DOCTORAL THESIS NO. 25

Making space for resilient urban well-being

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UNIVERSITY OF GÄVLE

Gävle University Press

Dissertation for the Degree of Doctor of Philosophy in Geospatial Information Science to be publicly defended on Friday 10th of December 2021 at 13:00 in Krusenstjernasalen, University of Gävle.

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Gävle University Press
ISBN 978-91-88145-79-6
ISBN 978-91-88145-80-2 (pdf)
urn:nbn:se:hig:diva-27137

Distribution:
University of Gävle
Faculty of Engineering and Sustainable Development
Department of Computer and Geospatial Sciences
SE-801 76 Gävle, Sweden
+46 26 64 85 00
www.hig.se

Svanenmärkt trycksak, 3041 0736 Kph Trycksaksbolaget 2020

Abstract

This thesis addresses the need for urban landscapes that provide resilient contributions to inhabitants' well-being while also limiting impacts on the Earth system. It aims to (1) advance a nuanced understanding of how urban environments relate to urban dwellers' well-being, and (2) formulate guidelines for planning that supports urban dwellers' well-being and align with global sustainability. The thesis consists of five empirical studies of Swedish and Danish urban landscapes in which day-to-day experiences and mental disorders were studied as different components of well-being. A variety of spatial and statistical analysis methods were leveraged, including public participation geographic information systems, remote sensing, deep learning, accessibility analysis, and spatial regression.

Results convey that urban environments relate to well-being in substantial ways, but these map poorly onto the simplistic urban-nature or urban-rural dichotomies that dominate current discourse. Support of well-being instead seems to depend on spatial conditions comprised of the street network's topological configuration, the population distribution, and the accessibility of natural settings. Since the 1990s, contrasts have intensified between stressful urban cores that are increasingly full of people and peripheral areas that are "left behind" and high-risk in terms of mental illness. Results show that urban neighbourhoods could contribute to well-being through fulfilment of three guidelines: (1) a balance of residential and daytime populations, (2) no extreme concentration of movement, and (3) accessible natural settings. Strategies in accordance with the guidelines can increase so-called *topodiversity*, which refers to variation in spatial conditions across an urban landscape that permits support of well-being through different pathways. Increasing topodiversity in both central and peripheral areas could improve urban landscapes' ability to resiliently support well-being.

Keywords: subjective well-being, affordances, social-ecological urbanism, urban resilience, geographic information system, depression, densification, complex adaptive system, spatial planning, green-blue infrastructure

Sammanfattning

Denna avhandling utgår från behovet av stadslandskap som på ett robust sätt stödjer invånarnas välbefinnande samtidigt som de minskar städers belastning på planeten. Den syftar till att (1) främja en nyanserad förståelse av hur stadsmiljöer relaterar till invånarnas välbefinnande, samt (2) att formulera riktlinjer för stadsplanering som avser att stödja stadsinvånares välbefinnande och samtidigt inte äventyrar global hållbarhet. Avhandlingen består av fem empiriska studier av svenska och danska stadslandskap i vilka vardagliga upplevelser och psykisk ohälsa studerades som olika delar av välbefinnande. I studierna används rumsliga och statistiska analysmetoder, så som public participation GIS, fjärranalys, deep learning, tillgänglighetsanalys, samt rumslig regression.

Avhandlingen visar att stadsmiljöers kopplingar till välbefinnande är betydande, men att de överensstämmer illa med de förenklade och ofta använda uppdelningar så som stad-natur eller stad-landsbygd. Stöd av välbefinnande verkar istället bero på rumsliga förutsättningar som utgörs av gatunätverkets topologiska sammansättning, befolkningens fördelning, samt naturområdens tillgänglighet. Sedan nittiotalet har en polaritet uppstått mellan å ena sidan alltmer tätbefolkade stadskärnor som upplevs som stressiga och områden i städernas utkanter som ”lämnas i sticket” och som innebär hög risk för mental ohälsa. Resultaten visar att stadsmiljöer kan bidra till välbefinnande om de på områdesskala uppfyller tre riktlinjer: (1) en balans av boende och dagbefolkning, (2) ingen extrem koncentration av folkflöden, samt (3) tillgängliga naturområden. Strategier i enlighet med de tre riktlinjerna kan öka s.k. *topodiversitet,* som avser variation i rumsliga förutsättningar över ett stadslandskap som tillåter att välbefinnande stöds genom olika processer. Ökad topodiversitet i både centrala och perifera områden kan förbättra stadslandskapets förmåga att robust stödja välbefinnande.

Nyckelord: subjektivt välbefinnande, affordance, social-ekologisk stadsbyggnad, urban resiliens, geografiska informationssystem, depression, förtätning, komplexa adaptiva system, grön infrastruktur

Acknowledgements

The main funder of this work was Formas, a Swedish research council for sustainable development, through the project Spatial and Experiential Analyses for Urban Social Sustainability (ZEUS, project number 2016-01193). Additionally, funding was received from University of Gävle and from Future Position X through the project Better life quality through Integrative GIS (BIG project).

List of papers

The thesis is based on the following papers.

Paper 1
Samuelsson, K., Giusti, M., Peterson, G.D., Legeby, A., Brandt, S.A., & Barthel, S. (2018). Impact of environment on people's everyday experiences in Stockholm. *Landscape and Urban Planning* 171: 7-17. doi: 10.1016/j.landurbplan.2017.11.009

Paper 2
Chen, T.H.K., Samuelsson, K., Thisted Horsdal, H., Closter, A.M., Barthel, S., Böcker Pedersen, C., Prishchepov, A.V., & Sabel, C.E. (manuscript). Three-dimensional urban structure and residential mobility correlate with the risk of developing mental disorders: a follow-up study.

Paper 3
Samuelsson, K., Chen, T.H.K., Antonsen, S., Brandt, S.A., Sabel, C., & Barthel, S. (2021). Residential environments across Denmark have become both denser and greener over 20 years. *Environmental Research Letters* 16: 014022. doi: 10.1088/1748-9326/abcf7a

Paper 4
Samuelsson, K., Colding, J., & Barthel, S. (2019). Urban resilience at eye level: Spatial analysis of empirically defined experiential landscapes. *Landscape and Urban Planning* 187: 70-80. doi: 10.1016/j.landurbplan.2019.03.015

Paper 5
Samuelsson, K., Barthel, S., Giusti, M., & Hartig, T. (2021). Visiting nearby natural settings supported wellbeing during Sweden's "soft-touch" pandemic restrictions. *Landscape and Urban Planning* 214: 104176. doi: 10.1016/j.landurbplan.2021.104176

Contributions to the papers

For Paper 1, Paper 4, and Paper 5, I coordinated the research team, designed the research with input from co-authors, acquired the data together with Matteo Giusti and Stephan Barthel, performed the analysis, interpreted the results together with co-authors, wrote most of the paper, and did most of the revisions. For Paper 2, I provided input on research design and analysis, interpreted the results together with co-authors, and wrote some of the paper. For Paper 3, I coordinated the research team, designed the research with input from co-authors, acquired the data together with Tzu-Hsin Karen Chen and Sussie Antonsen, performed the analysis together with Tzu-Hsin Karen Chen,

interpreted the results together with co-authors, wrote most of the paper, and did most of the revisions.

Publications outside the thesis

Giusti, M., & Samuelsson, K. (2020). The regenerative compatibility: A synergy between healthy ecosystems, environmental attitudes, and restorative experiences. *PLoS ONE* 15(1): e0227311. doi: 10.1371/journal.pone.0227311

Samuelsson, K., Barthel, S., Colding, J., Macassa, G., & Giusti, M. (2020) *Urban nature as a source of resilience during social distancing amidst the coronavirus pandemic*. OSF preprints. doi: 10.31219/osf.io/3wx5a

Colding, J., Wallhagen, M., Sörqvist, P., Marcus, L., Hillman, K., Samuelsson, K., & Barthel, S. (2020) Applying a systems perspective on the notion of the smart city. *Smart Cities* 3(2): 1-10. doi: 10.3390/smartcities3020022

Colding, J., Barthel, S., & Samuelsson, K. (2020) Supporting Bottom-Up Human Agency for Adapting to Climate Change. *One Earth* 3(4): 392-395. doi: 10.1016/j.oneear.2020.09.005

Linder, N., Giusti, M., Samuelsson, K., & Barthel, S. (2021) Pro-environmental habits: An underexplored research agenda in sustainability science. *Ambio*. https://doi.org/10.1007/s13280-021-01619-6

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Introduction

For most of human history, the Earth's surface was an unlimited expanse, but recently things have changed. In the 19th and 20th centuries, lands shaped by human activity far outgrew the wild lands on the planet (Ellis, Goldewijk, Siebert, Lightman, & Ramankutty, 2010). In the 21st century, as we make space for a still growing global population we find, first, that those increasingly rare wild and semi-wild lands are of immense importance for sustaining human civilization (Balmford et al., 2002; Millennium Ecosystem Assessment, 2005), and second, that the lands that house humans – towns and cities – have started competing for space on a globally relevant scale with farmlands (Bren d'Amour et al., 2017) and forests (Seto, Güneralp, & Hutyra, 2012). An accelerating urbanization in this century risks setting in motion chains of land use displacement with unforeseeable impacts on the Earth system (Barthel et al., 2019). The planet has never seemed smaller.

