Towards modeling health effects of urban densification

A.H.P. Luijben, J. Hoekstra, A. Ruijsbroek

Contact: Guus.Luijben@rivm.nl

Aug 8, 2023

Paper Practitioner application

Summary

In this project, through an iterative process, a simulation model on health effects of densification of a municipality's sub-district was developed and, using that model, scenarios were developed. As input, we used a causal loop diagram developed in group model building workshops with experts on health and living environment. Moreover, we based the model on a municipality's classification of space use.

Introduction

The aim of this project is to develop a method to answer a municipality's complex question: how to make informed choices about city densification in a way that mental health of residents will not be damaged or even will be improved.

Problem Statement

- In the next 10 years many new houses will be built in the Dutch sub-district we study.
- It is expected that the construction of many new houses will lead to densification: more people will live in this sub-district.
- Densification will change the living environment of the inhabitants of the sub-district.
- The living environment can impact the mental health of resident both positively and negatively via the exposure to environmental factors.
- We do not yet know exactly how the mechanisms work in urban densification, since it sets different mechanisms in motion that may interact with one another.

Reference mode

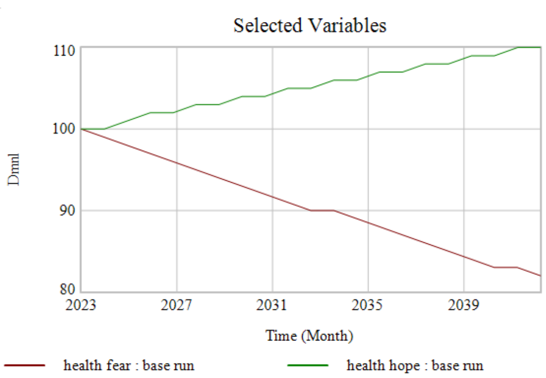

Figure 2: feared and wished change in future population health, by year.

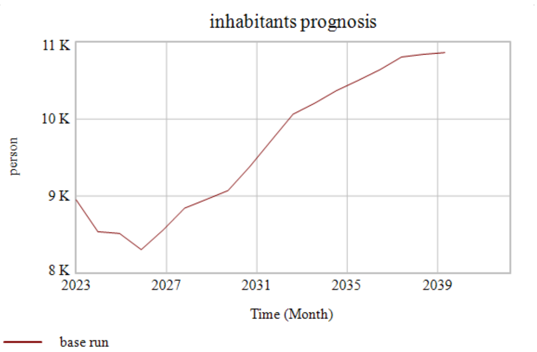

Figure 1: Prognosis of the number of inhabitants, by year.

Densification of the sub-district means that more people will have their home here. It is feared that population health will continuously decrease. It is hoped that ways will be found to increase population health.

Dynamic Hypothesis

Several theories link *environmental exposures* to chronic stress as a determinant for mental health problems:

1. *Environmental noise* increases when the number of inhabitants in a district increases (more nuisance from neighbors and traffic), when houses are demolished and when houses are built.
2. An increase in noise causes an increase in chronic stress.
3. If there is capacity for recovery, chronic stress gradually decreases. The decrease is reinforced by the presence of *public green space* in the living environment (Kaplan 1995). If the recovery capacity is small and public green space is absent, chronic stress remains high.
4. Recovery capacity increases with sufficient sleep. When sleep is insufficient (sleep quality poor), recovery capacity decreases.
5. Sleep deprivation increases and sleep quality decreases with prolonged high noise and with heat stress (Billings et al. 2020).
6. *Heat stress* arises when the temperature is high for a long time and the built environment retains a lot of heat (Wouters, 2017). More buildings in the district (high-rise for instance) means higher temperatures for a longer period.

Methods

We started by developing a simulation model of the dynamics of the spatial planning process (base model). To this base model, using the information from an expert based CLD, we added environmental factors related to mental health. This was a selection of the factors from the expert based CLD (Beenackers et al., 2023). The criterion in choosing these factors was the expected availability of data regarding the relationships between factors. We implemented the model in such a way that adding the remaining factors in the future is also possible.

With the simulation model we delivered, the effects of different scenarios on the health indicators chronic stress, recovery capacity and sleep (as determinants of mental health) can be estimated.

We chose to implement the simulation model as a System Dynamics model in Vensim. To feed data, we used an Access database.

