Introduction

Almost 75% of Europeans reside in urban areas, and this percentage is expected to rise to 84% by 2050 (United Nations Department of Economic and Social Affairs Population Division, 2019). Increasing population density *within* existing urban boundaries, also referred to as urban densification, is a key strategy to accommodate rapid population growth (Broitman and Koomen, 2015; Claassens et al., 2020; Cortinovis et al., 2019; Habitat, 2014; Stevenson et al., 2016; Tiitu et al., 2021; van Duinen et al., 2016). Urban densification has been especially apparent in Europe in the last decade (Cortinovis et al., 2022) and is likely to become more important with the 'no net land take' strategy that the European Commission proposed in 2011 (European Commission, 2011). This strategy should halt the loss of non-urban land by 2050. The Netherlands exemplifies this trend with densification accommodating a large share of the increase in residential housing stock over the past 20 years (Broitman and Koomen, 2020; Claassens et al., 2020; van Duinen et al., 2016).

In epidemiological and urban planning literature, considerable attention has been given to the presumed health-promoting effects of a compact city model: a city with high population density in combination with a mix of functions (high land-use mix) and short distances to functions, services and jobs (Burton et al., 1996; Kain et al., 2022). This model attributes health benefits to the promotion of public transport as the main source of transport, traffic calming and increased walking and

* Corresponding author.
E-mail addresses: m.beenackers@erasmusmc.nl (M.A. Beenackers), hanneke.kruize@rivm.nl (H. Kruize), lisa.barsties@rivm.nl (L. Barsties), annelies@anneliesacda.nl (A. Acda), i.bakker@windesheim.nl (I. Bakker), m.droomers@utrecht.nl (M. Droomers), c.b.m.kamphuis@uu.nl (C.B.M. Kamphuis), e.koomen@vu.nl (E. Koomen), j.e.nijkamp@pl.hanze.nl (J.E. Nijkamp), lenneke.vaandrager@wur.nl (L. Vaandrager), bvolker@nscr.nl (B. Völker), guus.luijben@rivm.nl (G. Luijben), annemarie.ruijsbroek@rivm.nl (A. Ruijsbroek).

https://doi.org/10.1016/j.healthplace.2024.103218
Received 13 October 2023; Received in revised form 30 January 2024; Accepted 21 February 2024
Available online 1 April 2024

cycling, resulting in reduced harmful emissions (Ribeiro et al., 2019) and increased physical activity (Chandrabose et al., 2021; Stevenson et al., 2016). Moreover, increased population density is assumed to have positive effects beyond direct impacts on health, including economic growth, reduced CO_2 emissions, and more efficient energy use (Burton et al., 1996; Ribeiro et al., 2019; Wang and Li, 2021; Westerink et al., 2013). Besides these potential desirable consequences, many studies show that densification can also pose serious health risks (Beenackers et al., 2018; Berghauser Pont et al., 2021; Chaix et al., 2006; Fecht et al., 2016; Meijer et al., 2012; Sundquist and Frank, 2004; Sundquist et al., 2004; Zijlema et al., 2015), especially in already densely populated areas where the health benefits of further urban densification may be less apparent. Densification also seems to affect mental health (Berghauser Pont et al., 2021; Sundquist et al., 2004; Tarkiainen et al., 2021) and mental health problems already cause a large health burden (James et al., 2018).

Urban densification may comprise a myriad of dynamic, multi-level interactive processes with disparate influences on health. An example of the contrasting influences of densification on health is when an influx of residents may demand a growth of neighbourhood facilities. The increased number of destinations within walking distance may lead to increased physical activity (Beenackers et al., 2012, 2018; Chandrabose et al., 2021; Saelens and Handy, 2008). However, it may also reduce the amount of green space or lead to increased noise, which may negatively affect mental health (de Kluizenaar et al., 2007; Haaland and van den Bosch, 2015; Leijssen et al., 2019; MacCutcheon, 2021; Markevych et al., 2017; Naess, 2014; Naess et al., 2019; Nieuwenhuijsen et al., 2017; Orban et al., 2016; Riedel et al., 2015; Riedel et al., 2019; van den Berg et al., 2016). These complexities require an integrated approach that takes urban reality dynamics into account. A system perspective can help to unravel the dynamic complexities and interrelations between different elements involved in a system (Carey et al., 2015; Diez Roux, 2011; Friel et al., 2017; Galea et al., 2010; Leischow et al., 2008; Luke and Stamatakis, 2012; Mabry et al., 2010; Northridge et al., 2003; Rutter et al., 2017; Rydin et al., 2012; Stronks and Nicolaou, 2018; Trochim et al., 2006). Understanding these complexities for mental health in a densifying urban environment is a prerequisite for adapting the underlying systems, and ultimately can provide opportunities to improve population mental health (Wolch et al., 2014; World Health Organization, 2022b).

How urban densification affects inhabitants might differ across groups, e.g., depending on financial resources that allow choice of the place to live. There are growing health inequalities and segregation of socioeconomic groups within cities (Hochstenbach and Musterd, 2018; Marcińczak et al., 2015; Musterd et al., 2017; Rydin et al., 2012). Different densification strategies and planning decisions could either mitigate or exacerbate segregation and socioeconomic inequalities in mental health (Northridge and Freeman, 2011; Rydin et al., 2012). Improving insights into the impact of urban densification on mental health in residents with low income is crucial to avoid further widening of the mental health gap between different population groups (Maass et al., 2016; World Health Organization, 2022b).

The aim of this paper is, therefore, to identify and visualize the many interacting and sometimes contrasting dynamics underlying the connections between urban densification and mental health, using causal loop diagrams (CLDs). The questions that will be addressed are *1) how may urban densification affect the urban system dynamics that impact mental health? And 2) how may these dynamics affect low-income residents specifically?*

2. Methods

This study adopts a complex system approach (Meadows and Wright, 2008). This section discusses the main principles of this approach and CLDs that are used to analyse urban system dynamics. It also describes the process of constructing the CLD on urban densification and mental health.

2.1. Complex systems approach

Complex systems are described as "an interconnected set of elements that is coherently organized in a way that achieves something." (p.11 Meadows and Wright, 2008)). The three main components of a system are therefore the elements, their interconnections, and the purposes or goals driving the system (Luke and Stamatakis, 2012; Meadows and Wright, 2008). Elements can decrease or increase over time. The interconnections between the elements are causal connections. The causal connections have a direction and a polarity.

In contrast to a reductionist approach, these causal connections are not seen as (sufficient) determinants in which A causes B, but as contributing elements in which A contributes to B. The polarity indicates whether an increase in A contributes to an increase in B (causal connection) or whether an increase in A contributes to a decrease in B (inverse causal connection). The causal connections do not have to be linear and often form feedback loops: circular chains of causal connections. Feedback loops can be reinforcing (e.g., vicious or virtuous loops) when the circular chain keeps reinforcing the changes (positive polarity) or balancing when the circular chain ends in the other direction as it has started, thereby balancing the process (negative polarity). These feedback loops can help to identify the underlying goals or purposes of a system. These goals determine how the system functions; they drive the decisions of the actors (e.g., residents, local governments) within the system (Meadows and Wright, 2008). Outcomes of a system, such as health, can be conceptualized as "outcomes of a multitude of interdependent elements within a connected whole" (Rutter et al., 2017). A further key characteristic of a complex system is its dynamic nature in which emergent outcomes can arise that cannot be predicted from its elements alone, making the whole more than the sum of its separate entities.

A causal loop diagram (CLD) is a visual representation of hypothesized system elements and their interconnections within certain system boundaries. A CLD visualizes how a system is understood, making underlying mental models explicit (Sterman, 2001). A CLD also makes feedback loops explicit and may help to identify leverage points in a system (Meadows and Wright, 2008). The development of a CLD involves stakeholders (in our case experts with well-known track-records in their work field) who build the qualitative model, by agreeing on the most relevant elements in the system at hand, and by formulating the causal relationships between these elements (Sterman, 2001). It can help to generate novel interdisciplinary hypotheses which may advance the development of theory, research, policy and practice across disciplines.

2.2. Core modelling team

In our study, the core modelling team consisted of five researchers (MAB, HK, LB, GL & AR) with expertise in public health, environmental health, and complex systems thinking. The core modelling team developed the research plan and refined the causal loop diagrams after each step in the process (as described in Table 1). The core modelling team also decided on the experts to be invited for the group model building workshops.

2.3. Data collection and analysis

Data collection and analysis were carried out during six group model building (GMB) workshops with experts, alternated with activities by the core modelling team. The protocols for the GMB workshops were developed using established scripts from Scriptapedia (Hovmand et al., 2012, 2015).

The first two GMB workshops were carried out online due to COVID-19 restrictions. The other workshops were carried out off-line. A

Table 1
Overview of the six workshops and the carried-out activities in each workshop.

Activities	Environmental & planning experts			Health experts		All experts
	WS1[a]	WS2	WS3	WS4	WS5	WS6
Workshop date	**07-2021**	**12-2021**	**02-2022**	**07-2022**	**09-2022**	**01-2023**
Mode of communication	**Online**	**Online**	**Online**	**Face-to-face**	**Face-to-face**	**Online**
Deciding on system boundaries	●					
Building Causal Loop Diagrams						
'Hopes and fears' [b]	●			●		
'Graphs over time' [b]	[d]			●		
'Variable elicitation' [b]	●	●		●		
'Model building' [b,c]		●		●		
'Transferring Group Ownership from One Image to Another' [b]			●		●	●
'Model review' [b]			●		●	●
Model analysis						
Identifying feedback loops			●		●	●
Discuss low-income groups					●	●
Identifying mechanisms and goals						●

[a] WS = Workshop.
[b] These activities were based on the "established scripts" from Scriptapedia (Hovmand et al., 2015). The end of all workshops was based on the established scripts 'Reflector feedback' and 'Next steps and closing'. The scripts were adapted to fit an online workshop for WS1, WS2, WS3 and WS6.
[c] In the workshop with environmental experts, the script 'initiating and elaborating Causal Loop Diagram (CLD)' (Hovmand et al., 2015) was used while for the workshop with the health experts, the initial CLD was created using a 'connection circle' (Hovmand et al., 2015), adapted for use with digital support via STICKE (Institute for Intelligent Systems Research and Innovation from Deakin University and World Health Organization Collaborating Centre for Obesity Prevention, 2022)).
[d] Graphs over time were not used in this workshop due to the online nature which deemed verbal explanations more appropriate.

schematic overview of the workshops and the included steps can be found in Table 1. In the online workshops, the online collaboration tool MURAL (Mural, 2021) was used to mimic the use of sticky notes and collaboration boards in the live workshops. Systems Thinking In Community Knowledge Exchange (STICKE) software (Institute for Intelligent Systems Research and Innovation from Deakin University, World Health Organization Collaborating Centre for Obesity Prevention, 2022) was used to draft the CLDs in the workshops. The relationship mapping tool KUMU (Kumu, 2023) was used to develop and visualize the final CLD.

A total of 16 scientific experts from the Netherlands participated in at least one of the expert workshops (see Table A1 in Appendix 1 for a description of the expertise of involved experts). Nine of them are environmental and planning experts with a known academic track record in densification, urban processes, or urban planning. The other seven are health experts with a known academic track record in public health, urban health, mental health, and health inequalities.

2.3.1. *Deciding on system boundaries and initial list of elements*

Firstly, the boundaries of the system under study were established by the core modelling team. The boundaries of a system model define what will be *inside* the scope of the model and what will be *outside* the scope of the model. The boundaries of the model under study were based on input from the environmental and planning experts on the main forms of urban densification, gathered during the first workshop (WS1 in Table 1).

The boundaries of the system under study are described in Table 2 in the results section. They were used to guide the development of the CLD.

2.3.2. *Building the causal loop diagram*

Next, two partial CLDs were developed in two sets of workshops. The first partial CLD, describing how urban densification affects the urban environment, was developed in sessions with only environmental and planning experts (WS2 and WS3 in Table 1). The second partial CLD, describing how urban environmental changes affect mental health, was developed in sessions with only health experts (WS4 and WS5 in Table 1).

After the initial model building workshops (WS2 and WS4 in Table 1), the core modelling team refined the partial CLDs. The alterations were then discussed with the experts in the subsequent workshops (WS3 and WS5 in Table 1). In these subsequent workshops, the partial CLDs were further refined. After workshop 5, the core modelling team integrated the two partial CLDs into one model, based on overlapping elements. The integrated CLD was refined and reviewed during the final workshop with all experts combined (WS6 in Table 1). With the input from this workshop, the core modelling team finalized the CLD.

2.3.3. *Model analysis*

During several workshops (WS3, WS4, WS5, and WS6 in Table 1), experts were challenged to identify feedback loops in the (partial) CLD. After the workshops, the core modelling team identified missing loops using the tool KUMU (Kumu, 2023), grouped the feedback loops that included similar elements, and reflected on related pathways to find the most important feedback loops and core mechanisms of the system. These were grouped together into subsystems. Only subsystems that included urban densification as well as one or more of the elements directly related to mental health were included. System goals were formulated by the core modelling team for the identified subsystems and for the overall CLD. The subsystems and the associated (sub)system goals were presented to the experts for discussion via email.

2.3.4. *Analysis of the impact on low-income residents*

In Workshop 5 and Workshop 6, the (partial) CLDs were discussed with respect to how the system might work specifically for low-income residents. The CLD was not altered, and income was not included as a separate element within the CLD (as it was outside the system under study). Instead, the experts discussed how elements, connections, structures, or mechanisms would work for low-income residents specifically.

2.4. *Ethics*

The study design was evaluated by the medical ethics committee of RIVM and Erasmus MC and a declaration of no objection was obtained. Participants in the workshops provided their written informed consent.