With increasing awareness of the detrimental impacts of sprawling urban development, a view emerged in the 1990s of compactness as the hallmark of sustainable urban form and densification (or alternatively intensification, compaction or infill development) as the process by which to turn dispersed urban landscapes compact (Jenks, Burton, & Williams, 1996; McLaren, 1992). Proponents argued that densification saves rural land from development, achieves more energy-efficient transportation and buildings, and provides a more varied and liveable environment for its inhabitants (Jabareen, 2006). The strategy was consequently taken up widely by planning authorities in Western industrialised societies. By now, scientific evidence in favour of densification is clear-cut regarding building energy savings (Creutzig, Baiocchi, Bierkandt, Pichler, & Seto, 2015; Güneralp et al., 2017) and halting encroachment on agricultural land (Bren d'Amour et al., 2017; Güneralp, Reba, Hales, Wentz, & Seto, 2020) and valuable ecosystems (Seto et al., 2012; Stott, Soga, Inger, & Gaston, 2015). These results show that continued urban sprawl in the 21st century must be avoided to mitigate climate change and the sixth mass extinction.

However, the validity and generalisability of often claimed social and well-being benefits with densification have been contested (Dempsey, Brown, & Bramley, 2012; Gren, Colding, Berghauser-Pont, & Marcus, 2019; Haaland & Konijnendijk van den Bosch, 2015; Neuman, 2005). Compact urban environments become heat islands (Chun & Guldmann, 2014) where mortality is higher during extreme heat events (Tan et al., 2010). Noise pollution is a major health concern in cities (Goines & Hagler, 2007; Passchier-Vermeer & Passchier, 2000) that could be implicated in the development of obesity (Pyko et al., 2017). Air pollution, which is estimated to cause 9 million deaths per year globally through cardiovascular and respiratory diseases (Lelieveld et al., 2020), is worse in high-density environments (Borck & Schrauth, 2021).

Associations between chronic exposure to air pollution and biological ageing has been observed already at primary school age (Hautekiet et al., 2021), which strikingly suggests that people age faster in dense urban environments. While densification often increases accessibility to local services (Dempsey et al., 2012), associations between density and social outcomes like social interaction and neighbourhood satisfaction have proven to be divergent and context-sensitive (Dempsey et al., 2012; Kyttä, Broberg, Haybatollahi, & Schmidt-Thomé, 2016; Kyttä, Broberg, Tzoulas, & Snabb, 2013; McCrea & Walters, 2012). One area that has received increasing attention is inhabitants' interaction with natural settings. In Europe, compact cities have less per capita greenspace (Fuller & Gaston, 2009) and infill development can incrementally decrease greenspace extent (Haaland & Konijnendijk van den Bosch, 2015). Greenspace supports urban inhabitants' health by way of mitigation (reducing exposure to noise, pollution, and heat), instoration (encouraging physical activity) and restoration (cognitive and psychophysiological recovery) (Markevych et al., 2017). The restoration pathway has received particular attention because psychological restoration is increasingly recognised as indispensable for coping with the stress of urban life (Hartig & Kahn, 2016), and greenspace exposure might safeguard mental health (Alcock, White, Wheeler, Fleming, & Depledge, 2014; Beyer et al., 2014; van den Berg, Maas, Verheij, & Groenewegen, 2010). One meta-analysis reported higher prevalence of depression in cities as compared with rural areas (Peen, Schoevers, Beekman, & Dekker, 2010), but another meta-analysis did not find this association (Lim et al., 2018). It is possible that different mechanisms of similar magnitude are at work in different environments. Intriguing partial evidence points towards the possibility that environmental gains from less energy-intensive day-to-day travel in dense environments is counter-acted by more energy-intensive leisure travel, but more precise environmental measurements are needed to untangle the relationships (Czepkiewicz, Heinonen, & Ottelin, 2018). In summary, these results show that densification is not a satisfactory alternative to sprawl if it is sweepingly and mindlessly applied.

For achieving sustainability, the planetary environmental emergency and human well-being cannot be separated (United Nations Environment Programme, 2021). This thesis addresses the need for creating urban landscapes that are healthy habitats for humans to live in while also mitigating impacts on the Earth system. In addition, the well-being benefits they deliver for their inhabitants need to be resilient, meaning that the benefits are maintained in the face of disturbance through adaptation or transformation (Meerow, Newell, & Stults, 2016). If neither sprawl nor densification is planning paradigms fit for this challenge, what principles could then guide 21st century urban planning? I adopt a spatial approach to this issue because despite the evidence above illustrating conflicting suggestions for how urban environments should be spatially organised, urban sustainability discourse remains dominated by typologies representing complete spatial monotony void of the complexity of real urban environments (Berghauser Pont, Stavroulaki, & Marcus, 2019a). The work to resolve these conflicts rests on spatial analysis

that with some higher degree of refinement incorporates the psychological and social processes that play out across urban landscapes.

The thesis summary is organised in the following way. The *Aims and research questions* are stated below. Then, the section *Urban landscapes and well-being as complex adaptive system* provides an account of the theoretical underpinnings and conceptual operationalisations of the thesis in three sub-sections that deal with (1) humans' interaction with their environment, (2) humans' social interactions in space, and (3) resilience of complex adaptive systems. The *Methods* section presents an overview of the methodological approach before introducing the study sites, datasets, and analysis methods. The *Results* section presents the empirical work of the thesis, first by summarising the five papers it is comprised of, and then by answering each of the thesis' three research questions. In the *Discussion* section, I consider in five sub-sections (1) the limitations of this work, (2) how subjective well-being and mental health relate to urban environments differently, (3) topodiversity, a potential organising concept for urban planning for resilient urban well-being, (4) methodological development for research and practice, and (5) emerging questions that are sparked by this and other recent work. I end with some concluding remarks in the *Conclusions* section.

Aims and research questions

This thesis seeks to be of theoretical and practical relevance to the research community and urban planners and designers by focusing on two aims. First, to advance a spatially and psychologically nuanced understanding of how urban environments relate to urban dwellers' well-being, as indicated by day-to-day experiences and mental health. Second, to develop analytic methods and formulate guidelines for urban spatial planning and design intending to support urban dwellers' well-being while aligning with global sustainability pursuits.

To reach the aims, the thesis addresses the following questions:

RQ1 How do urban environments relate to urban inhabitants' well-being, as indicated by day-to-day experiences and mental health?

RQ2 What is characteristic of urban environments that provide resilient support of well-being while also aligning with global sustainability pursuits?

RQ3 How do long-term patterns of population density change relate to changes in urban landscapes' ability to support well-being?

The questions are addressed in five papers that vary the outcome of focus between day-to-day experiences, mental health and urban landscapes, as well as the timescale at which it is studied (Figure 1).

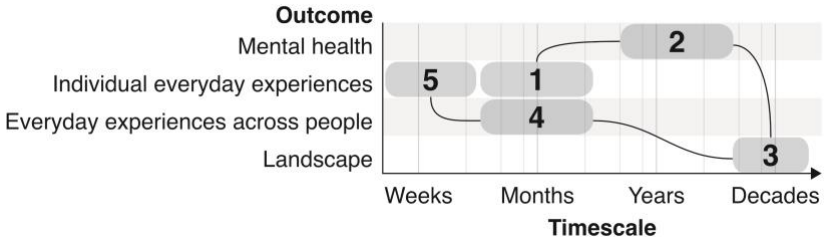

Figure 1. Outcome of focus and the timescale at which it is studied varies between the five papers in this thesis, to together answer the research questions of the thesis. The numbers denote the order that the papers are presented in the thesis.