Factors

We chose not to include all (32) factors from the CLD of the environment and health experts in the simulation model at once, because we estimated in advance that inclusion of all factors would not be possible within the time available. We have now included the following environmental and health factors in the model:

1. Chronic stress
2. Recovery capacity
3. Sleep quality
4. Heatstress
5. Noise
6. Public green space

These factors were connected to indicators of densification using the simplified CLD presented in Figure 3.

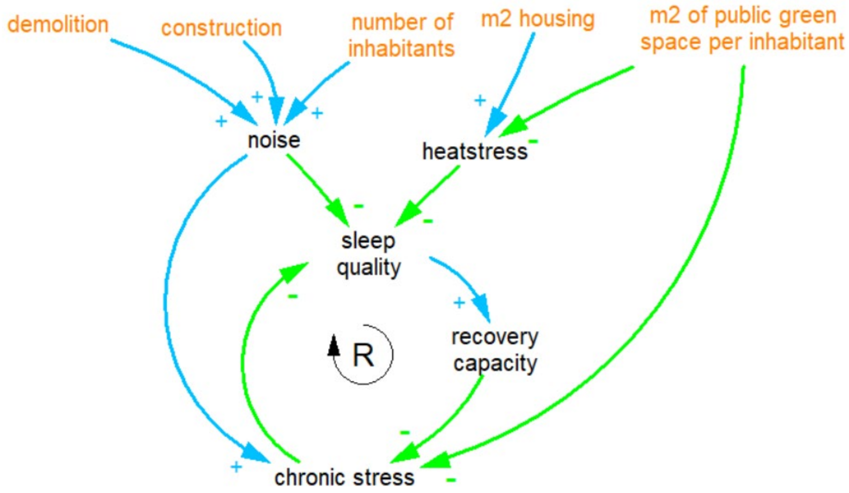

Figure 3: simplified CLD based on the CLD created with groups of experts on health and environment.

The model is structured in a way that allows other factors to be added in a subsequent version.

Three scenarios

By varying demolition and building of houses and public green space, we constructed three scenarios:

Degreen: 50% more houses, instead of green space

Dense: Demolish large houses; replace with smaller houses

High rise: Realizing high-rise buildings

These scenarios are fictitious and chosen as extremes in the diverse options of densification in existing residential areas.

Model

The goal of the model (Figure 4) is to estimate the effects of choices made in densifying a sub-district of a municipality in the Netherlands. A densification plan (in purple) is operationalized as building and demolishing both houses and public green spaces. The information used for input to the plan is a difference between the (future) health outcomes and desired health and the estimated and desired number of inhabitants in which implementation of the plan will result. Also, constraints, like e.g., available space and regulations or norms, are input to the plan.