3. Results

3.1. Boundaries

The boundaries of the system under study are described in Table 2. The time focus of our system was set to the next 20 years and focussed mainly on the Dutch urban context.

3.2. Description of the CLD

The final CLD included 32 elements and 90 causal connections (Fig. 1). Ten elements were introduced via the initial (partial) CLD developed by the environmental experts, ten were introduced via the initial (partial) CLD developed by the health experts, ten were included in both models and two were added during the joint workshop. Table A2 in Appendix 1 lists the definitions of the elements as agreed upon by the experts for the use in this CLD. The elements were colour-coded to visualize the general domains (e.g., facilities, see legend of Fig. 1). These general domains are indicative only and intended to increase the readability of the CLD. Some elements could fit into multiple domains. For instance, physical activity is labelled under 'Mobility', but also affects mental health and could have been coded as part of the 'Mental health contributors' as well. These choices were based on readability of the CLD.

In this study, the broad definition of mental health of the WHO was used: "the state of mental well-being that enables people to cope with the stresses of life, realize their abilities, learn well and work well, and contribute to their community" (World Health Organization, 2004). Mental health as a stand-alone element was left out of the CLD as it was considered the emerging outcome of the system and not an element within it. Several elements were considered key contributors to mental health and included in the CLD. Chronic stress and recovery capacity were considered together as a core process producing mental health. Health-related behaviours such as sleep and physical activity and health-related resources such as social support contribute to this core process.

The experts identified several system goals that were believed to drive the process of urban densification. Urban densification was considered to be motivated by beliefs of efficiency and scale benefits that cause agglomeration effects. These aspects derive value from the underlying belief that maximizing economic growth is to be strived for. Another goal underlying urban densification, as is the case in the Netherlands, is the desire to preserve greenspace outside city boundaries.

Table 2
Boundaries of the system under study.

Within the boundaries of the system	Outside the boundaries of the system
Densification by increasing the number of residential units and residents in an area.	Densification in number of temporary visitors to an area (e.g., tourists or commuters).
Densification of neighbourhoods or city areas within city borders.	Densification of the city as a whole or higher scale levels.
Densification in existing residential areas (residential densification, (small scale) inner urban greyfield and brownfield redevelopment, urban greenfield development).[a]	Densification in large areas with no previous residential function (large scale brownfield or greyfield redevelopment, agricultural or open land greenfield development, typically located at the borders of the urban area).[a]
Current residents (residing in an area that is densified) and new residents (moving into the area that is densified).	Residents moving out of the area that is densified.[b]

[a] Classification of urban developments based on Claassens et al. (2020).
[b] Residents that leave a densifying neighbourhood are considered important to the system. They are considered until they move. The causal chains for individuals after they moved out of the neighbourhood, are considered outside the boundaries of this system.

A total of six subsystems were identified in the overall CLD. Each subsystem included the number of inhabitants per hectare as an indicator for urban density (dark red element), and either chronic stress or recovery capacity as key contributors to mental health (purple elements). The element with the most outgoing connections was the number of inhabitants per hectare. Chronic stress, recovery capacity and social encounters were the elements with the most ingoing connections (see also Table A2 in Appendix 1). Five subsystems describe mechanisms on how the experts believe changes in the system caused by urban densification may impact mental health. The sixth subsystem shows how changes in mental health may impact the system and alter urban densification. The main elements and associated mechanisms of the subsystems are visualized in Figs. 2–7. Each subsystem and the accompanying goals are discussed below in more detail.

3.3. Subsystems

3.3.1. Subsystem 1 – neighbourhood stress and recovery

The main identified goal that is believed to drive subsystem 1 (Fig. 2) is that residents strive for recovery to maintain mental well-being in response to (environmental) stressors, by recognizing and using individual, social, and neighbourhood environmental resources that aid recovery. Neighbourhood environmental resources and related individual resources are described here. Social sources of recovery are discussed in subsystem 3.

The experts described how the mechanisms in subsystem 1 can affect these goals. They emphasized that increasing the number of inhabitants per hectare may amplify visual and auditory environmental stressors (e.g., noise), elevating chronic stress among residents. Urban densification may exacerbate heat stress since additional housing supply may absorb heat. At the same time, the experts state that densification may reduce recovery capacity. Sleep, as an individual source of recovery capacity, may be under pressure by these extra visual and auditory environmental stressors and heat stress.

With an influx of residents, there is also the risk that neighbourhood environmental sources of recovery capacity are reduced such as the amount of quiet (or low noise) places and (green) public space. These elements may be reduced, either by an absolute amount (e.g., new houses or facilities are built on previously green spaces or quiet places) or by a relative amount (i.e., the same amount of green spaces or quiet places is used by more residents). Less green spaces may additionally lower the (heat)stress reduction capacity of cities.

The experts discussed that chronic stress, recovery capacity, and sleep interact in reinforcing loops (R-1a and R-1b, a list with the description of all feedback loops can be found in Table A3 of Appendix 1), creating harmful 'vicious' loops. Balancing loops also emerge. Increasing numbers of inhabitants per hectare, amplifying stressors (B-1a), dwindling green spaces (B-1d), and quiet places (B-1b and B-1c) can erode a neighbourhood's physical quality, influencing housing demand and which could consequently limit further densification.

3.3.2. Subsystem 2 – housing affordability

Subsystem 2 (Fig. 3) focuses on housing affordability. The identified goal of this subsystem is that residents strive toward maximum utility, optimizing their housing opportunities and neighbourhood facilities within their budget constraints. Entrepreneurs and developers also strive for maximum utility, considering the assets of a location that make it attractive for residents to use facilities or buy a house (e.g., transportation infrastructure, facilities, jobs) and the price of that location.

This excerpt of the CLD visualizes one of the main drivers of urban densification that was discussed by the experts: the attraction (or pull) of the city. The city's pull, driven by opportunities such as jobs and services, spurs urban growth. Urban densification is believed to intensify with increased demand for facilities and jobs (in the tertiary sector) due to the increase in the number of residents. This, in turn, could increase

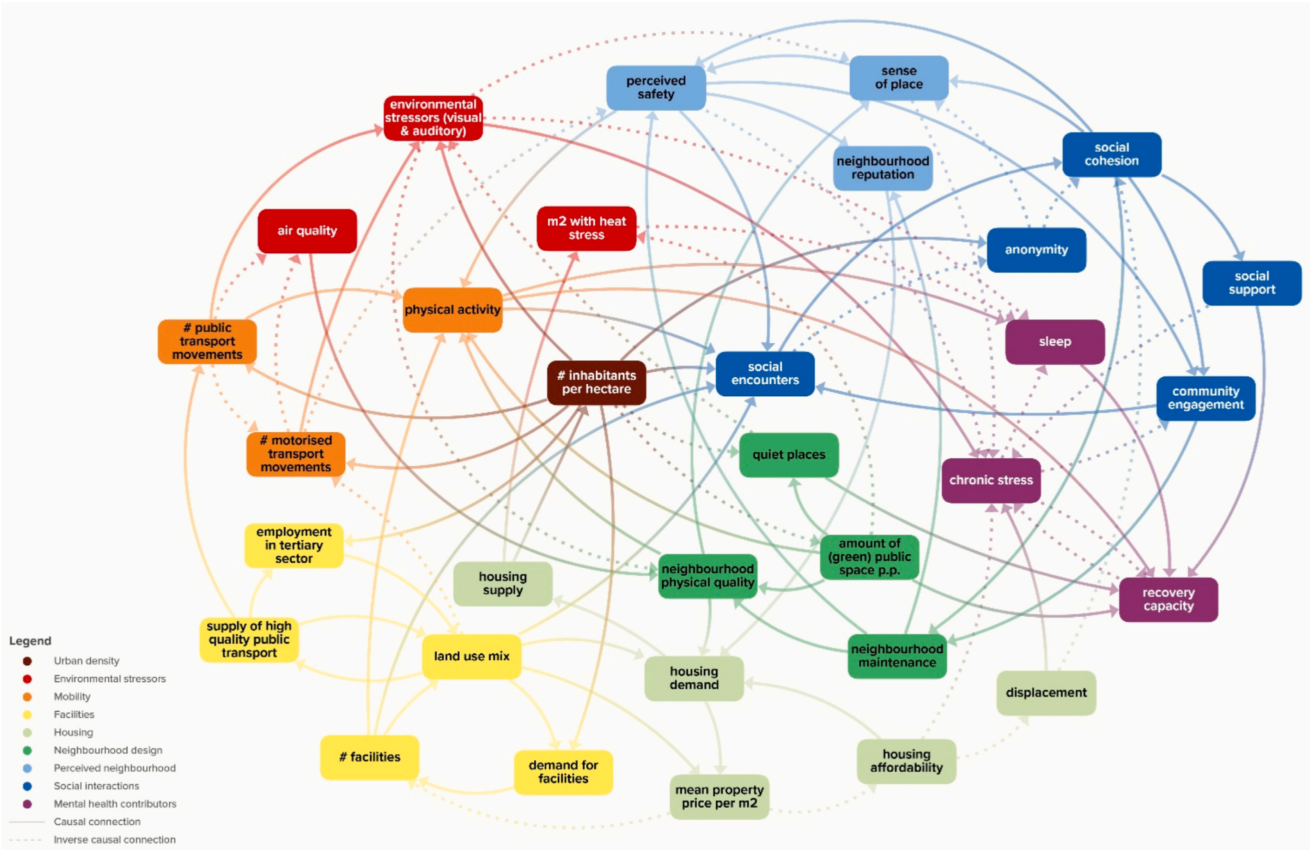

Fig. 1. Causal loop diagram on urban densification and mental health in the Dutch urban context.

land use mix, making the area more attractive and further boosting densification. The many reinforcing feedback loops (R-2a – R-2e) in this part of the CLD illustrate the pull of the city. However, the experts discussed that heightened attractiveness can often lead to higher housing prices, especially when supply is constrained. Increased attractiveness is thus likely to negatively affect housing affordability, which creates a risk of displacement and stress for residents who have less to spend. Rising housing prices may also limit housing demand and further densification, as illustrated by the balancing loops including the price-related elements (B-2a – B-2e).

3.3.3. *Subsystem 3 – social structures*

Subsystem 3 (Fig. 4) highlights how urban densification affects social structures. The identified goal of this subsystem is that residents strive toward meaningful social interactions.

The left side of the figure (yellow and light green) shows the simplified pull of the city loop (loops R-2a and R-2b, see also subsystem 2). The right side shows the mechanisms that experts describe on how an influx of residents could positively affect social structures due to increased opportunities for meaningful social encounters, partly stimulated by the increase of the number of facilities and land use mix. Simultaneously, being surrounded by more people can increase feelings of anonymity, which could negatively affect social cohesion. Social cohesion can impact experienced social support and, in turn, affect chronic stress and recovery capacity.

The experts emphasized that the reinforcing loops (R-3a – R-3f), in different configurations, between social encounters, anonymity, social cohesion, social support, stress, recovery capacity, and community engagement highlight the strength and importance of social processes for mental health. Whether the reinforcing loops will be vicious (negative) or virtuous (positive) will depend on the balance between the negative influences of urban densification on social cohesion (e.g., via anonymity) and the positive influences (e.g., via social encounters). The result of this balance cannot be deduced from this CLD but may depend on elements outside the boundaries of the system, such as social policies and activities.

3.3.4. *Subsystem 4 – sense of place and perceived safety*

Subsystem 4 posits the hypothesized pathways through sense of place and safety (Fig. 5). Sense of place refers to the attitudes and feelings that individuals and groups hold towards the geographical areas in which they live (Table A2 in Appendix 1). The main identified goal of subsystem 4 is that residents strive toward a sense of locational familiarity; most residents want to feel that they belong somewhere. It gives a sense of purpose and may protect against stress.

The experts discussed that the concept of sense of place can connect the physical aspects of a neighbourhood to the social and psychological elements of how residents react to it. They described that when there is a large influx of new residents leading to more environmental (visual and auditory) stressors and feelings of anonymity, sense of place can be disrupted. At the same time, an increase in meaningful social encounters, due to extra residents, and strong social cohesion can enhance sense of place.

In our CLD, sense of place is expected to lower chronic stress either directly or through increased feelings of safety. Both interact with the social processes described in subsystem 3. Numerous feedback loops (vicious/virtuous) link sense of place, perceived safety, physical activity, social encounters, social cohesion, anonymity, and chronic stress with each other (R-4a – R-4t). Perceived safety, social encounters and social cohesion are also highly connected elements within the CLD that are believed to affect many processes from densification to mental health, via key elements such as chronic stress and recovery capacity (not shown in this excerpt).