Demarcations

The urban environment is far from the only element to consider for fully understanding urban inhabitants' well-being. Other elements include education, social justice, local democracy, community, social networks, employment and culture (Dempsey, Bramley, Power, & Brown, 2009). For a practicable system demarcation, this thesis does however only engage with these issues to the extent that they intersect with the spatial analyses. Public participation geographic information systems (PPGIS), a method that this thesis relies on, holds promise for enhancing local participatory planning (Kahila-Tani, Broberg, Kyttä, & Tyger, 2015), but as the focus here is on how environments relate to well-being rather than how urban inhabitants can shape their environment, participatory planning will also not be thoroughly discussed.

Urban landscapes and well-being as complex adaptive system

Body and mind

"We need more well-toned, well-regulated nervous systems in our world."

(Shukman, 2021)

The last decades of the 20th century saw a new paradigm in psychology and neuroscience challenge the Cartesian view of the mind as a "disembodied logical reasoning device" (Clark, 1998, p. 1). Instead, the mind came to be seen as an emergent requisite for a body to function (Wilson, 2002). On this view, the body seeks to perform adaptive behaviour, meaning behaviour enhancing possibilities for survival and reproduction, which depends on feedback between the nervous system (of which the brain is a part), the rest of the body, and the environment (Chiel & Beer, 1997). The mind is a generative model of the world it inhabits, with perception and action as its fundamental components (Friston, 2010). The mind constantly generates predictions of the near future (Bar, 2007), where perception is for optimising predictions whereas action is for manipulating sensory input (Friston, 2010). Clark (1999) remarks that the embodied paradigm also acknowledges abstract cognition decoupled from the environment, but that unlike the disembodied paradigm it does not presuppose divisions between brain, body and environment. In fact, examples abound when abstract cognition makes use of sensorimotor simulation, suggesting that structures originally evolved for perception and action are "co-opted" by cognition (Buzsáki & Moser, 2013; Wilson, 2002).

The intimate link between perception and action is central to ecological psychology. Ecological psychology holds the primary objects of experience to be action possibilities that are manifested in the perceptual field and known as affordances (Gibson, 1986). Affordances are relations between abilities of the perceiving organism and features of a situation that is specific in time and space, affording the organism a certain behaviour in that situation (Chemero, 2003). Not only perception and action are involved in making predictions about the situation, but also analogies drawing on accumulations of past experience (Bar, 2007). This allows humans to turn a continuous stream of stimuli into discrete events, with event boundaries perceived at the time points when errors in prediction arise (Zacks, Speer, Swallow, Braver, & Reynolds, 2007). In this thesis, I take the countable form of the word experience to refer to such an event, meaning that an *experience* as used here is a psychological demarcation of a situation that can feature many affordances. Events are encoded in event memory (Zacks, 2020), often slightly distorted to fit with past experience (Heusser, Fitzpatrick, & Manning, 2021), creating world models that are somewhat path dependent but at the same time subject to change throughout the life-course.

Well-being, as used in this thesis, means a state of being in a person or among a group of people that is intrinsically valuable relative to that person or group. This conception is often called subjective well-being, a term that has grown in popularity to differentiate momentary psychological states, life satisfaction, and sense of purpose from traditional well-being measurements like fulfilment of fixed needs (e.g. food and shelter) and wants and desires (for which GDP or wealth is often used as a proxy) (Dolan & Metcalfe, 2012). Experiences can be indicators of momentary subjective well-being because they have an affective dimension, and subjective well-being encompasses both positive and negative affect (Burns, Anstey, & Windsor, 2011). I use subjective well-being to solely refer to its momentary aspect and as an experiential outcome, excluding life satisfaction and sense of purpose.

Perceived environmental threats to well-being cause a stress response called allostasis involving complex neurotransmitter and hormone release patterns that unfold on timescales from a few seconds to several hours (Kemeny, 2003; Sapolsky, Romero, & Munck, 2000). Appraisal of a situation in terms of its significance for well-being greatly influences the magnitude of the stress response; factors in humans as well as other animals that have been particularly highlighted are perceived threats to control and social evaluation (Dickerson & Kemeny, 2004; Evans & Lepore, 1992; Kemeny, 2003). Recovery from the stress response can happen in environments where these stressors are absent, and entail shifts towards both more positive affective states (Ulrich et al., 1991) and restored cognitive functioning (Kaplan, 1995). Frequent inability to recover from allostasis leads to allostatic load which is implicated in a wide range of mental and physiological pathologies (McEwen, 1998). For example, depressive and anxiety disorders, that are in this day and age among the leading causes of years lived with disability across the world (Ferrari et al., 2013; Lim et al., 2018; Whiteford, Ferrari, Degenhardt, Feigin, & Vos, 2015), can result from chronic allostatic load that cause an inability to correctly appraise environmental stressors (McEwen, 2003; Sapolsky, 2000). Importantly, subjective well-being and mental health are different well-being dimensions. While both positive and negative affect relates to depression and anxiety (Burns et al., 2011; Panaite, Rottenberg, & Bylsma, 2020), they are momentary phenomena while mental disorders can be thought of as self-perpetuating states of interacting symptoms (Borsboom, 2017).

Space and social life

> *"The world is giving us so much abstract information because we have put our mind in the world. […] We have not only designed the world, we have diagrammed it."*
>
> (Tversky, 2019)

Space is fundamental for humans' perception, action and cognition, because interacting with it is required for adaptive behaviour (Wilson, 2002). An important mental representation of space is the hippocampus' cognitive map that contains place cells (Epstein, Patai, Julian, & Spiers, 2017). Place cell

interaction underpins navigation by encoding the topological structure of space, meaning which spaces are connected with which (Wu & Foster, 2014). This activity is supported by processes in the visual cortex that continuously extract navigational affordances, or in other words possibilities to traverse the environment (Bonner & Epstein, 2017). Acting on a navigational affordance often entails transitioning from one psychological event to the next (Javadi et al., 2017; cf. Zacks et al., 2007). I use *place* in this thesis to mean a space that can be perceived as a unit and encapsulated in such an event, or in more everyday terms a space that is coherently experienced. When moving between places in a city, parts of the hippocampus track changes in the number of current navigational affordances (local topology), while other parts track the current place's prominence in the global network (global topology) (Javadi et al., 2017). That topology overshadows Euclidian distance in importance for spatial navigation might at first seem counterintuitive, but makes perfect sense if visual perception is actually perception of action potential (Gibson, 1986), because it is the topology that dictates potential for moving to other places. Even though supporting evidence in neuroscience has amassed fairly recently, support from naturalistic observations of humans in cities has been around for decades (Hillier, Penn, Hanson, Grajewski, & Xu, 1993). Topologically central places will more often than others fall on the "cognitively cheap" routes between destinations (which are often, but not always, among the shortest in Euclidian distance), thus facilitating co-presence of humans there (Penn, 2001). On the aggregate level, this is reflected in the number of pedestrians in places being highly predictable by the spatial configuration of the network, meaning the relative topological properties of places in relation to all other places in the network (Hillier, 1996).

The coupling between spatial order and social structure is fundamental to how human settlements come about, grow and function (Hillier & Hanson, 2009). The purpose of cities is to facilitate interaction between a lot of people (Batty, 2012), for which the space between buildings – streets, alleys and squares – is the medium (Hillier & Hanson, 2009). The space that facilitates economic and social exchange can be thought of as a "foreground network" set against the "background network" of mainly residential space (Hillier, 2009). Human interactions within cities scale exponentially with city population size (Schläpfer et al., 2014), so that large cities facilitate complex coordination of knowledge (Balland et al., 2020) and innovation also scales exponentially with population size (Arbesman, Kleinberg, & Strogatz, 2009; Bettencourt, Lobo, Helbing, Kühnert, & West, 2007). Yet, larger cities also quite literally harbour a higher pace of life, as captured for example in average walking speed (Bornstein & Bornstein, 1976). The idea that the social lives of urbanites is more fragmented and perfunctory than those of their rural counterparts has been around at least since the early 20th century (Simmel, 2002), if not for millennia (Aurelius, 2003). The impersonal quality to specifically urban behaviours has been argued to be a consequence of adaptation to overload (Milgram, 1970) as humans do not have the cognitive capacity to invest in all human interactions a city presents them with (Dunbar, 2020). Urban environments can instead be perceived as threatening control (Evans & Lepore,

1992) and presenting constant social evaluation (Van Os, Kenis, & Rutten, 2010) – precisely the environmental factors that increase the probability of a stress response in people (see section *Body and mind* above). A link between city living and stress processing has been experimentally confirmed (Lederbogen et al., 2011), possibly explaining why pathologies related to allostatic load, like depression and anxiety disorders, have by some been found to be more common in cities as compared with rural areas (Peen et al., 2010). Recent decades have seen a surge of research into urban restorative environments that can reduce allostatic load, where urban natural settings has been the most prominent area (among others, Berman, Jonides, & Kaplan, 2008; Berman et al., 2012; Hartig, Mitchell, de Vries, & Frumkin, 2014; MacKerron & Mourato, 2013; Markevych et al., 2017; van den Berg, Hartig, & Staats, 2007). Such settings can be thought of as part of the background network.