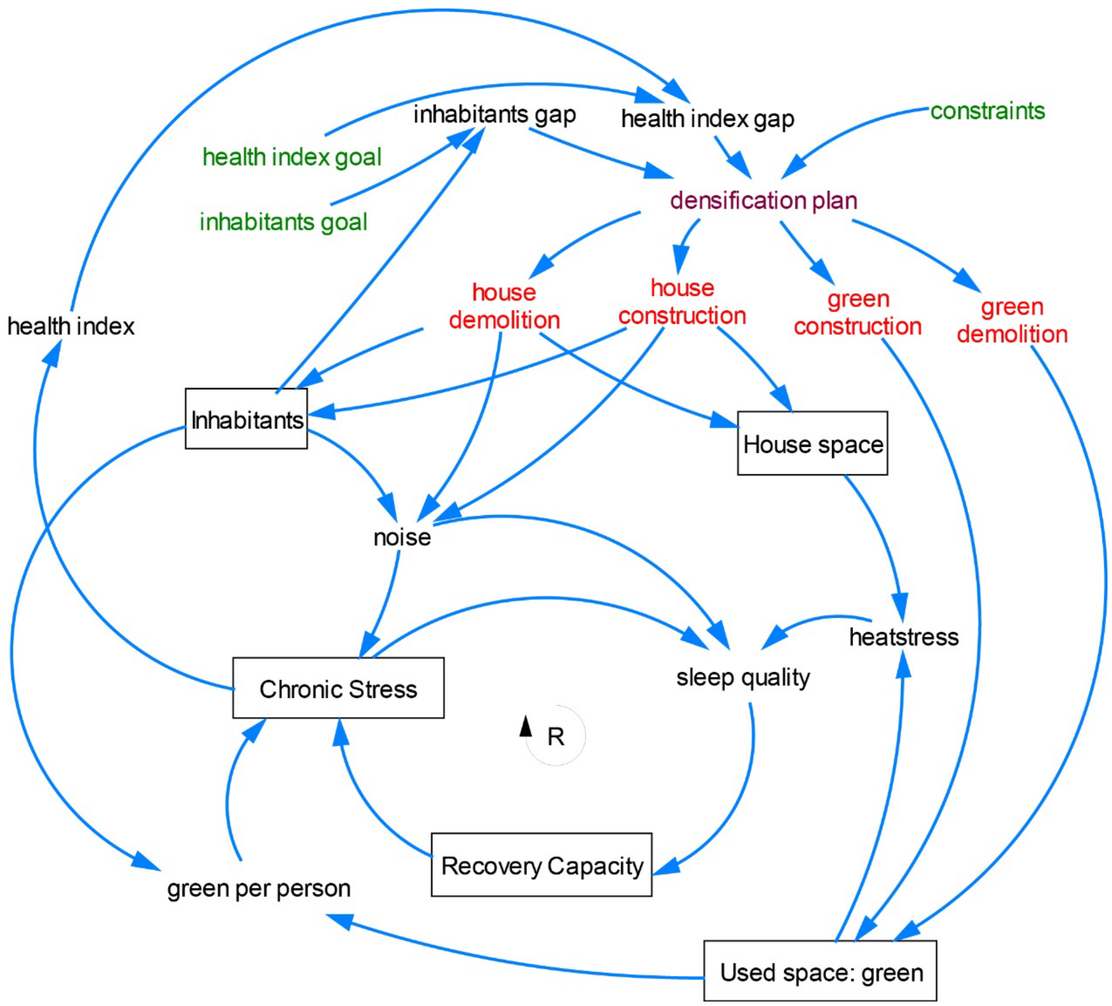

Figure 4: Simplified version of the model, variables that are modeled as stocks in the simulation model are indicated by a box.

The core of the model (Figure 4) consists of a reinforcing loop: between sleep via recovery capacity and chronic stress back to recovery capacity.

With an increase in household crowding and noise, these loops are reinforced (via an increase in chronic stress). An increase in heat stress also contributes to an increase in sleep deprivation. An increase in public green space will lower chronic stress.

There is a feedback loop between chronic stress, sleep deprivation and recovery capacity and between chronic stress and recovery capacity. There are no other feedback loops in the model.

The indicator of mental health in this version of the model is limited to (absence of) chronic stress. To make comparisons easier an index of this factor has been defined.

We implemented densification plans as scenarios. The densification plans and associated information feedback were not part of the model. This resulted in the model shown in simplified form in Figure 5.

Input into this model are the scenarios that represent choices in terms of building and demolishing houses and green space. Output is the number of inhabitants and the health index.