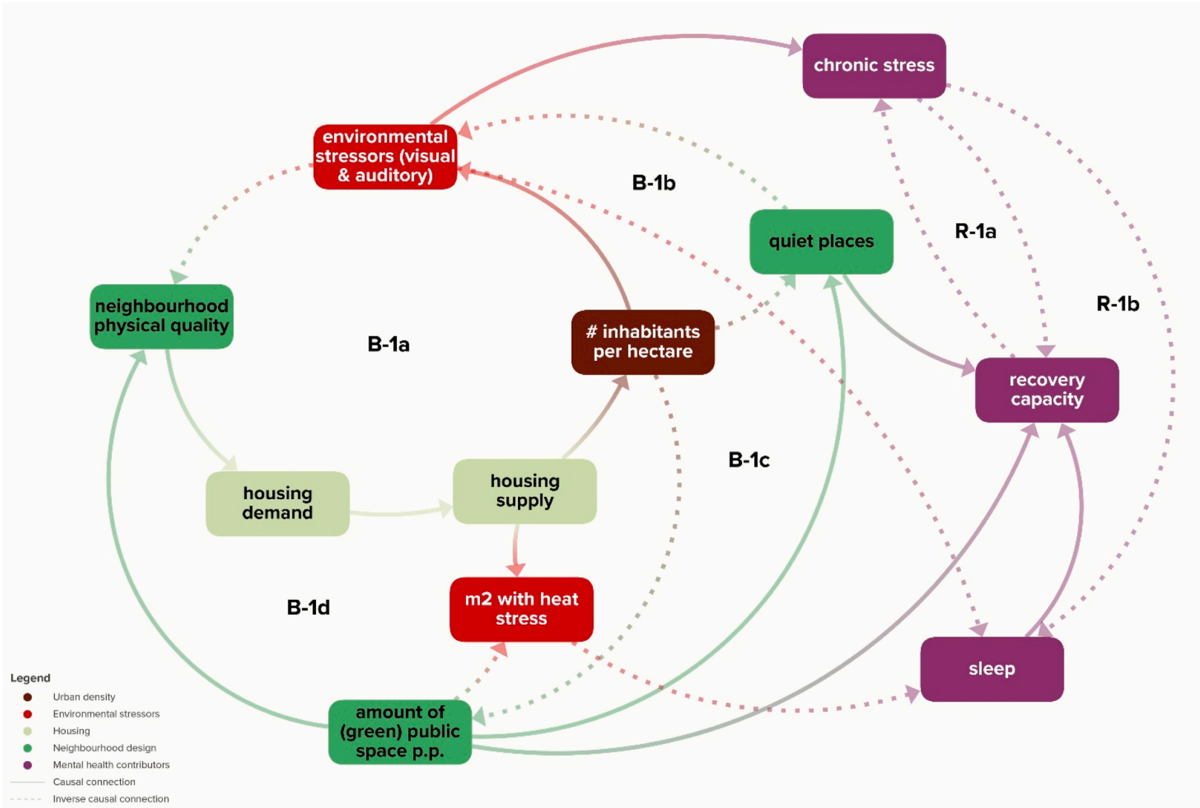

Fig. 2. Subsystem 1 - Neighbourhood stress and recovery. B= Balancing loop, R = Reinforcing loop. For descriptions of feedback loops B-1a – B-1d and R-1a – R-1b, see Table A3 of Appendix 1.

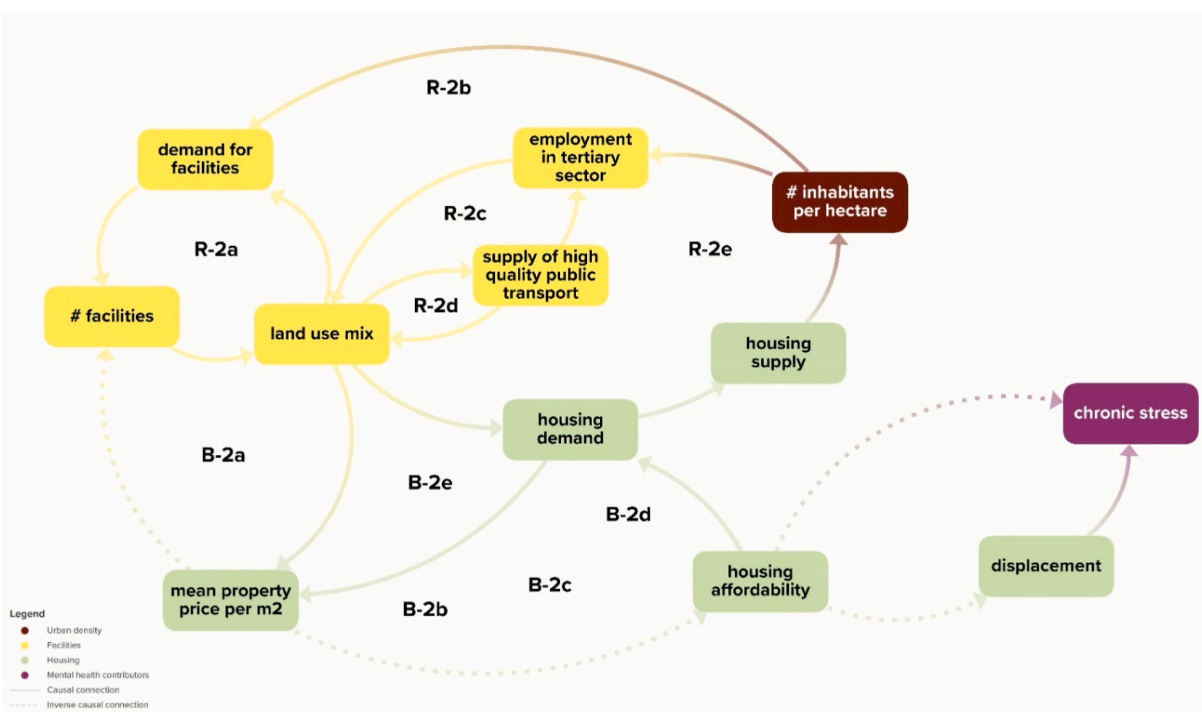

Fig. 3. Subsystem 2 - Housing affordability.
B= Balancing loop, R = Reinforcing loop.
For descriptions of feedback loops B-2a – B-2e and R-2a – R-2e, see Table A3 of Appendix 1.

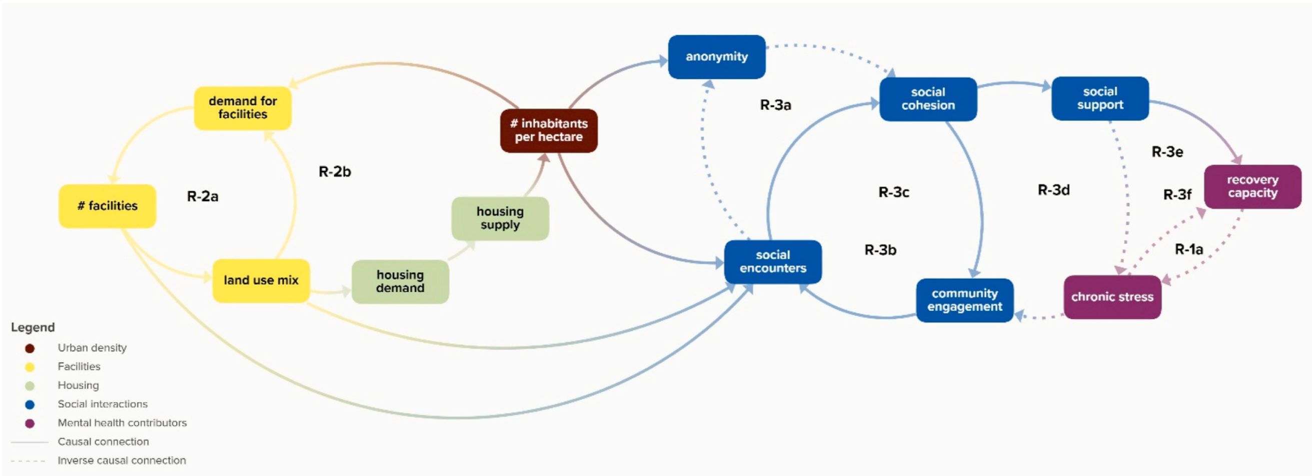

Fig. 4. Subsystem 3 - Social structures.
B= Balancing loop, R = Reinforcing loop.
For descriptions of feedback loops R-1a, R-2a – R-2b and R-3a – R-3f, see Table A3 of Appendix 1.

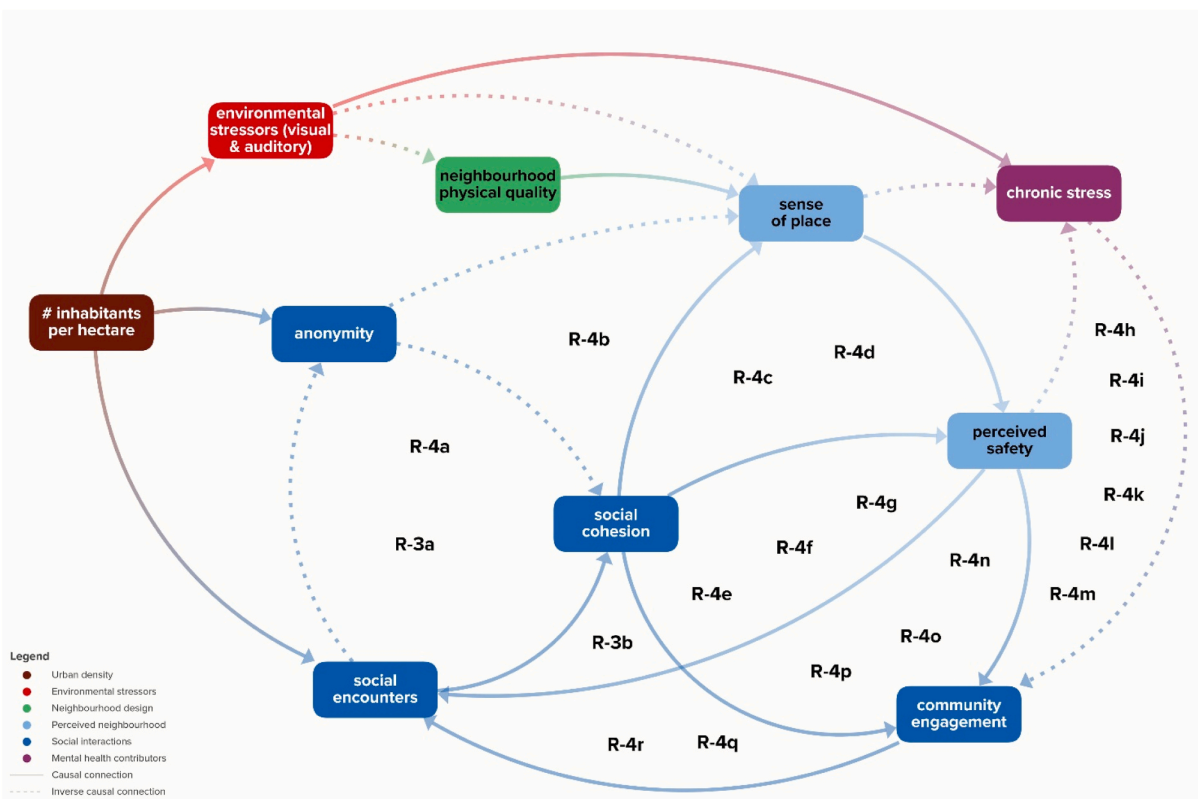

Fig. 5. Subsystem 4 - Sense of place and perceived safety.
B= Balancing loop, R = Reinforcing loop.
For descriptions of feedback loops R-3a – R-3b and R-4a – R-2r, see Table A3 of Appendix 1.

3.3.5. Subsystem 5 – mobility and physical activity

Subsystem 5 (Fig. 6) displays how urban densification may impact mental health through transport movements and physical activity. The main identified goal of subsystem 5 is efficiency. Urban and transportation planners aim for efficient location and travel plans to optimize travel time and benefits. Travelers also seek efficient routes for maximum utility (e.g., health, comfort) and minimal resource use (e.g., time, money, carbon footprint).

Experts described that an increase in residents in an area may increase transportation movements, both from private and public motorised transport, possibly negatively affecting air quality and other environmental stressors (e.g. noise). They emphasized that this is a reflection of the current state and that a higher share of electric vehicles or shared transportation might mitigate this in the future. Declining air quality and increasing environmental stressors could harm the physical quality of the neighbourhood, and consequently the recovery capacity and chronic stress of its inhabitants. The reduced physical quality of the neighbourhood is also assumed to impact housing demand and supply,

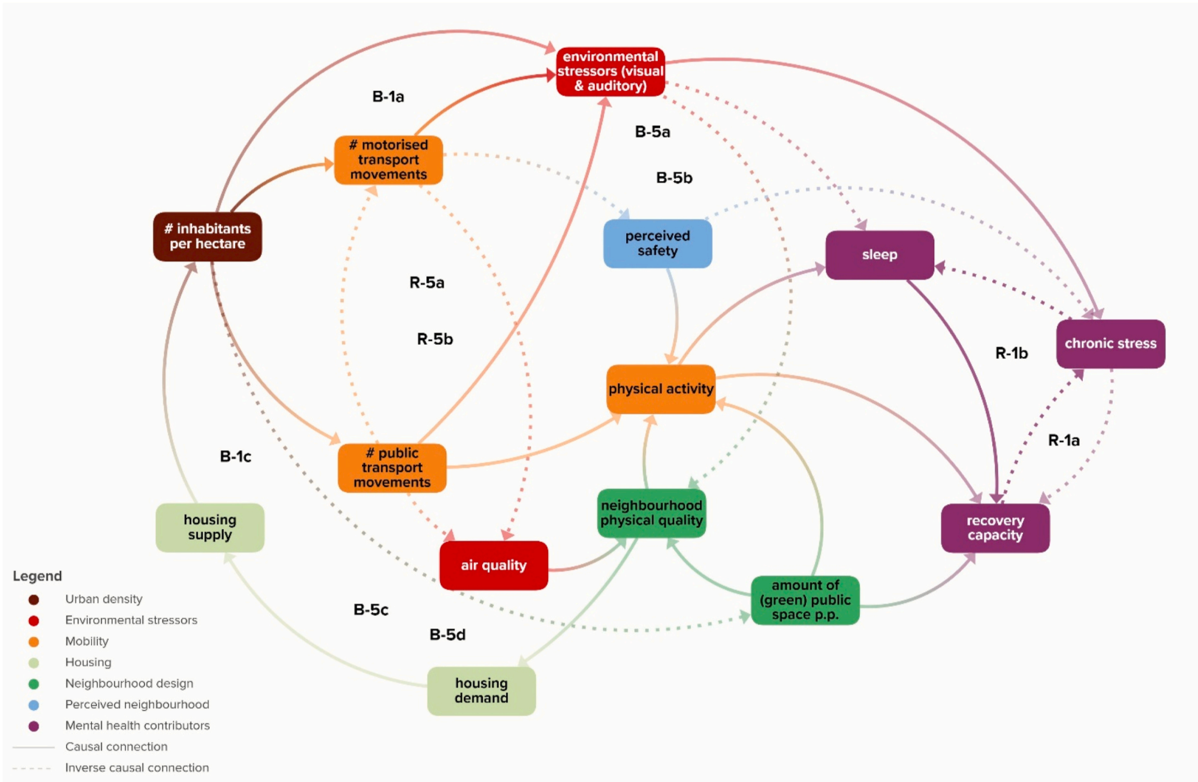

Fig. 6. Subsystem 5 - Mobility and physical activity.
B= Balancing loop, R = Reinforcing loop.
For descriptions of feedback loops B-1a, B-1c, R-1a – R-1b, B-5a – B-5d and R-5a – R-5b, see Table A3 of Appendix 1.