The interplay between spatial order and social structure reveals generalities in city growth. However, cities can be wildly different from each other because they have not grown in an abstract space but on the Earth's surface, which is physically and culturally non-uniform. This highlights the need to complement efforts to strip down urban processes to replicable laws with attention to holistic and contextual properties. This approach is commonplace in geography, where the tension between differentiation and generalization is long-standing (Goodchild & Li, 2021). Goodchild & Li (2021) argue for adherence to what they term "weak replicability" in the geographic domain, meaning that its principles or models should be partly replicable in space and time. The research designs of this thesis attempt to leverage weak replicability. To highlight contextuality, I use the word *landscape* to encapsulate a spatial continuum of all places in a city, both its foreground network and its background network. The terms landscape and place thus contain an implicit emphasis on psychological and social processes happening on the Earth's surface, as compared with the more stripped-off term *space*.

Resilience

> *"If engineers had designed evolution, it would still be perfectly replicating bacteria. […] [We] need to embrace robustness as the first principle beyond perfection."*
>
> (Kellis, 2020)

The places in a city where more people move are more attractive for locating businesses, making even more people move there (Hillier et al., 1993). The number of people being co-present in places in turn influence people's experiences. On the individual level, an experience of a situation is conditioned on past experiences (Bar, 2007) while also being encoded in memory in order to interpret future experiences (Zacks, 2020). On the collective level, shared experiences can turn into norms or formalised management institutions for intrapersonal behaviour that further increase the capacity for people to share space (Milgram, 1970). These phenomena describe a complex web of

interacting feedbacks that exemplify how cities are emergent complex adaptive systems (Batty, 2008). In complex adaptive systems, patterns at higher levels emerge from localized interactions (Levin, 1998), such as when economic activity or social atmosphere in a neighbourhood emerge from many individuals moving and acting within it. Emergent macro-scale phenomena then exert influence on local agents in cross-scale interactions (Levin et al., 2013), as when collective behaviour influences an individual's experience.

Feedbacks make the development of a complex adaptive system path dependent (Levin, 1998). When feedbacks create inertia in a system, they endow it with *resilience* (Holling, 1973), here taken as the capacity of the system to absorb disturbance and potentially reorganize so as to retain its central functions and dynamics (Walker, Holling, Carpenter, & Kinzig, 2004). To further understand the resilience of complex adaptive systems, three kinds of variable can be distinguished: i) state variables, that describe the central functions of the system, ii) slow variables, that are slower to change than state variables and determine how state variables respond to disturbance, and iii) drivers, that are external to the system and influence slow and state variables but are not influenced by them (Walker, Carpenter, Rockstrom, Crépin, & Peterson, 2012). If a system is not resilient against disturbance, it can pass a threshold and undergo a critical transition that abruptly alters the system state by activating novel dynamics (Scheffer, Carpenter, Foley, Folke, & Walker, 2001). Management of complex adaptive systems has to determine what system states are desirable or undesirable (Carpenter, Walker, Anderies, & Abel, 2001) in order to avoid critical transitions away from desirable states or to undermine the resilience of undesirable states (Elmqvist et al., 2019). Critical transitions are notoriously difficult to predict because erosion of the system's resilience is often not visible before a threshold is crossed (Scheffer et al., 2012). Yet, research has identified some structural features of systems that determine resilience. Biggs, Schlüter, & Schoon (2015) draw on social-ecological systems research to propose feedbacks between system components, their diversity, and their connectivity as three system features that should be managed to increase resilience of desirable system states. More specifically, the diversity that matters for resilience is functional redundancy in combination with diversity in responses to disturbance (Kotschy, Biggs, Daw, Folke, & West, 2015). Gao, Barzel, & Barabási (2016) use mathematical analysis to corroborate the importance of connectivity and feedbacks, where resilient connectivity implies varying number of connections between components and redundancy of these connections.

Urban resilience is the ability of an urban system to maintain desired functions in the face of disturbance, to adapt to change, and to transform parts of the system that limit adaptive capacity (Meerow et al., 2016). History has proved cities to often be remarkably resilient (Batty, 2008). Yet, the long-term perspective also provides accounts of how slowly eroding resilience can interact with exogenous disturbance to cause cities to perish, such as in the case of increasing vulnerability in Angkor's water infrastructure to climatic variability in the 13th century (Penny et al., 2018). Today, urbanization, climate change and other drivers operating on the global scale challenge urban

resilience in increasingly complex ways (Elmqvist et al., 2019), highlighting the need to address urban resilience by asking "for whom, to what, when and where?" (Meerow & Newell, 2016). In this thesis, urban inhabitants' well-being is considered as the primary state variable that demands resilience, with behaviour and experiences as mediating state variables. These are conditioned on the urban landscape, which is considered as the primary slow variable. The urban landscape can change due to internal dynamics such as collective behaviour and economic activity that influence competition for land (Batty, 2012), but also in response to external drivers. Migration and relocation of daytime activities (such as workplaces and schools) are the main drivers considered here (which together largely encompass but are not synonymous with urbanisation). Change in the urban landscape in response to these drivers is reflected in processes like densification and urban greening that ultimately could impact well-being. Following resilience theory (Scheffer et al., 2012), the thesis considers urban landscapes' ability to support well-being both in terms of slowly shifting baselines as well as in response towards novel rapidly unfolding disturbance. The thesis does not closely engage with a separate literature on psychological resilience that explores how individuals' experiences over the life course shape their adaptation to psychological hardship (Luthar, 2015).

Methods

Overall approach

The general methodological approach in this thesis for relating the fundamental components of the studied system – urban landscapes and human well-being – is quantitative spatial analysis and statistical analysis of first-hand empirical data on day-to-day urban life. Within the confines of this general approach, different methods are used to provide different vantage points of the system. The major consideration here is a trade-off between accuracy in describing urban space and urban life on the one hand, and ability to capture patterns over time or across large spatial scales on the other. Thus, a primary division of system components into environment and well-being is complemented by a primary division of vantage points of the system into cross-sectional city-scale and longitudinal large-scale (Table 1). Different data sources and specific methods to analyse these are chosen to have matching spatiotemporal resolution. The cross-sectional studies use methods that approximate human-environment interactions in real life well but cannot handle temporal dynamics. The longitudinal studies use methods that provide only a blurry picture of day-to-day urban life on the ground but where the strength lies in detection of patterns over long timespans and across large spatial scales.

Table 1. Overview of data sources and methods for data collection and analysis employed in the thesis. Numbers in superscript denote the papers for which the data sources and methods were used.

	Environment	**Well-being**
Cross-sectional, city-scale	Land-use data[1,4,5] Sociodemographic data[1,4,5] Accessibility analysis[1,4,5]	Public participation GIS[1,4,5] Spatial regression[1,5]
Longitudinal, large-scale	Remote sensing[2,3] Residential registry[2,3]	Psychiatric registry[2] Conditional regression[2]

Study sites

The papers of this thesis study urban environments in Sweden (Paper 1, Paper 4 and Paper 5) and Denmark (Paper 2 and Paper 3). Sweden and Denmark are Nordic countries with industrialised economies and comprehensive welfare states. While many urban cores in Sweden and Denmark date from pre-modern times, urban landscapes have been particularly imprinted by an expansion phase in the 1940s to 1980s, with development of satellite suburbs and satellite towns that aimed to provide the population with access to both transit and open space (Bamford, 2009).