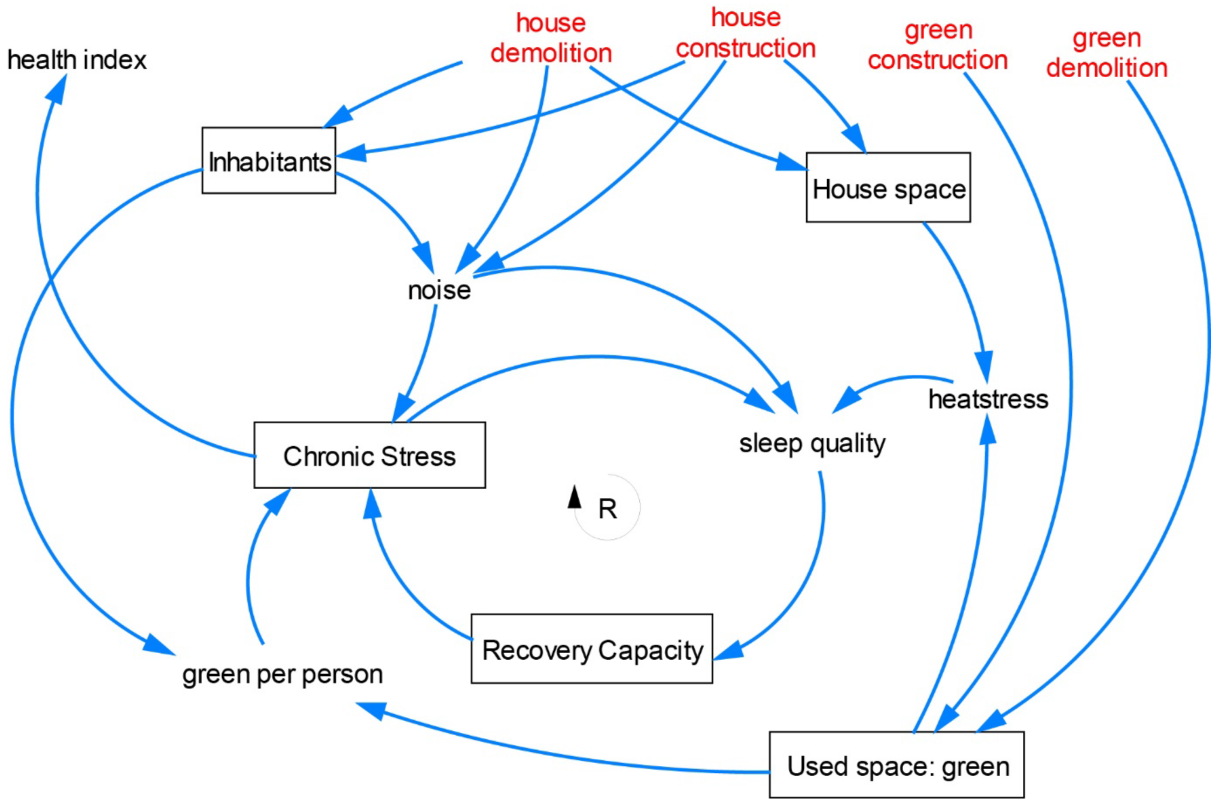

Figure 5: Simplified version of the model without densification plan, variables that are modeled as stocks in the simulation model are indicated by a box.

Results

Three scenarios were used as inputs to the model. We compared the effects of the scenarios on the number of residents and the mental health of subdistrict residents.

Number of inhabitants

The targeted increase, of 21% over 17 years, in the subdistrict's population is achieved in all three scenarios. The three scenarios differ in the rate of growth. In the 'Degreen' scenario, the targeted population is reached in 2034, while in the 'High Rise' and 'Dense' scenarios in 2037. Because of the demolition of houses in the Dense and High-Rise scenarios, the population decreases in the first 4 years. In 'Degreen', green public space is used for new construction and no houses are demolished. Therefore, the 'Degreen' scenario has no decline in population.

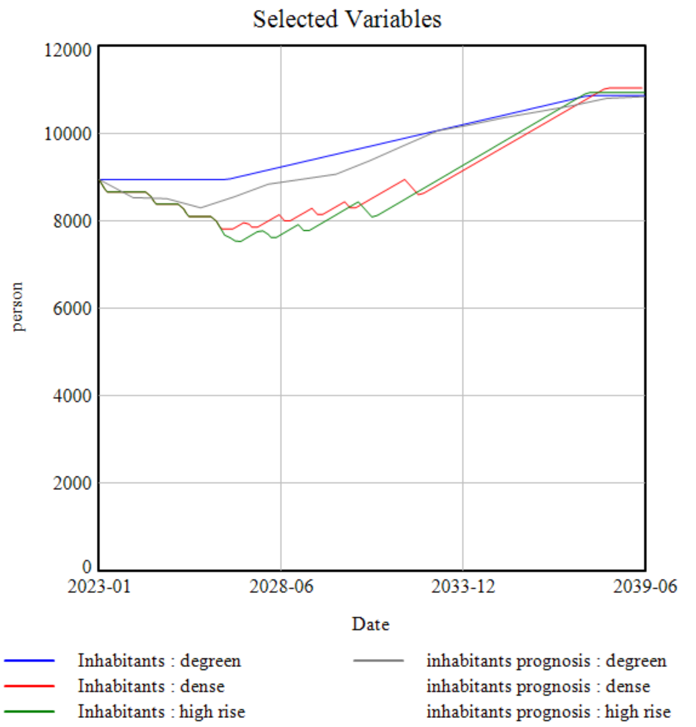

Figure 6: The number of inhabitants over time, according to three scenarios and the prognosis

Health index

Noise resulting from demolition and construction activities, the reduction of public green space, crowding and heat stress are expected to have a negative impact on residents' health.