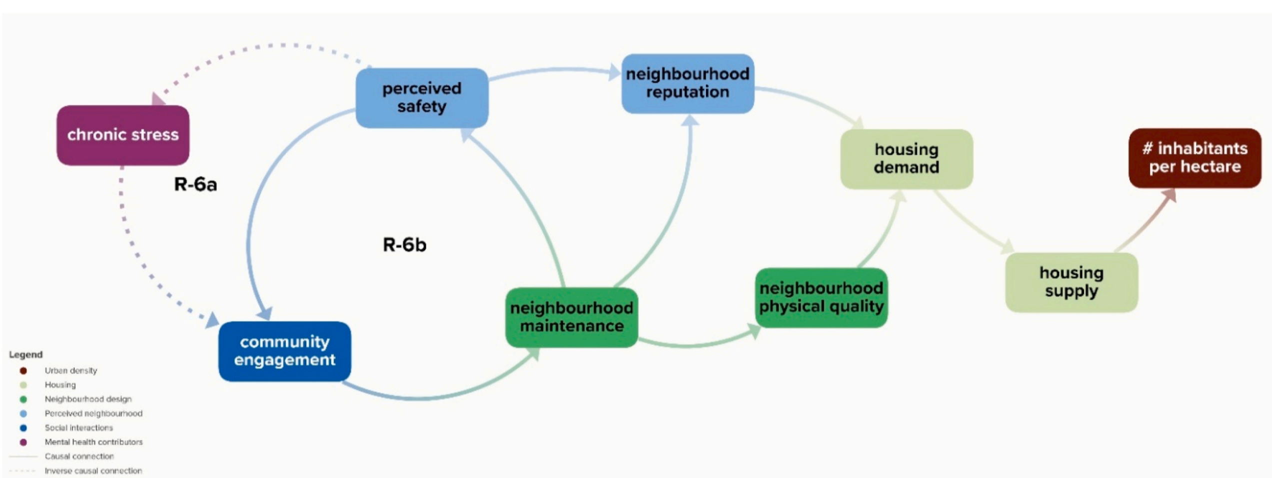

Fig. 7. Subsystem 6 - From stress to densification.
B= Balancing loop, R = Reinforcing loop.
For descriptions of feedback loops R-6a – R-6b, see Table A3 of Appendix 1.

constraining densification, as shown in Fig. 6.

The experts described that an increase in transportation movements can lower perceived safety and reduce physical activity. However, this can be offset if increased public transportation boosts physical activity when more residents walk or cycle the ‘last mile’. More physical activity can positively affect the stress-recovery cycle directly and indirectly via sleep (and other pathways not included in this visualization). Physical activity may also be hindered if the amount of green public space per person decreases because of urban densification.

Reinforcing loops R-5a and R-5b reveal more public transportation curbing motorised transport, partially countering its negative effects.

3.3.6. *Subsystem 6 –from stress to densification*

Fig. 7 highlights the hypothesized pathways of how chronic stress may impact urban densification, creating a full (balancing) loop between the previously discussed subsystems and densification. The identified goal of this subsystem is that residents wish to keep their neighbourhood attractive and maintained. Too much stress can interfere with this goal and may lead to a negative spiral where residents start to neglect their neighbourhood and care less about each other, resulting in undesirable neighbourhood processes.

Experts discussed that residents may withdraw from their community due to mental health problems or chronic stress, decreasing their community engagement. In turn, they may have less interest in keeping their neighbourhood clean and tidy (neighbourhood neglect) or to make the effort to report to the municipality when something gets damaged (e.g., a bench, tree, pathway). This could affect safety perceptions, the physical quality of the neighbourhood, and social cohesion (the latter is not shown here, but in subsystem 3). These mechanisms may also reinforce each other, as visualized by loops R-6a and R-6b. If the physical quality decreases and residents feel less safe, this may harm the reputation of the neighbourhood. The experts discussed that these processes could influence the demand for housing, which, over time, can hamper urban densification.

3.4. Amplified impact of densification on residents with low income

When analysing the CLD with experts, several pathways were identified via which the system could affect residents with low income in particular. The overall conclusion is that urban densification may have a larger impact on the mental health of residents with a low income than on the mental health of their higher-income counterparts. The experts identified two main mechanisms.

3.4.1. Accumulation of stress

The experts described that residents with low incomes more often experience higher levels of chronic stress, in the first place because of reasons other than those directly related to the neighbourhood environment. An example is worries about making ends meet, that is, whether there is enough money for basic needs, such as food, heating and electricity, rent, and health care. They emphasized that residents with low income more often live in neighbourhoods with more environmental stressors (e.g., noise, heat stress) and psychosocial stressors (e.g., crowding, social disorganization, racial discrimination, crime, and economic deprivation). These differences in environmental conditions may amplify already existing individual disadvantages related to income level in ways that are harmful to health. Furthermore, the experts pointed out that living with chronic stressors affects physical and mental health in itself, which leads to lower tolerance for additional (environmental) stressors. So, when densification happens in these neighbourhoods, this accumulation of stress can further amplify chronic stress which, in turn, takes a toll on recovery capacity. The vicious circle between stress and recovery capacity may be exacerbated as well, since higher levels of stress also require higher levels of recovery capacity.

3.4.2. Access to resources

The second mechanism the experts described was related to access to several types of resources. Having less access to important resources can render residents with low incomes more vulnerable to adverse health effects of environmental exposure. First, low income may limit the freedom of choice on where and how to live due to financial constraints. Furthermore, having little private space, indoor as well as outdoor, is likely to create a higher dependency on neighbourhood public space, such as neighbourhood green space. When densification reduces the amount of public (green) space (subsystem 1), it is therefore expected to affect the recovery capacity of residents with low income more severely. The reduced choice due to limited financial resources is illustrated in the mechanisms related to housing affordability and displacement (subsystem 2). The experts emphasize that densification may drive up housing prices potentially leading to displacement of residents with low incomes (subsystem 2). Second, the experts described that residents with low income may experience more barriers when navigating institutions to bring about desired changes or prevent unwanted changes in their living environment. Finally, the experts discussed that having a low income may hinder access to adequate coping strategies or resources to deal with the (environmental) stressors or promote mental health. These individual coping strategies may affect the strength of the relationship between environmental stressors and chronic stress and between chronic stress and recovery capacity in the CLD.

4. Discussion

This study applied a systems perspective to identify and visualize how urban densification may affect neighbourhood system dynamics that contribute to mental health, using an expert-based causal loop diagram (CLD) that integrated interdisciplinary expert knowledge via group model building techniques. Central questions were: 1) How may urban densification affect the urban system dynamics that impact mental health? and 2) how may these dynamics affect low-income residents specifically?

The CLD, describing how urban densification affects urban system dynamics that impact mental health, included 32 elements that were linked via 90 causal connections. The feedback loops in the CLD were numerous because many smaller loops fed into each other, creating almost endless possibilities. A total of six subsystems were identified in the CLD. Five subsystems described how urban densification may impact mental health via processes of 1) increasing stress and reduced recovery, 2) decreasing housing affordability, 3) disrupted social structures, 4) decreasing sense of place and safety, and 5) mixed effects on mobility and physical activity. A sixth subsystem described how changes in mental health may affect urban densification.

In particular, the current CLD warrants attention to social processes, resources for recovery capacity, and potential sources of stress to safeguard mental health in densifying neighbourhoods. Many of the identified loops in our CLD were vicious reinforcing loops initiated by increased population density. Neglecting these processes in urban densification plans may pose a risk to mental health.

4.1. Stress and recovery

In the first and the third subsystem, it was hypothesized how densification could affect sources for stress and recovery at the neighbourhood, individual, and social level. The neighbourhood could both foster stress recovery or restoration (in our CLD identified as public green spaces and quiet spaces) as well as hamper them (in our model via visual and auditory environmental stressors and heat stress) (Gee and Payne-Sturges, 2004; Kruize et al., 2014). Seeing green spaces as restorative resources aligns with a vast body of literature (Hartig et al., 2014; Kruize et al., 2019; Marselle et al., 2019; van den Berg et al., 2016). The restorative capacity is thought to be achieved by providing a buffer to environmental stressors (Hartig et al., 2014; Marselle et al., 2019), help cope with stress (e.g. the stress reduction theory (Ulrich et al., 1991)) and redirect attention (e.g. the attention restoration theory (Kaplan, 1995)). Indirect, green spaces also offer settings for physical activity and social encounters (Cardinali et al., 2023; Hartig et al., 2014; Kruize et al., 2019; Markevych et al., 2017; Marselle et al., 2019; Nieuwenhuijsen et al., 2017; Ulrich et al., 1991; van den Berg et al., 2019; WHO Regional Office for Europe, 2016). Previous literature also illustrates that densifying neighbourhoods often lose green spaces (Balikçi et al., 2022; Berghauser Pont et al., 2021; Haaland and van den Bosch, 2015) which could therefore pose a threat to mental health.

The importance of social structures for mental health (subsystem 3) is underscored by many sociological and psychological theories, such as those on social cohesion (e.g. (Friedkin, 2004; Kawachi and Berkman, 2014), going back as far as (Durkheim, 1897)), social capital (Bourdieu, 2018), social support (Kawachi and Berkman, 2001), and social-ecological models (Sallis et al., 2008; Stokols, 1992)). In our CLD, there was a positive causal connection between urban density and social encounters. Although this is intuitive, there is also evidence suggesting the opposite, i.e., that densification has an adverse effect on social interactions (Berghauser Pont et al., 2021). This was also discussed in the expert workshops, resulting in two pathways from densification to social cohesion; one positive pathway via social encounters and one – connected – negative pathway via increased anonymity. The dominance of either pathway may depend on the specific design of the neighbourhood, pre-existing cohesion, cultural context, or organized activities (e.g., (Dempsey et al., 2012). Notably, certain social stressors and recovery factors found in the literature were not incorporated into the CLD of this study. For example, the review by Berghauser Pont (Berghauser Pont et al., 2021) suggests that density could exacerbate crime in a neighbourhood although the supporting evidence remains limited.

4.2. Sense of place

According to the experts, the potential increase in environmental stressors and feelings of anonymity due to densification may disrupt the sense of place and negatively affect perceived safety and chronic stress. At the same time, larger numbers of inhabitants in an area may increase the likelihood and the number of social encounters, that may strengthen social cohesion, and enhance the sense of place. The concept of sense of place is interesting here, as it establishes a link between the tangible features of a neighbourhood and the way the neighbourhood is perceived. Rooted in theories from psychology, geography, and sociology, the idea of a sense of place is described as the outcome of interconnected psychological, social, and environmental processes concerning physical places (DeMiglio and Williams, 2008; Eyles and Williams, 2008). The link to stress and health is thought to act via well-being and pathways such as enhanced attitudes and self-confidence (Eyles and Williams, 2008). In addition, the concept of sense of place may also relate to the concept of sense of coherence, described in the salutogenic model of health (Antonovsky, 1996; Mittelmark et al., 2022). This model focuses on resources and assets for health. These assets and resources contribute to people's sense of coherence (SoC), and thereby to their health. Neighbourhoods can contribute to the development of a strong SoC by offering neighbourhood resources that enable individuals to protect and promote their own health (in our CLD visual as the inputs for recovery capacity).

4.3. The pull of the city

Our CLD describes the attraction or pull of the city (e.g., supply of jobs, services, facilities) as the main driver of densification (e.g., subsystem 2). This pull of the city is well documented in urban economic literature (e.g. (Duranton and Puga, 2014; Glaeser and Gottlieb, 2006)) and is seen in Dutch city trends (Broitman and Koomen, 2020). This densification of cities is enhanced in the Netherlands by the scarcity of greenfield development locations (Claassens et al., 2020) and compact city policies (Ostendorf, 2017). It is also well documented that the more attractive an area is perceived to be (as described by the pull of the city), the higher the property values (Zuidberg, 2021), especially when supply is limited (Glaeser and Gyourko, 2002; Molloy, 2020). In our CLD, it is hypothesized that this also affects the affordability of housing and creates a risk of displacement and stress for residents who have less to spend. In the Netherlands, neighbourhoods are often improved by local authorities, which could stimulate these pricing effects (Aalbers, 2019; Kleinhans, 2003). This displacement phenomenon as part of gentrification is extensively documented (Atkinson, 2004; Hochstenbach and Musterd, 2018; Marcińczak et al., 2015; Musterd et al., 2017). Gentrification impacts may be mitigated when appropriate policies are implemented or sustained, e.g., related to social housing or rent control (Ghaffari et al., 2018). When residents with lower incomes can stay and also profit from these improvements, this may also have a positive impact on their mental health.