The Swedish studies mostly focus on Stockholm, Sweden's capital and largest city. Stockholm is one of the fastest growing cities in Europe; the municipality has grown from about 810 000 inhabitants in 2008 to about 976

000 in 2021 (a roughly 20% increase), while the region in the same years has grown from about 1.98 million to about 2.39 million inhabitants (a roughly 21% increase). Stockholm is situated between the Baltic Sea and Lake Mälaren and has large areas of water for a city. It also has large continuous nature areas fairly close to the city centre, for example the National City Park and the Nacka reserve. Built-up areas, nature areas and water bodies each make up roughly one third of the city's area. The city's core consists of mostly compact closed blocks with a central business district and surrounding mixed-use neighbourhoods. Suburbs are varied, including low-density areas of detached housing, modernistic apartment blocks largely dating from the functionalist era of the 1940s and 1950s or from the Million Programme of the 1960s and 1970s, and since the 1990s some newly developed mixed-use neighbourhoods.

Denmark's population in 2021 was about 5.84 million people, up from about 5.11 million in 1985 (a roughly 14% increase). It covers an area of about 43 000 km^2, with a population density of 138 persons/km^2 which is far higher than any other Nordic country. The predominant land-use is agriculture, which is interspersed with built-up areas and forest. It is a highly urbanised country: about 88% of the population live in urban areas, up slightly from 84% in 1985. Copenhagen is the capital and the largest city. Like Stockholm, it has been growing in recent decades. About 800 000 people live in the city, up from about 656 000 in 2008 (a roughly 22% increase), and about 1.86 million in the region, up from about 1.65 in 2008 (a roughly 13% increase).

Even though methodological choices were made with generalisability in mind, the results of this thesis can above all inform a Nordic context. Differences regarding geography, climate, culture, planning tradition and urban life in general exist between these countries, but from an international perspective the similarities are greater than the differences, which is why this thesis mostly focuses on what can be learned from viewing the cases as manifestations of the same kind of system rather than emphasising their differences.

Cross-sectional city-scale analysis

Publicly available spatial data

Acknowledgment of the complexity of human-environment interactions in day-to-day urban life risks leaving researchers paralysed. In this thesis, the approach to measuring the environment is consciously driven by pragmatic considerations around the trade-off between accuracy and scalability. To be able to capture a wide range of variables of the physical environment across whole urban landscapes, Paper 1, Paper 4 and Paper 5 make use of publicly available curated data. These papers study Swedish cities, where publicly available spatial data are accurate enough to differentiate between places in an urban landscape. For example, the Swedish national land cover database (Swedish Environmental Protection Agency, 2020) distinguishes between 25 land cover classes on a 10-metre resolution raster. Demographic statistical units (Statistics Sweden, 2020) that are often a few hundred meters across contain information on the number of residents and the daytime population

within them, as well as the age and income of residents. This is sufficient to approximate social and economic activity in places and distinguish between them in these respects. As methodological development is an aim of the thesis, another guiding consideration has been to uphold reproducibility as much as possible, which public data facilitates.

Experiential data

The cross-sectional studies use experiences as geographical indicators of support for or undermining of well-being. Experiences are measured by applying a public participation geographic information system (PPGIS). PPGIS is a method whereby people of some targeted group or the general public are invited to access a geographic information system (GIS) (often on an online platform), to provide place-based data on local knowledge (Gregory Brown & Kyttä, 2014). The method is employed here because it enables connecting context-sensitive multifaceted experiential data, that used to only be attainable through qualitative methods (Kyttä et al., 2013), to places in a way that scales and lends itself to co-analysis with other spatial data.

Data from two surveys constructed through the PPGIS software Maptionnaire (Maptionnaire, 2020) are analysed in this thesis. The first, analysed in Paper 1 and Paper 4, was called *Where is your Stockholm?* (Giusti, Barthel, & Samuelsson, 2017) and ran from September 21st 2015 until May 31st 2016. The objective was to have respondents record regularly occurring positive or negative experiences in their day-to-day life happening in the landscape of Stockholm. Information about the survey was spread through research principal Stockholm Resilience Centre's webpage and social media accounts and by the researchers in Facebook groups about specific local areas of Stockholm. It also featured at Färgfabriken, an art hall and policy-practice arena in southern Stockholm, during an autumn 2015 exhibition, and several municipalities within Stockholm County spread information about the survey online and in local newspapers.

The second survey, analysed in paper 5, was called *Vår Stad: Hur förändrar en kris våra vanor i staden?* ("Our City: How does a crisis change our habits in the city?") and was implemented in spring 2020 with the objective to understand how people changed their outdoor movement in response to the coronavirus pandemic and what the ensuing implications for well-being were. It was initially launched as a collaboration between KTH Royal Institute of Technology and the municipalities of Stockholm, Gothenburg and Uppsala. University of Gävle joined as a collaborator on April 28th 2020, about 6 weeks into the first wave of COVID-19 in Sweden, when a nationwide version of the survey was introduced. Due to the rapidly evolving and uncertain situation around pandemic restrictions in the spring of 2020, and because the involved municipalities sought to quickly spread the survey to as many of their citizens as possible, a convenience sampling approach directed towards the public was used. The survey was only available in Swedish and was aimed towards all citizens aged 15 and older. Information about it was published as a news item at the webpages of University of Gävle, Stockholm Resilience Centre and in the newsletter KTH School of Architecture and the Built Environment.

Information was also published on Stockholm municipality's webpage for urban planning (https://vaxer.stockholm) and on Gothenburg municipality's main and urban planning webpages (https://goteborg.se and https://stadsutveckling.goteborg.se/). Data was retrieved for analysis on June 15th, when the first wave had considerably languished.

Accessibility analysis

GIS provide opportunities to transform input spatial data to better represent real urban life. In this project, this is not merely a methodological side point but integral for giving the studies theoretical validity. While being largely omitted in most urban sustainability discourse, descriptions of urban form are heavily emphasised in some parts of it, such as space syntax research (Hillier, 2009). A central proposition in space syntax is that the incompatibility between a dynamic urban life and static representations of it can partly be overcome by incorporating relations between spaces in the representations. This is of importance when studying momentary experiences because these are influenced by dynamic patterns that vary over time, such as the amount of people in the place where the experience happens.

I use the term accessibility analysis to cover some different methods used in Paper 1, Paper 4 and Paper 5 that are all employed to incorporate relations between data to better approximate real-life situations. Although this underlying motivation is consistent, specific applications differ due to input data and scientific aims of the papers and the exploratory nature of methodological development in this thesis. Paper 1 uses address point measurements of residential and daytime population and polygon land-use data, and it focuses on day-to-day experiences, while Paper 5 uses area-level population data and raster land-use data, and it focuses on use of local places. Such differences motivate that Paper 1 operationalises accessibility analysis as what is within 500 metre walking distance of an experience whilst in Paper 5, we measure what is within 50-250 m Euclidian distance.

While Paper 1 and Paper 5 both treat each experience as an isolated phenomenon (although situated in a spatial context), Paper 4 has a more explicit complex systems approach and focuses on compositions of experiences on the neighbourhood scale and on street network connectivity. Therefore, it operationalises accessibility analysis through the concept of spatial configuration from space syntax (Hillier, 1996). Spatial configuration here explicitly disregards metric distances and instead refers to the topological relations between streets and paths in the network. This is based on the empirically supported notion that people tend to move between destinations along the topologically shortest routes (Hillier et al., 1993). Following previous research from Stockholm (Ståhle, Marcus, & Karlström, 2005), in this paper we use 3–6 topological steps in the network as boundaries for what places are accessible from each other in day-to-day life.

Spatial regression

Just as with accessibility analysis, spatial regression is used in this thesis to increase the validity of the studies. However, while accessibility analysis is

used to better approximate processes within the system, spatial regression is used for calibration and filtering out of processes that are partly outside the system boundaries. Among a wide variety of specific applications, the fundamental idea of spatial regression is to take advantage of spatial relations between data to reduce bias in regression models. On the whole, spatial regression applications have regrettably seen fairly limited use in most fields that deal with urban sustainability, but they have been thoroughly developed in other fields such as landscape ecology (Bardos, Guillera-Arroita, & Wintle, 2015; Dormann, 2007; Dormann et al., 2007) and econometrics (Anselin & Rey, 2014; Haining, 2003). Some methods, like spatial lag models and geographically weighted regression, attempt to incorporate spatial processes that govern relations between studied variables. Spatial error models, on the other hand, try to account for the influence of other spatial processes than the ones studied by making use of spatial patterns among model residuals. In settings where many spatial processes are likely to influence the outcome of interest (such as experiences in urban landscapes), this approach reduces bias and increases validity and generalisability (Bardos et al., 2015). Specifically, the models used in Paper 1 and Paper 5 are logistic spatial error models that draw mostly on an approach that Dormann et al. (2007) and Bardos et al. (2015) call autologistic regression.