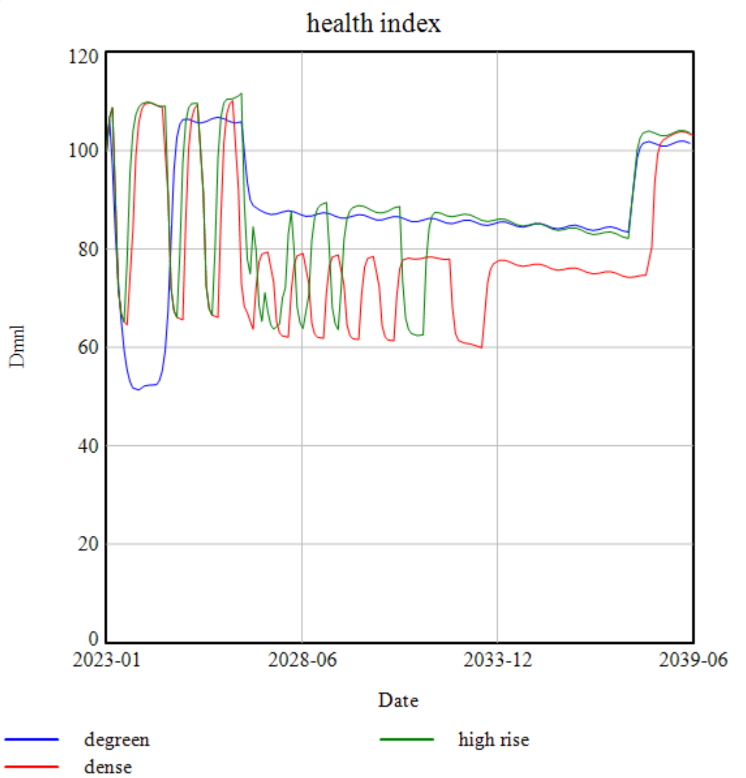

Figure 7: Health index over time, in three scenarios

Figure 7 shows the health index over time in the three scenarios. This figure shows that Health will deteriorate in every scenario. In all scenarios periods with lower and higher health will alternate. If part of the public green space is sacrificed (scenario degree, blue line), this will lead to deteriorating health within a few months. In the other two scenarios, some of the population will move in the first few months because the houses they live in will be demolished. Because of a reduction in population, this will lead to an increase in health. When the demolition period arrives, health will decrease. Until and including this period of construction, every year a period of heat stress will lead to deteriorated health. When new houses are built there will again be more public green space, better houses, and less heat stress.

Discussion

To match the information used in making policy choices, we based the model on the municipality's classification of space use. In retrospect, this made the model very detailed and made studying its behavior difficult.

In a subsequent iteration, simplification of the model is needed on the one hand, and, on the other hand, expansion with additional factors (such as social cohesion, for example) on the other, and more precise modeling of the health part is desirable.

Conclusions

We have demonstrated that it is possible to develop a system dynamics model that can inform policy choices. System dynamics modeling contributes to the understanding of the dynamics of densification and the possibilities to influence the effects on health. Possible additions to the model were identified. Additional interaction with stakeholders and experts will be needed to improve the understanding of specific health effects of densification

References

M.A. Beenackers, H. Kruize, L. Barsties, A. Acda, I. Bakker, M. Droomers, C.B.M. Kamphuis, E. Koomen, J.E. Nijkamp, L. Vaandrager, B. Volker, A.H.P. Luijben, A. Ruijsbroek (2023, submitted). Urban densification in the Netherlands and its impact on mental health: an expert-based causal loop diagram.

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,* 2(1), pp. 378–401. DOI: https://doi.org/10.5334/bc.125

Billings, M. E., Hale, L., & Johnson, D. A. (2020). Physical and Social Environment Relationship With Sleep Health and Disorders. *Chest*, *157*(5), 1304–1312. https://doi.org/10.1016/j.chest.2019.12.002

Kaplan, S (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology*, 15(3), pp. 169-182

Wouters, H., et al. (2017), Heat stress increase under climate change twice as large in cities as in rural areas: A study for a densely populated midlatitude maritime region, Geophys. Res. Lett., 44, 8997-9007, https://doi.org/10.1002/2017GL074889