4.4. Changing mobility

The mobility pathways described in subsystem 5 hypothesize that urban densification may lead to more public and private transport movements due to the increased number of inhabitants. This increase seems to counter the vast research on the limiting impact of urban density on personal car use (following the seminal work of (Newman and Kenworthy, 1989)). The subsystem refers, however, to the basic effect that adding more people to an existing urban area is expected to increase the absolute number of trips made with various transport modes. In relative terms it is likely that the share of public transport increases, although there may be a time lag in this response as substantial investments and behavioural change are required. This complexity is also hinted at in recent critical reflections on the Newman and Kenworthy type of studies that emphasize the importance of e.g., scale and distributional factors in explaining the link between density and automobile dependence (e.g., (Ewing et al., 2018)). Average trip distances are reported to be lower in high-density areas, but this is often assessed in cross-sectional studies that look at variation between cities and not at changes over time (e.g., (Ralph et al., 2016). Moreover, this effect seems to depend on density levels (levelling off above certain threshold values (Berghauser Pont et al., 2021). Based on these insights we assume that increasing densities in a city may result in an increase in the total amount of kilometres travelled within that area.

The model aligns with the predicted increase in public (or shared) transportation and physical activity (for transport) when urban densification occurs, since more people are expected to walk or cycle, including the 'last mile' to work or home and vice versa, after using public transport (Berghauser Pont et al., 2021; Burton et al., 1996). At the same time, air quality and perceived safety may deteriorate, which –together with a potential decrease in green space-may lead to a decrease in physical activity, and therefore to less recovery. However, environmental (health) literature also states that fewer cars and more cycling and walking may offer more public space, providing opportunities for residents to interact, contribute to climate change mitigation through CO_2 reductions, and stimulate economic profits due to a reduction in traffic jams (Burton et al., 1996; Gerlofs-Nijland et al., 2021; Giles-Corti et al., 2016; Nieuwenhuijsen and Khreis, 2016; Staatsen et al., 2017; van Wee and Ettema, 2016). So, when motorised transport movements can be minimized during densification and are replaced by active transport such as walking and cycling, this may positively impact mental health and other societal issues.

4.5. A limit to densification

The CLD also describes how densification may be limited. A balancing effect may occur when housing prices surge, negatively affecting housing demand and limiting further densification. These balancing loops (mainly in subsystems 1 and 2) follow the classic economic rationale that residents choose a location by weighing the attributes of the available alternatives within their budget restraints to maximize their utility (Duranton et al., 2015; McFadden, 1977). Some of the main environmental attributes affecting utility are included in the CLD (e.g. physical quality of the neighbourhood, number of facilities). However, the simplification of including one element for all facilities may hide how different types of facilities (e.g., schools, shops, health care) in the neighbourhood affect this process.

Another process that may limit densification, was through increased chronic stress. This may decrease community engagement (subsystem 6). The consequential decay may affect perceived safety, physical quality, and social cohesion, affecting the reputation of the neighbourhood, and in the long run urban densification. The loops in this subsystem depict processes recognized by theories about neighbourhood disorder, such as social disorganization theory (Sampson, 2012; Sampson et al., 1997) and the spiral of decay theory (Skogan, 1992). These theories describe how neighbourhood disorder, like public incivilities and area deterioration, can fuel disorder and criminal behaviour, leading to feelings of unsafety among residents. As a result, residents may withdraw themselves from the public realm. This may hinder the community's ability to take action against deviant behaviour through positive social connections and social control, allowing crime and disorder to spread (Sampson, 2012; Sampson et al., 1997; Skogan, 1992). The lack of explicit elements like crime or public incivilities could be considered as a limitation of the CLD. However, the main process appears to be covered with the included elements and connections.

4.6. Increased health risk for residents with low income

In response to our research question of how urban densification may affect mental health of low-income residents specifically, the experts stated that health risks are likely amplified for residents with low income due to the possible accumulation of stressors, the reduced resilience as a result of this and the limited access to mitigating resources.

The detrimental (mental) health effects of an accumulation of stress combined with more unfavourable living conditions in residents with low income are well-described in scientific literature (Cutrona et al., 2006; deFur et al., 2007; Gee and Payne-Sturges, 2004; Macintyre, 2007; Soobader et al., 2006) and correspond with social causation theory (Goldman, 1994; Kröger et al., 2015). Secondly, the hypothesized lower access to personal resources is also well documented in the literature, including fewer resources (financial, social, power) that allow to choose where to live (Huang et al., 2014), mitigate or cope with environmental stressors (Diderichsen et al., 2019; Kruize et al., 2014; WHO Regional Office for Europe, 2019), influence neighbourhood changes such as densification or how densification is implemented (Kruize et al., 2014), or access or recognize resources that promote mental health (Mittelmark et al., 2022). There is also some critique that it is not *always* true that neighbourhood circumstances are worse for people with less income and this may depend on the resource in question, their quality, how they are perceived, or the local (historical) context (Macintyre, 2007). The limited choice of living environment for people with low income may cause a worse person-environment fit for this population, which may influence the perceived access and relevance of resources. A worse person-environment fit could compound stress and possibly selective migration, which could affect mental health (Tran et al., 2020).

In this study, we focused on residents with low income. However, other residents in vulnerable positions and with a higher dependency on the neighbourhood environment, such as children or older adults, should be considered as well. Furthermore, our system boundaries were limited to the residents of the densifying neighbourhood. Although displacement was included in the model, the actual processes for those who (are forced to) leave the neighbourhood if gentrification occurs were outside the scope of this study but likely impact mental health as well (Lim et al., 2017).

4.7. Clashing system goals

The identified goals for the subsystems are a subset of the total set of goals that drive the entire urban system at different levels (macro, city, neighbourhood, individual). The goals of urban dynamics related to densification revolve around maximizing economic growth (at the macro level such as the city or country level) and utility (at the individual and neighbourhood level). There may be other macro- or city-level goals that drive the processes in our CLD which are outside the boundaries of the system such as political motivations. The economic drivers of densification may clash with the more individual-level goals of maintaining a balance between stress and recovery in a densifying urban environment. For example, the presupposed prospect of economic growth may motivate developers to efficiently use available land for houses that will generate measurable revenue, potentially reducing quiet and green spaces (Haaland and van den Bosch, 2015). This may not align with the needs of residing residents who may experience an increased need for these quiet and green spaces due to the influx of new residents and accompanying stressors. Which needs and goals translate into the final spatial development plans may be determined by disparities in power within a neighbourhood. Urban developers in general have more power while residents bear the primary consequences of these environmental changes (Carlisle, 2010; De Weger et al., 2018). This emphasizes the need to meaningfully involve residents from an early stage in neighbourhood (re)development plans to safeguard their needs and their health (De Weger et al., 2018). Placemaking strategies – strategies to transform public spaces to strengthen the connections between people and these places – may be an interesting strategy to bridge power gaps among different stakeholders in the neighbourhood and to connect the physical elements with the social and individual elements that are affected by urban densification (Ellery and Ellery, 2019).

4.8. Strengths and limitations

This is the first system map that we know, which identifies and visualizes a complex system on urban densification and its related neighbourhood system dynamics affecting residents' mental health, using collective knowledge and experiences from a broad set of disciplines. The CLD in this study was developed with scientific experts with a known academic track record in densification, urban processes, urban planning, environmental health, public health, urban health, mental health, health inequalities, and complex systems thinking. This provided a rich set of information needed to build this broad system map which can inform new research, broadening our interdisciplinary understanding of these mechanisms. The comparison of our results of the CLD with the existing literature showed that many theories describe only a piece of the puzzle. Although these theories are valuable for understanding a certain subsystem, system maps, such as our CLD, can visualize the interconnectedness of these pieces of the puzzle, which are important to capture the full effects of urban densification.

Although many academic and professional perspectives were represented, the expert group was not diverse from other perspectives. Mainly white experts with a Dutch background participated, and while the physical environmental experts were mainly male, the social and health experts were predominantly female. This lack of diversity may have affected the included elements and connections. Another limitation is that only experts were consulted. There are other perspectives, e.g., from policymakers and residents (especially those with low income), to explore. Furthermore, although most health experts had some expertise on mental health, no trained psychologist or psychiatrist was present to provide a more in-depth view of the psychological elements. Because the CLD was about mental health in general and not about specific diseases, we believe the impact of this omission is limited and may be further elaborated on in future CLDs.

A CLD, like all models, is a simplification of the assumed reality. The visualized connections are assumed to be causal, but this does not mean they are true in all situations. First, the CLD aims to reflect the Dutch urban context, which is different from many other countries. Furthermore, the dominance of certain feedback loops can depend on many circumstances, many of which are also included in the CLD. Something that could not be integrated properly in the CLD is *how* urban densification is realized, e.g. what types of houses are built (e.g. social housing, private upper class housing) and where these different types are being built. Different densification strategies (Claassens et al., 2020) and executions can result in different outcomes. For example, there is some evidence that higher density can be combined with more green space or higher quality green space (Haaland and van den Bosch, 2015). This can mitigate the potential harmful elements of densification. It depends on the decisions of municipalities and developers to implement such possibilities. Furthermore, the way decisions on densification plans emerge and how they are communicated can significantly affect how changes are perceived by residents, which can bridge power inequities (De Weger et al., 2018) and affect elements such as a sense of place and stress.

Furthermore, the focus of this CLD was on the neighbourhood level. We realize that urban densification has also effects on other levels, not described here. One example is the effects on air pollution as a result of the mobility changes described earlier. Even though air pollution may decrease on a macro-level when densification facilitates a modal shift, the effect on the local urban environment may be different with potentially (at first) an increase in emissions because of the population increase.

Although this CLD does not provide a clear guide on how to densify in a way that is conducive to mental health, it does provide potential entry points for action, or so-called leverage points (Meadows and Wright, 2008), that can guide discussions on healthy densification. It also draws attention to elements that have been understated so far, such as the importance of social dynamics, multi-level resources for recovery capacity, and the extra risk potential for residents in vulnerable positions, such as residents with low-income.

More research is needed to test the hypothesized causal connections and mechanisms in the CLD. Furthermore, while a CLD can be used to unravel causal mechanisms, it cannot demonstrate what the (system) effect would be if parts of the system changes (Crielaard et al., 2022). For that, a simulation model is needed, which is often the next step in complex system approach. This can provide opportunities to assess the system effects of potential interventions and policies. To make the CLD applicable in practice, interaction with local policymakers, professionals, and residents is also required (Barsties et al, submitted). The current CLD should be used with caution, serving more as a discussion tool rather than a definitive visualization of facts. CLDs like these, or subsequent versions, hold potential in exploring the intended and unintended consequences or opportunities associated with policy decisions, and can be a helpful framework to guide future empirical evaluation studies into mental health effects of urban densification. They offer insights into pathways that may not always be at the forefront of urban (re)development decisions, such as social mechanisms and mental health.

5. Conclusions

In this study, we developed an expert-based system map (CLD) that identifies and visualizes how urban densification can affect neighbourhood dynamics that contribute to mental health, by combining knowledge from a wide range of disciplines. It provides entry points for action that can guide discussions on healthy densification. The current CLD warrants attention to social processes, resources for recovery capacity, and potential sources of stress in densifying neighbourhoods to safeguard mental health. Extra attention should be paid to residents with low income who more often experience an accumulation of stressors and who have fewer (financial) resources (including power) to choose where to live, mitigate environmental stressors, or influence neighbourhood changes. This puts them at a greater risk of experiencing possible negative mental health consequences of urban densification. Despite the potential economic, climate, and physical health benefits of urban densification, it is important to consider the potential risks to mental health as well.

These insights into the dynamic mechanisms in a densifying neighbourhood that can impact mental health can help generate novel interdisciplinary hypotheses. This could advance the development of theory, research, policy, and practice across disciplines related to urbanization, densification, mental health, and health inequalities, which is needed to keep our growing cities healthy and sustainable for all, while at the same time securing the required affordable housing in cities.

Funding

This research was supported by the Strategic Program of the Netherlands National Institute for Public Health and the Environment (RIVM) (grant number S/020012), by a grant from the Netherlands Organization for Scientific Research (NWO/ZonMw) (grant number 09150161810158 / VI.Veni.194.041), and by the European Union's Horizon 2020 research and innovation programme (grant number 956780). The funding sources were not involved in any of the research activities. Views and opinions expressed are those of the authors only and do not necessarily reflect those of the funding sources.

CRediT authorship contribution statement

Mariëlle A. Beenackers: Conceptualization, Funding acquisition, Investigation, Methodology, Visualization, Writing – original draft. **Hanneke Kruize:** Conceptualization, Funding acquisition, Investigation, Methodology, Writing – review & editing. **Lisa Barsties:** Investigation, Writing – review & editing, Methodology. **Annelies Acda:** Validation, Writing – review & editing. **Ingrid Bakker:** Validation, Writing – review & editing. **Mariël Droomers:** Validation, Writing – review & editing. **Carlijn B.M. Kamphuis:** Validation, Writing – review & editing. **Eric Koomen:** Validation, Writing – review & editing. **Jeannette E. Nijkamp:** Validation, Writing – review & editing. **Lenneke Vaandrager:** Validation, Writing – review & editing. **Beate Völker:** Validation, Writing – review & editing. **Guus Luijben:** Investigation, Methodology, Writing – review & editing. **Annemarie Ruijsbroek:** Conceptualization, Funding acquisition, Investigation, Methodology, Writing – review & editing.