Longitudinal large-scale analysis

Remote sensing

For measuring changes in the environment over long timescales, Paper 2 and Paper 3 rely on remote sensing. Since the launch of NASAs Landsat Program in 1972, remote sensing through satellites has become one of the fundamental methods to understand and monitor urbanisation (Zhu et al., 2019). Beginning with Landsat 4 in 1982, there is now decades of publicly available continuous satellite imagery coverage of the Earth's surface at a 30-metre spatial resolution and at 16-day intervals. Google Earth Engine (Gorelick et al., 2017) is an online interface that allows application of algorithms to remove cloud and cloud shadow pixels (Zhu & Woodcock, 2012) and the mosaicking together of different images, facilitating the creation of consistent and noise-reduced time series.

The spectral data from the different bands of the satellites can be further treated to reveal different kinds of information to match the scientific aim at hand. Paper 2 uses a novel deep learning method (Chen et al., 2020) that classifies the horizontal and vertical density of the built environment based on high-dimensional patterns in the spectral data. Paper 3 on the other hand makes use of the Normalised Difference Vegetation Index (NDVI) that is a simple arithmetic transformation of the red and near-infrared bands, and an often-used proxy for presence of urban vegetation (e.g. Du et al., 2019; Gascon et al., 2016; Jin, Gergel, Lu, Coops, & Wang, 2019).

Population registries

As mentioned in the section *Resilience*, both residential migration and daytime activity relocation are thought to matter for urban landscapes' relationships to well-being, but no daytime population registry was available for implementation in Paper 2 and Paper 3. However, address point measurements of residence records from the Danish Residence Database (Pedersen, 2018) are used to measure residential population density in Paper 3, similar to how it is measured in Paper 1. In addition, both Paper 2 and Paper 3 use this database for estimating exposure to environments by measuring variables of the environment within Euclidian buffer distances around residential address points. Although people's day-to-day activity spaces are neither circular in shape nor confined to only the closest environment surrounding the home (Hasanzadeh, Broberg, & Kyttä, 2017), this approach rests on a "proximity argument", i.e. that over long timescales and averaged across a large number of people, the environment immediately surrounding the home will provide a good proxy for environmental exposure.

In Paper 2, the Danish Residence Database is linked to the Danish Psychiatric Central Research Register (PCRR) (Mors, Perto, & Mortensen, 2011) to relate urban form surrounding the home to risks of developing depression or neurotic disorders. It contains information about all patients treated at psychiatric departments in Denmark since 1970. Diagnoses of depression and neurotic disorders in the PCRR are relatively uncommon, as most mild mental disorders are treated by general practitioners (Mors et al., 2011). For example, in a cohort of ~3.4 million people, ~58 000 individuals (~1.7%) were admitted with a depressive episode between January 1 1994 and December 31 2012 (Meier et al., 2015).

Matched case-control modelling

In observational studies with few cases and a high risk of confounding, matching between cases and controls is a modelling strategy to increase the generalisability across the population. For each case, a number of controls that match the case on one or several variables are drawn from the study population. Paper 2 uses conditional logistic regression, where each case is matched to eight controls on sex, birthday +/- 15 days, and no history of the same diagnosis on the date the matched case was first diagnosed. Because each case is compared with its matched controls, the resulting estimates are of *relative* risk, which can be generalized across the population.

Results

Summary of papers

Paper 1

A central tension in urban planning that is addressed throughout this thesis is the one between urban densification and provision of urban natural settings (see *Introduction*). Any hope of resolving the tension rests on moving away from an urban-nature dichotomy in mind and language and coarse area-level descriptions towards a complex adaptive systems-based view of urban landscapes as overlapping land uses in which humans move between and experience places in non-trivial ways. Paper 1 takes aim at such a refined understanding of how urban landscapes relate to people's day-to-day experiences. The research question is: How does presence of or spatial proximity to various features of the environment relate to people's regularly occurring experiences? A novel method is developed that combines PPGIS, accessibility analysis and spatial regression. We relate the results of an online PPGIS survey (1784 experiences of 1032 respondents) to seven features of the environment (residents, daytime population, natural temperature regulation, and distance to green areas, water, major roads and playgrounds). We further estimate the probability of positive and negative experiences across the landscape by extrapolating from the regression model.

All features of the environment except distance to playgrounds and/or schoolyards show significant associations with experiential outcome, after accounting for spatial autocorrelation among the data. Number of residents and proximity of natural settings and water, all common indicators in urban planning, display weak relationships. However, areas dominated by large daytime populations or proximity to major roads have very low rates of positive experiences. Areas with high natural temperature regulating capacities (often large continuous nature areas containing voluminous trees) have very high rates of positive experiences. The spatially explicit approach highlights specific areas where many people likely have negative experiences, and which should be considered for transformation.

Paper 2

Paper 1 analysed day-to-day experiences as an important component of well-being. Paper 2 focuses on mental health over time as another, but related, component of well-being. Although many studies point towards a heightened risk for urban over rural dwellers of being affected by depressive and anxiety disorders, there is little consensus about the risks associated with distinct types of urban form. Intraurban differences are important to uncover because people move and because urban design can modify built environments. Paper 2 aims to increase the understanding of intraurban differences in risks of being affected by depression or anxiety. We ask (i) What are the associations between exposure to different kinds of urban form and risks of depressive or anxiety disorders? (ii) How are these associations moderated by age and

income? (iii) What are the associations between changing urban form exposure due to moving and risks of depressive or anxiety disorder? We assess longitudinal individual-level urban form exposure and incidence rate ratios (IRRs) of neurotic and mood disorders among >3.7 million Danes. Deep learning on time-series satellite data were used to distinguish six urban form types based on building spacing and height. The urban form types were measured within a 250-meter radius around each person's residence(s) 0 to 5 years prior to diagnosis.

We reveal, after adjusting for many confounding factors, considerable IRR differences within urban landscapes. Dense inner-city areas did overall not carry greater risks than the baseline (rural areas). Areas combining multistorey buildings with open space carried the lowest risks (IRRs of 0.57–0.76), whereas the highest risks were found for one- or two-storey environments in the urban peripheries (IRRs of 1.11–1.33). Moderation by age or income revealed further diversity among associations. For example, dense inner-city areas were associated with lower disorder risks for young adults (IRRs < 0.75). The results suggest that sprawling urban development can burden public mental health, but that spatial planning has the potential to improve it, particularly by focusing on the urban peripheries.

Paper 3

Paper 3 focuses on urban landscapes as a slow variable. The aim is to understand long-term changes in population density and greenness in residential environments on the local scale that matter for people's well-being. We investigate patterns of change in these variables across 21 years (1995–2016), combining a dataset of address-level population data covering all of Denmark (>2 million address points) with satellite image-derived NDVI data. The approach allows a countrywide analysis that measures environments around individual addresses at high spatial resolution. We ask (i) What are the patterns of annual changes over the study period in residential population density and greenness around Danish residential addresses? (ii) How do these patterns differ between low- middle- and high-density environments? (iii) Are there different patterns in greenness when comparing the peak period (July) and the majority of the growing season (May-August)?

Changes in population are geographically unevenly spread across Denmark, with the largest increases in the central areas of cities and the largest decreases in their peripheral areas, largely overlapping with those areas that Paper 2 found to be high-risk for mental disorders. NDVI fluctuates considerably from year to year, but there is a general trend that the growing season average greenness of most residential environments in Denmark has increased. This is the case also in environments that have witnessed densification. In fact, the most common change within 500-metre neighbourhoods around individual address points is of joint increases in population and NDVI (28%), followed by increasing NDVI with stable population figures (21%). In contrast, only 8% of neighbourhoods around address points have seen a decline in either population or NDVI. Increases in greenness are of similar magnitude in low- middle- and high-density environments, but linear regression predicts the data

best in middle- and high-density environments where the increasing trend is highly certain. We find no evidence for an increased peak period greenness, suggesting that climate change accounted for most greening by way of longer growing seasons and that any areal change in urban greenspace was small in comparison. However, we also find no decline in peak period greenness, suggesting that population densification happened without large areal losses of greenspace. In other words, while climate change reasonably accounted for most greening, the trends were simultaneously enabled by urban planning policies that seek to preserve or enhance blue-green elements in already built-up environments.