Declaration of Competing interest

None.

Data availability

The data used in this article are qualitative data specific to the developed system model and are not suitable or available for other research activities.

Acknowledgements

Next to the co-authoring experts, we thank Maarten Hoorn, Arjan Harbers, Fenne Pinkster, Bas Hilckmann, Richard de Brabander, Kees Maat, Ruben Vrijhoef, and Mark Noordzij for their expert contributions to the workshops. We also thank Reint Huijzendveld, Fleur Ter Ellen, Michelle Eykelenboom, and Arne Mellaard for their help during the workshops.

Appendix 1

Table A1
Description of consulted experts and core modelling team

Name	Organization	Expertise
Consulted experts (in alphabetical order)		
Acda, A.	Annelies Acda Advies – public health, policy and the built environment (Consultancy)	Socioeconomic inequalities in health, public health, public health policy processes, policy planning to improve a healthy environment
Bakker, I.	Department of Urban Innovation, Research Centre of Social Innovations Flevoland, Windesheim University of Applied Sciences	Healthy environment, positive health, health in urban transitions, practice based and participative action research
de Brabander, R.	InHolland University of Applied Science Rotterdam	Social exclusion, social sustainability and ecology
Droomers, M.	Department of Public Health, City of Utrecht	Socioeconomic inequalities in health, social determinants of health, public health policy advice
Harbers, A.	PBL (Netherlands Environmental Assessment Agency)	Urban planning and design, urbanism
Hilckmann, B.	The Hague University of Applied Sciences	Sustainable mobility, urban accessibility
Hoorn, M.	Platform31 (Dutch knowledge and networking organization within the built environment)	Urbanization, spatial planning, liveability
Kamphuis, C.B.M.	Department of Interdisciplinary Social Science, Utrecht University	Socioeconomic inequalities in health, the role environmental factors for health and health-related behaviour, systems thinking
Koomen, E.	Department of Spatial Economics, Vrije Universiteit Amsterdam	Urban densification and its underlying drivers, environmental impacts and relationship with (spatial) planning
Maat, C.	Department of Transport and Planning, Faculty of Civil Engineering & Geosciences, Delft University of Technology	Built environment and mobility, travel behaviour
Nijkamp, J.E.	Department of Healthy Cities, Research Centre for Built Environment NoorderRuimte, Hanze University of Applied Sciences Groningen	Healthy cities, built environment and health, neighbourhood health inequalities
Noordzij, J.M.	The Mulier Institute	Urban sociology, human geography, built environment and health
Pinkster, F.M.	Department of Human Geography, Planning and International Development Studies, University of Amsterdam	Geography of everyday life, home and belonging, politics of place, urban inequality and governing marginality.
Vaandrager, L.	Health and Society, Wageningen University and Research	Environmental and social justice, healthy living environments, salutogenesis, systems thinking
Völker, B.	Department Human Geography and Spatial Planning, Utrecht University; Netherlands Centre for the Study of Crime and Law Enforcement (NSCR)	Social networks, social capital, social cohesion, networks in urban spaces, perception of safety in neighbourhoods
Vrijhoef, R.	HU University of Applied Sciences Utrecht	Sustainable and circular urban development, supply chains and construction
Core modelling team (in alphabetical order)		
Name	**Organization**	**Expertise**
Barsties, L.	National Institute for Public Health and the Environment (RIVM)	Social epidemiology, group model building
Beenackers, M.A.	Department of Public Health, Erasmus MC	Urban health, healthy living environments, health inequalities
Kruize, H.	National Institute for Public Health and the Environment (RIVM); HU University of Applied Sciences Utrecht	Environmental epidemiology, environmental health inequalities, healthy urban development
Luijben, G.	National Institute for Public Health and the Environment (RIVM)	Public health, system dynamics, complex systems thinking
Ruijsbroek, A.	National Institute for Public Health and the Environment (RIVM)	Healthy living environment, health inequalities

Table A2
Definitions of elements in the causal loop diagram.

#	General domain	Element name	Definition	Number of incoming connections	Number of outgoing connections
0	Emerging outcome	Mental health	The state of mental well-being that enables people to cope with the stresses of life, realize their abilities, learn well and work well, and contribute to their community. (World Health Organization, 2004)	–	–
1	Urban density	# Inhabitants per hectare	Number of inhabitants per hectare (10 000 m^2).	1	9
2	Environmental stressors	Environmental stressors (visual & auditory)	Visual and auditory (noise and sounds) elements in the environment, which stimulate a negative response. *(Adapted from Collins English* Dictionary, 2023*; environmental stressor entry)*	4	4
3		Air quality	The degree to which the air in a particular place is clean and free from pollution. *(Adapted from Oxford Advanced American* Dictionary, 2023*; air quality entry)*	2	1
4		m^2 with heat stress	Square meters in an area in which individuals are exposed to heat stress, in which heat stress is defined as the negative effect of the thermal energy (heat) environment on an individual (McGregor and Vanos, 2018).	2	1
5	Mobility	Physical activity	Any bodily movement produced by skeletal muscles that requires energy expenditure. It refers to all bodily movement including during leisure time, for transport to get to and from places, or as part of a person's work (World Health Organization, 2022a).	5	3
6		# Public transport movements	The number of daily movements (e.g., expressed in kilometres) via public transport (e.g., buses, trains, trams, subways).	2	4
7		# Motorised transport movements	The number of daily movements (e.g., expressed in kilometres) via non-public motorised vehicles (e.g., cars, motorcycles, scooters, buses, etc.).	3	3

(continued on next page)

Table A2 (*continued*)

#	General domain	Element name	Definition	Number of incoming connections	Number of outgoing connections
8	Facilities	Supply of high-quality public transport	The amount of high-quality transport routes and stops in an area. Aspects affecting quality are e.g., frequency of trips, reliability, safety, destinations along the offered routes.	1	3
9		# Facilities	The number of buildings, services and equipment that are provided for a particular purpose such as shopping, care, sport and recreation. *(Adapted from Oxford Advanced American* Dictionary, 2023*; facilities entry)*	2	3
10		Demand for facilities	The degree that people need or want to make use of facilities.	2	1
11		Employment in tertiary sector	The number of paid jobs in the tertiary sector, which is the sector that provides services.	2	1
12		Land use mix	The evenness of distribution of square meters of residential, commercial, and office development (Frank et al., 2005).	3	6
13	Housing	Housing demand	The degree that people need or want to buy or rent a dwelling in the area (e.g., house, apartment, etc.).	4	2
14		Housing supply	The total number of dwellings available in an area (e.g., house, apartment, etc.).	1	2
15		Housing affordability	The ability of households to buy or rent adequate housing, without impairing their ability to meet basic living costs (OECD, 2021).	1	3
16		Displacement	The amount of people who are forced to leave their home or their neighbourhood. *(Adapted from Oxford Advanced American* Dictionary, 2023*; displacement entry)*	1	2
17		Mean property price per m2	The mean (average) price per m2 of a building or area of land, or both together.	2	2
18	Neighbourhood design	Amount of (green) public space per person	The total square meters of green and other public spaces in an area, divided by the number of residents residing in that same area.	1	5
19		Quiet places	Places with good sound quality and limited noise disturbance.	2	2
20		Neighbourhood physical quality	The degree to which desirable physical features in a neighbourhood are present, safe and well maintained.	4	3
21		Neighbourhood maintenance	The work residents put in to keep private and public buildings and areas (e.g., houses, gardens, streets) in good condition by checking or repairing it. *(Adapted from Oxford Advanced American* Dictionary, 2023*; maintenance entry)*	2	3
22	Mental health contributors	Chronic stress	A consistent state of worry or mental tension over a prolonged period of time. *(Adapted from (World Health Organization, 2023))*	7	3
23		Recovery capacity	The degree a person is able to return to a normal state after a stressful event or a stressful period. *(Adapted from Oxford Advanced American* Dictionary, 2023*; recovery entry)*	6	1
24		Sleep	The average amount and quality of sleep a person has each night.	4	1
25	Social interactions	Social encounters	The number of times a person is able to meet another person.	6	2
26		Social support	The provision of assistance or comfort to others, typically to help them cope with biological, psychological, and social stressors. *(*American Psychological Association Dictionary of Psychology, 2023*; social support entry)*	1	2
27		Social cohesion	The extent of connectedness and solidarity among groups in society (Manca, 2014).	3	5
28		Community engagement	The process of working collaboratively with and through groups in the neighbourhood to address issues affecting the wellbeing of residents (McCloskey et al., 2011).	3	2
29		Anonymity	The degree that people do not know or recognize each other in the neighbourhood.	2	2
30	Perceived neighbourhood	Sense of place	Attitudes and feelings that individuals and groups hold towards the geographical areas in which they live (Ellery and Ellery, 2019). In the CLD, an emphasis is placed on the positive attitudes and feelings that provide people with a feeling of belonging.	4	2
31		Perceived safety	Fear and anxieties caused by real or assumed threats (Ruijsbroek et al., 2015). In the CLD, perceived safety refers both to perceived traffic safety and perceived safety from crime.	4	5
32		Neighbourhood reputation	The meaning and esteem residents and other involved parties attribute to a neighbourhood. It refers to the relatively stable image a neighbourhood has among city residents and to its place in the urban neighbourhood hierarchy (Hortulanus, 1995).	2	1

Table A3
Description of the feedback loops in the six subsystems.

Label	Type	Subsystem	Description
B-1a	Balancing	Subsystem 1, subsystem 5	# inhabitants per hectare → environmental stressors → neighbourhood physical quality → housing demand → housing supply → # inhabitants per hectare
B-1b	Balancing	Subsystem 1	# inhabitants per hectare → quiet places → environmental stressors → neighbourhood physical quality → housing demand → housing supply → # inhabitants per hectare
B-1c	Balancing	Subsystem 1, subsystem 5	# inhabitants per hectare → amount of (green) public space p.p. → neighbourhood physical quality → housing demand → housing supply → # inhabitants per hectare
B-1d	Balancing	Subsystem 1	# inhabitants per hectare → amount of (green) public space p.p. → quiet places → environmental stressors → neighbourhood physical quality → housing demand → housing supply → # inhabitants per hectare
R-1a	Reinforcing	Subsystem 1	chronic stress → recovery capacity → chronic stress
R-1b	Reinforcing	Subsystem 1, subsystem 5	chronic stress → sleep → recovery capacity → chronic stress
B-2a	Balancing	Subsystem 2	land use mix → mean property price per m2 → # facilities → land use mix
B-2b	Balancing	Subsystem 2	housing demand → mean property price per m2 → housing affordability → housing demand
B-2c	Balancing	Subsystem 2	# inhabitants per hectare → employment in tertiary sector → land use mix → mean property price per m2 → housing affordability → housing demand → housing supply → # inhabitants per hectare
B-2d	Balancing	Subsystem 2	# inhabitants per hectare → demand for facilities → # facilities → land use mix → mean property price per m2 → housing affordability → housing demand → housing supply → # inhabitants per hectare
B-2e	Balancing	Subsystem 2	land use mix → housing demand → mean property price per m2 → # facilities → land use mix
R-2a	Reinforcing	Subsystem 2, subsystem 3	land use mix → demand for facilities → # facilities → land use mix
R-2b	Reinforcing	Subsystem 2, subsystem 3	# inhabitants per hectare → demand for facilities → # facilities → land use mix → housing demand → housing supply → # inhabitants per hectare
R-2c	Reinforcing	Subsystem 2	land use mix → supply of high quality public transport → employment in tertiary sector → land use mix
R-2d	Reinforcing	Subsystem 2	land use mix → supply of high quality public transport → land use mix
R-2e	Reinforcing	Subsystem 2	# inhabitants per hectare → employment in tertiary sector → land use mix → housing demand → housing supply → # inhabitants per hectare
R-3a	Reinforcing	Subsystem 3, subsystem 4	social encounters → anonymity → social cohesion → community engagement → social encounters
R-3b	Reinforcing	Subsystem 3, subsystem 4	social encounters → social cohesion → community engagement → social encounters
R-3c	Reinforcing	Subsystem 3	chronic stress → community engagement → social encounters → anonymity → social cohesion → social support → chronic stress
R-3d	Reinforcing	Subsystem 3	chronic stress → community engagement → social encounters → social cohesion → social support → chronic stress
R-3e	Reinforcing	Subsystem 3	chronic stress → community engagement → social encounters → social cohesion → social support → recovery capacity → chronic stress
R-3f	Reinforcing	Subsystem 3	chronic stress → community engagement → social encounters → anonymity → social cohesion → social support → recovery capacity → chronic stress
R-4a	Reinforcing	Subsystem 4	perceived safety → social encounters → anonymity → social cohesion → perceived safety
R-4b	Reinforcing	Subsystem 4	perceived safety → social encounters → anonymity → sense of place → perceived safety
R-4c	Reinforcing	Subsystem 4	perceived safety → social encounters → social cohesion → sense of place → perceived safety
R-4d	Reinforcing	Subsystem 4	perceived safety → social encounters → anonymity- social cohesion → sense of place → perceived safety
R-4e	Reinforcing	Subsystem 4	perceived safety → social encounters → social cohesion → perceived safety
R-4f	Reinforcing	Subsystem 4	perceived safety → community engagement → social encounters → anonymity → social cohesion → sense of place → perceived safety
R-4g	Reinforcing	Subsystem 4	perceived safety → community engagement → social encounters → social cohesion → sense of place → perceived safety
R-4h	Reinforcing	Subsystem 4	chronic stress → community engagement → social encounters → anonymity → sense of place → chronic stress
R-4i	Reinforcing	Subsystem 4	chronic stress → community engagement → social encounters → anonymity → social cohesion → sense of place → chronic stress
R-4j	Reinforcing	Subsystem 4	chronic stress → community engagement → social encounters → social cohesion → perceived safety → chronic stress
R-4k	Reinforcing	Subsystem 4	chronic stress → community engagement → social encounters → anonymity → sense of place → perceived safety → chronic stress
R-4l	Reinforcing	Subsystem 4	chronic stress → community engagement → social encounters → anonymity → social cohesion → perceived safety → chronic stress
R-4m	Reinforcing	Subsystem 4	chronic stress → community engagement → social encounters → anonymity → social cohesion → sense of place → perceived safety → chronic stress
R-4n	Reinforcing	Subsystem 4	perceived safety → community engagement → social encounters → anonymity → sense of place → perceived safety
R-4o	Reinforcing	Subsystem 4	perceived safety → community engagement → social encounters → social cohesion → perceived safety
R-4p	Reinforcing	Subsystem 4	perceived safety → community engagement → social encounters → anonymity → social cohesion → perceived safety
R-4q	Reinforcing	Subsystem 4	chronic stress → community engagement → social encounters → social cohesion → sense of place → perceived safety → chronic stress
R-4r	Reinforcing	Subsystem 4	chronic stress → community engagement → social encounters → social cohesion → sense of place → chronic stress
B-5a	Balancing	Subsystem 5	# inhabitants per hectare → # motorised transport movements → environmental stressors → neighbourhood physical quality → housing demand → housing supply → # inhabitants per hectare
B-5b	Balancing	Subsystem 5	# inhabitants per hectare → # public transport movements → environmental stressors → neighbourhood physical quality → housing demand → housing supply → # inhabitants per hectare
B-5c	Balancing	Subsystem 5	# inhabitants per hectare → # motorised transport movements → air quality → neighbourhood physical quality → housing demand → housing supply → # inhabitants per hectare
B-5d	Balancing	Subsystem 5	# inhabitants per hectare → # public transport movements → air quality → neighbourhood physical quality → housing demand → housing supply → # inhabitants per hectare
R-5a	Reinforcing	Subsystem 5	# inhabitants per hectare → # public transport movements → # motorised transport movements → environmental stressors → neighbourhood physical quality → housing demand → housing supply → # inhabitants per hectare
R-5b	Reinforcing	Subsystem 5	# inhabitants per hectare → # public transport movements → # motorised transport movements → air quality → neighbourhood physical quality → housing demand → housing supply → # inhabitants per hectare
R-6a	Reinforcing	Subsystem 6	chronic stress → community engagement → maintenance → perceived safety → chronic stress
R-6b	Reinforcing	Subsystem 6	perceived safety → community engagement → maintenance → perceived safety

References

Aalbers, M.B., 2019. Introduction to the Forum: from third to Fifth-wave gentrification. Tijdschr. Econ. Soc. Geogr. 110, 1–11.

Antonovsky, A., 1996. The salutogenic model as a theory to guide health promotion. Health Promot. Int. 11, 11–18.

Atkinson, R., 2004. The evidence on the impact of gentrification: new lessons for the urban renaissance? Eur. J. Hous. Pol. 4, 107–131.

Balikçi, S., Giezen, M., Arundel, R., 2022. The paradox of planning the compact and green city: analyzing land-use change in Amsterdam and Brussels. J. Environ. Plann. Manag. 65, 2387–2411.

Barsties, L.S., Ruijsbroek, A., Beenackers, M.A., Luijben, G., van den Berg, S.W., (Submitted for publication). Residents' perceptions of urban densification and health – A systems dynamics approach.

Beenackers, M.A., Foster, S., Kamphuis, C.B., et al., 2012. Taking up cycling after residential relocation: built environment factors. Am J Prev Med 42, 610–615.

Beenackers, M.A., Oude Groeniger, J., Kamphuis, C.B.M., Van Lenthe, F.J., 2018. Urban population density and mortality in a compact Dutch city: 23-year follow-up of the Dutch GLOBE study. Health Place 53, 79–85.

Berghauser Pont, M., Haupt, P., Berg, P., Alstäde, V., Heyman, A., 2021. Systematic Review and Comparison of Densification Effects and Planning Motivations. Buildings and Cities.

Bourdieu, P., 2018. The Forms of Capital, the Sociology of Economic Life. Routledge, pp. 78–92.

Broitman, D., Koomen, E., 2015. Residential density change: densification and urban expansion. Comput. Environ. Urban Syst. 54, 32–46.

Broitman, D., Koomen, E., 2020. The attraction of urban cores: densification in Dutch city centres. Urban Stud. 57, 1920–1939.

Burton, E., Jenks, M., Williams, K., 1996. The Compact City: A Sustainable Urban Form?, first ed. Routledge.

Cardinali, M., Beenackers, M.A., van Timmeren, A., Pottgiesser, U., 2023. Preferred reporting items in green space health research. Guiding principles for an interdisciplinary field. Environ. Res. 228.

Carey, G., Malbon, E., Carey, N., et al., 2015. Systems science and systems thinking for public health: a systematic review of the field. BMJ Open 5, e009002.

Carlisle, S., 2010. Tackling health inequalities and social exclusion through partnership and community engagement? A reality check for policy and practice aspirations from a Social Inclusion Partnership in Scotland. Crit. Publ. Health 20, 117–127.

Chaix, B., Rosvall, M., Lynch, J., Merlo, J., 2006. Disentangling contextual effects on cause-specific mortality in a longitudinal 23-year follow-up study: impact of population density or socioeconomic environment? Int. J. Epidemiol. 35, 633–643.

Chandrabose, M., Owen, N., Hadgraft, N., Giles-Corti, B., Sugiyama, T., 2021. Urban densification and physical activity change: a 12-year longitudinal study of Australian adults. Am. J. Epidemiol. 190, 2116–2123.

Claassens, J., Koomen, E., Rouwendal, J., 2020. Urban density and spatial planning: the unforeseen impacts of Dutch devolution. PLoS One 15, e0240738.

Cortinovis, C., Geneletti, D., Haase, D., 2022. Higher immigration and lower land take rates are driving a new densification wave in European cities. Npj Urban Sustainability 2.

Cortinovis, C., Haase, D., Zanon, B., Geneletti, D., 2019. Is urban spatial development on the right track? Comparing strategies and trends in the European Union. Landsc. Urban Plann. 181, 22–37.

Crielaard, L., Uleman, J.F., Chatel, B.D.L., et al., 2022. Refining the causal loop diagram: a tutorial for maximizing the contribution of domain expertise in computational system dynamics modeling. Psychol. Methods 29 (1), 169–201.

Cutrona, C.E., Wallace, G., Wesner, K.A., 2006. Neighborhood characteristics and depression: an Examination of stress processes. Curr. Dir. Psychol. Sci. 15, 188–192.

de Kluizenaar, Y., Gansevoort, R.T., Miedema, H.M., de Jong, P.E., 2007. Hypertension and road traffic noise exposure. J. Occup. Environ. Med. 49, 484–492.

De Weger, E., Van Vooren, N., Luijkx, K.G., Baan, C.A., Drewes, H.W., 2018. Achieving successful community engagement: a rapid realist review. BMC Health Serv. Res. 18.

deFur, P.L., Evans, G.W., Hubal, E.A.C., et al., 2007. Vulnerability as a function of individual and group resources in cumulative risk assessment. Environmental Health Perspectives 115, 817–824.

DeMiglio, L., Williams, A., 2008. A sense of place, a sense of well-being. In: Eyles, J., Williams, A. (Eds.), Sense of Place, Health and Quality of Life. Ashgate Publishing, Ltd.

Dempsey, N., Brown, C., Bramley, G., 2012. The key to sustainable urban development in UK cities? The influence of density on social sustainability. Prog. Plann. 77, 89–141.

Diderichsen, F., Hallqvist, J., Whitehead, M., 2019. Differential vulnerability and susceptibility: how to make use of recent development in our understanding of mediation and interaction to tackle health inequalities. Int. J. Epidemiol. 48, 268–274.

Diez Roux, A.V., 2011. Complex systems thinking and current impasses in health disparities research. Am J Public Health 101, 1627–1634.

Duranton, G., Henderson, V., Strange, W., 2015. Handbook of Regional and Urban Economics. Elsevier.

Duranton, G., Puga, D., 2014. The Growth of Cities, Handbook of Economic Growth 2, P. Aghion and S. Durlauf. Elsevier, Amsterdam.

Durkheim, E., 1897. Le suicide: étude de sociologie. Alcan.

Ellery, P.J., Ellery, J., 2019. Strengthening community sense of place through Placemaking. Urban Planning 4, 237–248.

European Commission, 2011. Roadmap to a Resource Efficient Europe COM (2011) 571. European Commission Brussels, Belgium.

Ewing, R., Hamidi, S., Tian, G., et al., 2018. Testing Newman and Kenworthy's theory of density and automobile dependence. J. Plann. Educ. Res. 38, 167–182.

Eyles, J., Williams, A., 2008. Sense of Place, Health and Quality of Life. Ashgate.

Fecht, D., Fortunato, L., Morley, D., Hansell, A.L., Gulliver, J., 2016. Associations between urban metrics and mortality rates in England. Environ. Health 15 (Suppl. 1), 34.

Frank, L.D., Schmid, T.L., Sallis, J.F., Chapman, J., Saelens, B.E., 2005. Linking objectively measured physical activity with objectively measured urban form: Findings from SMARTRAQ. Am. J. Prev. Med. 28, 117–125.

Friedkin, N.E., 2004. Social cohesion. Annu. Rev. Sociol. 30, 409–425.

Friel, S., Pescud, M., Malbon, E., et al., 2017. Using systems science to understand the determinants of inequities in healthy eating. PLoS One 12, e0188872.

Galea, S., Riddle, M., Kaplan, G.A., 2010. Causal thinking and complex system approaches in epidemiology. Int. J. Epidemiol. 39, 97–106.

Gee, G.C., Payne-Sturges, D.C., 2004. Environmental health disparities: a framework integrating psychosocial and environmental concepts. Environ. Health Perspect. 112, 1645–1653.

Gerlofs-Nijland, M., Staatsen, B., Geelen, L., et al., 2021. Road Transport Facts and Figures. How Healthy and Environmentally Friendly Is Our Transport Today? RIVM, Bilthoven.

Ghaffari, L., Klein, J.L., Baudin, W.A., 2018. Toward a socially acceptable gentrification: a review of strategies and practices against displacement. Geography Compass 12.

Giles-Corti, B., Vernez-Moudon, A., Reis, R., et al., 2016. City planning and population health: a global challenge. Lancet 388, 2912–2924.

Glaeser, E.L., Gottlieb, J.D., 2006. Urban resurgence and the consumer city. Urban Stud. 43, 1275–1299.

Glaeser, E.L., Gyourko, J., 2002. The Impact of Zoning on Housing Affordability. National Bureau of Economic Research Cambridge, Mass., USA.

Goldman, N., 1994. Social-factors and health - the causation-selection issue revisited. Proceedings of the National Academy of Sciences of the United States of America 91, 1251–1255.

Haaland, C., van den Bosch, C.K., 2015. Challenges and strategies for urban green-space planning in cities undergoing densification: a review. Urban For. Urban Green. 14, 760–771.

Habitat, U.N., 2014. A New Strategy of Sustainable Neighbourhood Planning: Five Principles. United Nations Human Settlements Programme, Nairobi, Kenya.

Hartig, T., Mitchell, R., de Vries, S., Frumkin, H., 2014. Nature and health. Annu. Rev. Publ. Health 35 35, 207.

Hochstenbach, C., Musterd, S., 2018. Gentrification and the suburbanization of poverty: changing urban geographies through boom and bust periods. Urban Geogr. 39, 26–53.

Hortulanus, R.P., 1995. Stadsbuurten: Bewoners en beheerders in buurten met uiteenlopende reputaties [Urban neighbourhoods—residents and managers in neighbourhoods with divergent reputations]. VUGA, Den Haag.

Hovmand, P.S., Andersen, D.F., Rouwette, E., et al., 2012. Group model-building scripts' as a collaborative planning tool. Syst. Res. Behav. Sci. 29, 179–193.

Hovmand, P.S., Rouwette, E., Andersen, D.F., Richardson, G.P., 2015. Scriptapedia. Wikibooks, San Francisco, CA, USA.

Huang, Q.X., Parker, D.C., Filatova, T., Sun, S.P., 2014. A review of urban residential choice models using agent-based modeling. Environ. Plann. Plann. Des. 41, 661–689.

Institute for Intelligent Systems Research and Innovation from Deakin University, World Health Organization Collaborating Centre for Obesity Prevention, 2022. Systems Thinking in Community Knowledge Exchange (STICKE).

James, S.L., Abate, D., Abate, K.H., et al., 2018. Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990-2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet 392, 1789–1858.

Kain, J.H., Adelfio, M., Stenberg, J., Thuvander, L., 2022. Towards a systemic understanding of compact city qualities. J. Urban Des. 27, 130–147.

Kaplan, S., 1995. The restorative benefits of nature - toward an integrative framework. J. Environ. Psychol. 15, 169–182.

Kawachi, I., Berkman, L.F., 2001. Social ties and mental health. Journal of Urban Health-Bulletin of the New York Academy of Medicine 78, 458–467.

Kawachi, I., Berkman, L.F., 2014. Social capital, social cohesion, and health. In: Glymour, M.M. (Ed.), Social Epidemiology, second ed. Oxford University Press, New York.

Kleinhans, R., 2003. Displaced but still moving upwards in the housing career? Implications of forced residential relocation in The Netherlands. Hous. Stud. 18, 473–499.