Paper 4

Research on complex adaptive systems has revealed that sudden and surprising changes in these can come about because of largely invisible gradual changes in underlying slow variables (see section *Resilience*). In light of decades-long residential population concentration, this raises concerns regarding shifting baselines in urban landscapes' ability to support human well-being, and whether this ability is resilient. Paper 4 focuses on different kinds of day-to-day experience as indicators of different pathways between urban form and well-being and collections of experiences on the neighbourhood scale as indicating the landscape's ability to support well-being on a systemic level. The aim is to increase understanding about what kinds if experience that exist together on the neighbourhood scale, and how these compositions of experiences are related to urban form. Drawing on previous work around resilience principles (Biggs et al., 2015), we define the concept "resilience at eye level" as a neighbourhood-level diversity of experiences and a level of connectivity between them that limits adverse experiential outcomes, and evaluate it across Stockholm. The research questions are (i) What kinds of day-to-day experience do people have in Stockholm and how common are they? (ii) How do these experiences coexist on the neighbourhood scale to make up different experiential landscapes and what is the spatial distribution of these? (iii) What are the relations between diversity, connectivity, and proportion between positive and negative experiences in different experiential landscapes? (iv) What are the relations between experiential landscapes and urban form? The diversity principle is operationalised by latent class analysis, which creates a classification of experiences based on attributes respondents assigned them. Connectivity between experiences is assessed by topological spatial analysis, and a typology (a systematic classification of types) of experiential landscapes is created that takes both diversity and connectivity of experiences into account.

From analysing 1460 experiences from 780 respondents, we find 11 categories of experience (seven positive and four negative). These make up eight typologies of experiential landscape, with differing levels of diversity and connectivity. There is a general trade-off between connectivity and the proportion of experiences that are positive, but also some deviations from this pattern. Diversity of experiences is highest at intermediate levels of connectivity. Typologies supportive of well-being exist in environments that

balance residential and daytime populations, avoid extreme concentration of movement flows and have accessible natural settings. Typologies hindering wellbeing fail in one or several of these respects.

Paper 5

The coronavirus pandemic provided the context for the largest natural experiment in history with respect to urban landscapes' ability to support human well-being. It entailed restrictions on access, movement and social behaviour in populations around the world practically overnight. Paper 5 addresses possibilities for place-based coping as an aspect of urban resilience towards such extreme events. In the context of the coronavirus pandemic, this part of urban resilience stems from enabling access to places that support well-being but without imposing dangerously increased risk of infection. The aim in Paper 5 is to explore how changes in place use following pandemic restrictions relate to self-perceived changes in people's well-being. We analysed data from an online place-based survey on 2845 places across Sweden that respondents abstained from visiting, visited with similar frequency, or visited more frequently in May 2020 as compared with before the pandemic. The research questions are (i) What geographical and sociodemographic properties of places are associated with positive or negative changes in well-being, respectively, from visiting or abstaining from visiting the place during social distancing, respectively? (ii) How do neighbourhoods' spatial vulnerability to pandemic restrictions and accessibility to places for coping vary across an urban landscape? In spatial logistic regression models, we relate place variables (fields, forests, water, residential population density and daytime population density) to self-perceived changes in well-being from visiting the given place less or more often. As an illustrative case, we perform a spatial analysis by mapping our models onto the landscape of Stockholm.

Abstaining from visiting places with natural settings located in areas of high residential density was associated with a self-perceived negative influence on well-being. Yet, fields, forests and water were strongly associated with places people claimed well-being benefits from during pandemic restrictions. The further a visited place was from the respondent's home, the more likely it was to have a positive well-being influence. The spatial analysis shows that some neighbourhoods are likely more resilient than others when coping with pandemic restrictions. Both the most and least resilient neighbourhoods span the socio-economic spectrum. The results suggest that easy and safe access to natural settings by foot or bike for all urban dwellers is integral to urban resilience towards a pandemic.

Answers to the thesis' research questions

Urban environments' associations to well-being

How do urban environments relate to urban inhabitants' well-being, as indicated by day-to-day experiences and mental health?

There is no universal way that high-density environments are experienced. Yet, there are substantial patterns in how environments relate to day-to-day experiences, meaning that urban design has the potential to improve subjective well-being but that dichotomies like urban-nature or dense-green are unhelpful in this regard. Residential and daytime population density display markedly different associations: daytime population is by far the better predictor, where high densities are almost universally negatively experienced. The negative experiences tend to happen daily and during brief moments. They are often either about difficulties to walk or bicycle, or of dullness and boredom, which possibly reflect different experiential conditions during and outside office hours, respectively. Places that are low-density and with few natural settings, such as those that are close to major roads, tend to be reliably negatively experienced. Nature-abundant environments are very important for positive experiences. They tend to have higher probabilities of providing positive experiences when they are forested, remote and secluded. These positive experiences are often either about escape and calmness, or of taking care of the place.

Just as an urban-nature dichotomy relates poorly to day-to-day experiences, an urban-rural dichotomy relates poorly to risks of suffering from depression or anxiety disorders. Residents of the city centres are at relatively low risk of neurotic and mood disorders, and sparse multistorey environments that often are at the edges of inner-city areas facing water bodies or large nature areas are associated with the lowest risks. Low-rise areas on the urban peripheries conversely carry the greatest risks, higher than both city centres and rural areas.

Urban environments that support well-being

What is characteristic of urban environments that provide resilient support of well-being while also aligning with global sustainability pursuits? On the neighbourhood scale, they balance residential and daytime populations (balance guideline), avoid extreme concentration of movement flows (movement guideline), and have accessible natural settings (nature guideline) (Figure 2).

This thesis found that people are different with respect to their positive experiences. Encouragingly enough, many kinds of environment seem to afford experiences promoting well-being for lots of people, and many neighbourhoods contain possibilities for a diversity of experiences promoting well-being. On the other hand, the neighbourhoods in Stockholm that produce negative experiences seem to do it for almost everyone. Thus, this research question is best answered with general qualitative guidelines for transformation of environments that challenge well-being, rather than with precise quantitative prescriptions for each physical characteristic for implementation everywhere. Negatively experienced areas are mostly centrally located and fail to fulfil the balance and movement guidelines, and to some extent also the nature guideline. They concentrate the movements of lots of people that are cramped together during office hours but feel void and unsafe outside office hours.

Figure 2. Three guidelines for environments that support well-being. On the neighbourhood scale, they (1) balance residential and daytime populations (balance guideline), (2) avoid extreme concentration of movement flows (movement guideline), and (3) have accessible natural settings (nature guideline).

As for mental health, since the analysed data does not encompass daytime population or the street network, translation between urban form types and the guidelines are based on an assumption that should be uncontroversial: that residential population and daytime population tend to be most mixed in the multistorey urban form types found in cities' central areas. The evidence then indicates that the balance guideline is most decisive for supporting mental health, as a main difference was observed between multistorey and low-rise urban form. However, the nature guideline seems additionally decisive, as a smaller difference was observed between compact and sparse environments.

Population density change and well-being

How do long-term patterns of population density change relate to urban landscapes' ability to support well-being?