Kröger, H., Pakpahan, E., Hoffmann, R., 2015. What causes health inequality? A systematic review on the relative importance of social causation and health selection. Eur. J. Publ. Health 25, 951–960.

Kruize, H., Droomers, M., van Kamp, I., Ruijsbroek, A., 2014. What causes environmental inequalities and related health effects? An analysis of evolving concepts. Int J Environ Res Public Health 11, 5807–5827.

Kruize, H., van der Vliet, N., Staatsen, B., et al., 2019. Urban green space: creating a Triple Win for environmental sustainability, health, and health equity through behavior change. Int. J. Environ. Res. Publ. Health 16.

Kumu, 2023. Relationship Mapping Software. Kumu.

Leijssen, J.B., Snijder, M.B., Timmermans, E.J., et al., 2019. The association between road traffic noise and depressed mood among different ethnic and socioeconomic groups. The HELIUS study. Int. J. Hyg Environ. Health 222 (2), 221–229.

Leischow, S.J., Best, A., Trochim, W.M., et al., 2008. Systems thinking to improve the public's health. Am. J. Prev. Med. 35, S196–S203.

Lim, S., Chan, P.Y., Walters, S., et al., 2017. Impact of residential displacement on healthcare access and mental health among original residents of gentrifying neighborhoods in New York City. PLoS One 12.

Luke, D.A., Stamatakis, K.A., 2012. Systems science methods in public health: dynamics, networks, and agents. Annu Rev Public Health 33, 357–376.
Maass, R., Kloeckner, C.A., Lindstrom, B., Lillefjell, M., 2016. The impact of neighborhood social capital on life satisfaction and self-rated health: a possible pathway for health promotion? Health Place 42, 120–128.
Mabry, P.L., Marcus, S.E., Clark, P.I., Leischow, S.J., Mendez, D., 2010. Systems science: a revolution in public health policy research. Am J Public Health 100, 1161–1163.
MacCutcheon, D., 2021. Negative responses to urban residential noise as a social rebound effect of increasing population density: Legislative challenges and auditory territoriality. Noise Health 23, 35–41.
Macintyre, S., 2007. Deprivation amplification revisited; or, is it always true that poorer places have poorer access to resources for healthy diets and physical activity? Int. J. Behav. Nutr. Phys. Activ. 4.
Manca, A.R., 2014. Social cohesion. In: Michalos, A.C. (Ed.), Encyclopedia of Quality of Life and Well-Being Research. Springer Netherlands, Dordrecht, pp. 6026–6028.
Marcińczak, S., Musterd, S., Van Ham, M., Tammaru, T., 2015. Inequality and rising levels of socio-economic segregation: lessons from a pan-European comparative study. In: Tammaru, T., Marcińczak, S., Van Ham, M., Musterd, S. (Eds.), Socio-economic Segregation in European Capital Cities: East Meets West Routledge.
Markevych, I., Schoierer, J., Hartig, T., et al., 2017. Exploring pathways linking greenspace to health: Theoretical and methodological guidance. Environ. Res. 158, 301–317.
Marselle, M.R., Martens, D., Dallimer, M., Irvine, K.N., 2019. Review of the mental health and well-being benefits of biodiversity. Biodiversity and health in the face of climate change 175–211.
McCloskey, D.J., McDonald, M.A., Cook, J., et al., 2011. Community engagement: definitions and organizing concepts from the literature. In: Clinical and Translational Science Awards Consortium, Community Engagement Key Function Committee Task Force on the Principles of Community Engagement, second ed. Principles of Community Engagement NIH.
McFadden, D., 1977. Modelling the Choice of Residential Location.
McGregor, G.R., Vanos, J.K., 2018. Heat: a primer for public health researchers. Publ. Health 161, 138–146.
Meadows, D.H., Wright, D., 2008. Thinking in Systems: A Primer. Chelsea Green Publishing.
Meijer, M., Kejs, A.M., Stock, C., et al., 2012. Population density, socioeconomic environment and all-cause mortality: a multilevel survival analysis of 2.7 million individuals in Denmark. Health Place 18, 391–399.
Mittelmark, M.B., Bauer, G.F., Vaandrager, L., et al., 2022. The Handbook of Salutogenesis.
Molloy, R., 2020. The effect of housing supply regulation on housing affordability: a review. Reg. Sci. Urban Econ. 80, 1–5.
Mural, 2021. Online Collaboration Tool. Mural.
Musterd, S., Marcinczak, S., van Ham, M., Tammaru, T., 2017. Socioeconomic segregation in European capital cities. Increasing separation between poor and rich. Urban Geogr. 38, 1062–1083.
Naess, P., 2014. Urban form, sustainability and health: the case of greater Oslo. Eur. Plann. Stud. 22, 1524–1543.
Naess, P., Saglie, I.L., Richardson, T., 2019. Urban sustainability: is densification sufficient? Eur. Plan. Stud. 28 (1), 146–165.
Newman, P.W.G., Kenworthy, J.R., 1989. Gasoline consumption and cities: a comparison of US cities with a global survey. J. Am. Plann. Assoc. 55, 24–37.
Nieuwenhuijsen, M.J., Khreis, H., 2016. Car free cities: pathway to healthy urban living. Environ. Int. 94, 251–262.
Nieuwenhuijsen, M.J., Khreis, H., Triguero-Mas, M., Gascon, M., Dadvand, P., 2017. Fifty Shades of green: pathway to healthy urban living. Epidemiology 28, 63–71.
Northridge, M.E., Freeman, L., 2011. Urban planning and health equity. J. Urban Health 88, 582–597.
Northridge, M.E., Sclar, E.D., Biswas, P., 2003. Sorting out the connections between the built environment and health: a conceptual framework for navigating pathways and planning healthy cities. J. Urban Health 80, 556–568.
OECD, 2021. Building for a Better Tomorrow: Policies to Make Housing More affordable., Employment, Labour and Social Affairs Policy Briefs. OECD, Paris.
Orban, E., McDonald, K., Sutcliffe, R., et al., 2016. Residential road traffic noise and high Depressive Symptoms after five Years of follow-up: results from the Heinz Nixdorf Recall study. Environ. Health Perspect. 124, 578–585.
Ostendorf, W., 2017. New Towns and Compact Cities: Urban Planning in the Netherlands between State and Market, Change and Stability in Urban Europe. Routledge, pp. 177–192.
Ralph, K., Voulgaris, C.T., Taylor, B.D., Blumenberg, E., Brown, A.E., 2016. Millennials, built form, and travel insights from a nationwide typology of US neighborhoods. J. Transport Geogr. 57, 218–226.
Ribeiro, H.V., Rybski, D., Kropp, J.P., 2019. Effects of changing population or density on urban carbon dioxide emissions. Nat. Commun. 10, 3204.
Riedel, N., Kockler, H., Scheiner, J., et al., 2019. Urban road traffic noise and noise annoyance-a study on perceived noise control and its value among the elderly. Eur J Public Health 29 (2), 377–379.
Riedel, N., Kockler, H., Scheiner, J., Berger, K., 2015. Objective exposure to road traffic noise, noise annoyance and self-rated poor health - framing the relationship between noise and health as a matter of multiple stressors and resources in urban neighbourhoods. J. Environ. Plann. Manag. 58, 336–356.
Ruijsbroek, A., Droomers, M., Groenewegen, P.P., Hardyns, W., Stronks, K., 2015. Social safety, self-rated general health and physical activity: changes in area crime, area safety feelings and the role of social cohesion. Health Place 31, 39–45.
Rutter, H., Savona, N., Glonti, K., et al., 2017. The need for a complex systems model of evidence for public health. Lancet 390, 2602–2604.
Rydin, Y., Bleahu, A., Davies, M., et al., 2012. Shaping cities for health: complexity and the planning of urban environments in the 21st century. Lancet 379, 2079–2108.
Saelens, B.E., Handy, S.L., 2008. Built environment correlates of walking: a review. Med. Sci. Sports Exerc. 40, S550–S566.
Sallis, J.F., Owen, N., Fisher, E.B., 2008. Ecological Models of Health Behavior, Health Behavior and Health Education: Theory, Research, and Practice, fourth ed. Jossey-Bass, San Francisco, CA, US, pp. 465–485.
Sampson, R.J., 2012. Great American City: Chicago and the Enduring Neighborhood Effect. University of Chicago Press.
Sampson, R.J., Raudenbush, S.W., Earls, F., 1997. Neighborhoods and violent crime: a multilevel study of collective efficacy. Science 277, 918–924.
Skogan, W.G., 1992. Disorder and Decline: Crime and the Spiral of Decay in American Neighborhoods. University of California Press.
Soobader, M., Cubbin, C., Gee, G.C., Rosenbaum, A., Laurenson, J., 2006. Levels of analysis for the study of environmental health disparities. Environ. Res. 102, 172–180.
Staatsen, B., van der Vliet, N., Kruize, H., et al., 2017. INHERIT. Exploring Triple-Win Solutions for Living, Moving and Consuming that Encourage Behavioural Change, Protect the Environment, Promote Health and Health Equity. EuroHealthNet, Brussels.
Sterman, J.D., 2001. System Dynamics: Systems Thinking and Modeling for a Complex World. Irwin McGraw-Hill, Boston, MA, USA.
Stevenson, M., Thompson, J., de Sa, T.H., et al., 2016. Land use, transport, and population health: estimating the health benefits of compact cities. Lancet 388, 2925–2935.
Stokols, D., 1992. Establishing and maintaining healthy environments. Toward a social ecology of health promotion. Am. Psychol. 47, 6–22.
Stronks, K., Nicolaou, M., 2018. Embracing complexity in social epidemiology. Lancet Public Health 3, e352–e353.
Sundquist, K., Frank, G., 2004. Urbanization and hospital admission rates for alcohol and drug abuse: a follow-up study of 4.5 million women and men in Sweden. Addiction 99, 1298–1305.
Sundquist, K., Frank, G., Sundquist, J., 2004. Urbanisation and incidence of psychosis and depression: follow-up study of 4.4 million women and men in Sweden. Br. J. Psychiatry 184, 293–298.
Tarkiainen, L., Moustgaard, H., Korhonen, K., et al., 2021. Association between neighbourhood characteristics and antidepressant use at older ages: a register-based study of urban areas in three European countries. J. Epidemiol. Community Health 75, 426–432.
Tiitu, M., Naess, P., Ristimaki, M., 2021. The urban density in two Nordic capitals - comparing the development of Oslo and Helsinki metropolitan regions. Eur. Plann. Stud. 29, 1092–1112.
Tran, L.D., Rice, T.H., Ong, P.M., et al., 2020. Impact of gentrification on adult mental health. Health Serv. Res. 55, 432–444.
Trochim, W.M., Cabrera, D.A., Milstein, B., Gallagher, R.S., Leischow, S.J., 2006. Practical challenges of systems thinking and modeling in public health. Am J Public Health 96, 538–546.
Ulrich, R.S., Simons, R.F., Losito, B.D., et al., 1991. Stress recovery during exposure to natural and urban environments. J. Environ. Psychol. 11, 201–230.
United Nations Department of Economic and Social Affairs (Population Division), 2019. World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). United Nations, New York.
van den Berg, M., van Poppel, M., van Kamp, I., et al., 2016. Visiting green space is associated with mental health and vitality: a cross-sectional study in four european cities. Health Place 38, 8–15.
van den Berg, M.M., van Poppel, M., van Kamp, I., et al., 2019. Do physical activity, social cohesion, and Loneliness mediate the association between time spent Visiting green space and mental health? Environ. Behav. 51, 144–166.

van Duinen, L., Rijken, B., Buitelaar, E., 2016. Transformatiepotentie: woningbouwmogelijkheden in de bestaande stad. [Tranformation potential: possibilities for housing construction in the existing city. Planbureau voor de Leefomgeving, Den Haag.
van Wee, B., Ettema, D., 2016. Travel behaviour and health: a conceptual model and research agenda. J. Transport Health 3, 240–248.
Wang, Q., Li, L.J., 2021. The effects of population aging, life expectancy, unemployment rate, population density, per capita GDP, urbanization on per capita carbon emissions. Sustain. Prod. Consum. 28, 760–774.
Westerink, J., Haase, D., Bauer, A., et al., 2013. Dealing with sustainability Trade-Offs of the compact city in Peri-urban planning across European city regions. Eur. Plann. Stud. 21, 473–497.
WHO Regional Office for Europe, 2016. Urban Green Spaces and Health. A Review of Evidence. WHO Regional Office for Europe Copenhagen.
WHO Regional Office for Europe, 2019. Environmental Health Inequalities in Europe. Second Assessment Report. WHO Regional Office for Europe, Copenhagen.
Wolch, J.R., Byrne, J., Newell, J.P., 2014. Urban green space, public health, and environmental justice: the challenge of making cities 'just green enough'. Landsc. Urban Plann. 125, 234–244.
World Health Organization, 2004. Promoting Mental Health: Concepts, Emerging Evidence, Practice: Summary Report. World Health Organization.
World Health Organization, 2022a. Physical Activity.
World Health Organization, 2022b. World Mental Health Report: Transforming Mental Health for All. World Health Organization, Geneva.
World Health Organization, 2023. What Is Stress?.
Zijlema, W.L., Klijs, B., Stolk, R.P., Rosmalen, J.G., 2015. (Un)Healthy in the city: Respiratory, Cardiometabolic and mental health associated with urbanity. PLoS One 10, e0143910.
Zuidberg, J., 2021. Prijzen koopwoningen stijgen harder in de dure en meest stedelijke wijken. [Prices of houses rise steeper in the expensive and most urbanized neighbourhoods]. Esb 106, 504–507.