Paper 3 showed that since the 1990s, there has strictly speaking not been an urbanisation process in Denmark, as the share of people living within metropolitan landscapes has not changed much. Instead, population density has decreased in urban peripheries and increased in the cities' central areas. A

corresponding analysis of Swedish cities was not undertaken, but municipality-level data from Statistics Sweden[1] and district-level data from Stockholm municipality (Stockholms stad, 2021) give indications of similarly centralizing flows in the Stockholm region. Paper 4 showed that negative experiences related to challenges with sharing space with others are most common in Stockholm's most central areas. These facts taken together seem to suggest that contrasts have intensified in Nordic cities between on the one hand environments in the urban cores that are increasingly full of people and on the other hand some peripheral environments constructed during the preceding paradigm that are "left behind" with relatively high prevalence of depressive and anxiety disorders. Generally, the residential environments of individuals have shifted towards being denser and more highly built. These migration patterns work against the movement and nature guidelines. However, the mental disorder risk data suggest that they have divergent effects on the balance guideline across the population. Living in dense areas is not a general risk factor for suffering from depression or anxiety disorders, possibly because fulfilment of the balance guideline creates possibilities for a diversity of experiences promoting well-being. Peripheral high-risk areas have seen declines in population since the 1990s, but the dominating direction of causality is not obvious. Risk factors in these environments, for example lack of possibilities to take part in urban social life or escape for seclusion and restorative environments, might be recognized by residents so that they "vote with their feet" by moving out. It is also possible that as people move out, a sense of displacement occurs among those staying that can sometimes predate mental disorder development. The latter possibility is supported by the result that individuals that move into low-rise suburban areas, against the general trend, run the greatest disorder risks.

Even though the extent to which green areas have been turned into built-up ones is limited, the erosion of the nature guideline due to migration patterns is important with respect to cities' ability to deal with sudden disturbance while continuing to function. The case of social distancing during the coronavirus pandemic suggests that urban resilience towards disturbances requiring that people keep apart has on the whole decreased. In Stockholm, neighbourhoods with less resilience towards the effects of social distancing span the socio-economic spectrum. Yet, residents of low-income neighbourhoods are possibly left more vulnerable as they may not have the means to travel, showing how urban well-being in the face of disturbance is an issue of environmental justice.

[1]Municipality-level population:
https://www.statistikdatabasen.scb.se/pxweb/en/ssd/START__BE__BE0101__BE0101A/BefolkningNy/
Municipality-level built-up area extent:
https://www.statistikdatabasen.scb.se/pxweb/en/ssd/START__MI__MI0803__MI0803A/MarkanvKn/

Discussion

Limitations

Potential sample biases

The experiential evidence of this thesis relies of data collected through convenience sampling with PPGIS, which is not without caveats. Convenience sampling seldom results in representative samples. Both surveys used in this thesis produced samples in which women and middle-aged people are overrepresented, as compared to the general population of Sweden. While these biases were accounted for in the analysis, biases that do not covary much with demographic data are more difficult to know and account for. Difficulties encountered by groups of people in using digital technology, commonly referred to as the "digital divide" (Katz & Gonzalez, 2016), is pertinent to PPGIS sampling. Other groups of people might simply lack interest in partaking. When PPGIS is used to collect data on preferences related to planning, convenience sampling risks systematically attracting people that do not represent the public well (Brown, Kelly, & Whitall, 2013). Although this risk of bias is greater when the mapping involves expressing preferences than, as is the case here, providing descriptions (Brown, 2017), the fact that some groups' experiences might not be well represented in the data should be kept in mind when interpreting the results in this thesis. For example, the survey on changes in place use in response to the coronavirus pandemic that Paper 5 is based on collected relatively few places that people obtained a negative wellbeing influence from visiting. This might be because we surveyed relatively few "essential workers" (people that work in healthcare, schools, public transport or supermarkets) who has been described as being at particular risk of challenges to well-being during the pandemic (The Lancet, 2020).

Omitted variables

Another limitation concerns important environmental variables that due to scope and data availability were omitted in the analysis. Here, I want to highlight in particular transportation. Experiences often deviate from the non-spatial model in Paper 1 around public transportation junctions, where they tend to be considerably more negative than the model predicts. As these negative experiences are often occurring briefly and on a day-to-day basis, commuting to work by public transport is likely a decisive factor for subjective well-being in Stockholm.

Differences between study sites

A third limitation concerns the transferability of results between cities in the Nordics. Synthesizing the results relies on an assumption that these cities function and develop in broadly similar ways. In some respects, there might however be important differences. For example, a study of Gothenburg found that areas where greenness decreased between 1986 and 2019 were larger than those where it increased during the same time period (Blinge, 2021), which

intuitively is in contrast to the findings of Paper 3. While this work relies on slightly different materials, such as measurements being made across the whole landscape rather than specifically around residential addresses and a handful of high-quality measurement dates rather than annual time series of median values among dozens of measurement dates per year, it raises questions around how divergent developments have been across cities in the Nordics. In 2004, Sweden had nearly twice as much impervious surface per capita as Denmark (218 m^2 compared to 114 m^2) (Elvidge et al., 2007). Data from the European Environment Agency points towards infrastructure development between 2000 and 2016 in Denmark actually contributing to increased vegetation productivity (European Environment Agency, 2020). Furthermore, Denmark scored considerably higher than Sweden on the Ecosystem Service component of the 2020 Environmental Performance Index that reflects loss of ecosystem service producing land covers (Wendling et al., 2020). This should serve as an important reminder that one cannot expect to observe a certain development in one Nordic city just because it is observed in another. Instead, different land use norms and planning strategies that steered past and will steer future development in Denmark and Sweden could mean that the cities' greenness develops differently in these countries.

As for generalizability within Sweden, it is important to remember that most empirical data comes from Stockholm which in terms of population is an order of magnitude larger than many other Swedish cities. The sharing of space that most notably underpins the movement principle is reasonably a more pressing issue here than in other Swedish cities, although it is difficult to estimate how large such differences are without further comparative empirical analysis.

On the differences between subjective well-being and mental health in relation to urban landscapes

The results concerning day-to-day experiences and mental health might seem incompatible, as the most central areas produce mostly negative experiences while the peripheral ones are high-risk in mental disorders. However, these results appear to be in concert after some unpacking. Stockholm's central neighbourhoods include both a negatively experienced central business district (in the Norrmalm district) and surrounding generally positively experienced mixed-use areas (the districts of Vasastan, Östermalm, Södermalm, and Kungsholmen). The latter kind corresponds better to most areas of the urban form types with relatively low risks of mental disorders (compact multistorey, e.g. Nørrebro or Vesterbro in Copenhagen, and sparse multistorey, e.g. Sydhavnen in Copenhagen).

Furthermore, as remarked in the section *Body and mind*, subjective well-being and mental health are different well-being dimensions. While central areas more often produce negative affect and contain higher proportions of negative experiences, they also contain higher absolute numbers of positive experiences compared with suburban areas. Positive affective states can have a protective function against depression (Panaite et al., 2020). It is unknown to

what extent this effect is independent from or interacting with other protective psychosocial factors like social connectedness and social support, but it is independent from negative affect (Steptoe, Dockray, & Wardle, 2009). Stier et al. (2021) argue that higher quantities of more superficial social interactions in large cities might simultaneously explain why they sometimes produce lower subjective well-being outcomes while still contributing to lower depression risks. This leads to why it is crucial to look beyond cities as uniform entities to compare with each other or rural areas, and to a potential explanation for why certain suburban areas stand out as particularly high-risk within urban landscapes. Because these areas do not fulfil the balance guideline, many of their inhabitants commute for work in the city. It is possible that these individuals "get the worst of both worlds" if they work in stressful areas producing negative affect and live in ones not producing positive affect due to limited access to both social connectedness and restorative settings. On top of potentially causing unfavourable environment interactions, lengthy commutes by car (but not public transportation) have in themselves been found to be a risk factor for depression (Wang, Rodríguez, Sarmiento, & Guaje, 2019), further indicating that the balance guideline could serve to protect public mental health.

Topodiversity: An organising concept for resilient urban well-being?

In the Nordics, the prevailing paradigm in urban planning discourse has since the 1990s been densification, which has been a reaction towards a transit-oriented dispersion paradigm in the 1940s-1980s when most of the metropolitan landscapes were constructed (Bamford, 2009). In service of a paradigm that moves beyond densification and sprawl and in light of the results of this thesis, I want to revisit an idea that was brought up in the section *Space and social life*: that cities are constituted by a topological "foreground network", where movement flows are concentrated and more social and economic activity takes place, and a topological "background network" that creates secluded spaces for restoration (Hillier, 2009). Destinations co-evolve with changes in these networks, and humans move in them between the destinations, influencing the development of yet other destinations as well as each other's experiences. Furthermore, the networks and destinations develop in a geographic context, including a natural landscape that the network can provide access to or shield people off from. These co-evolving processes create spatial conditions for environments to support well-being, where certain spatial conditions support well-being through certain pathways. For example, spatial conditions in the foreground network better support well-being through access to urban services whereas those in the background network better support well-being through psychological restoration. I propose the term *topodiversity* to mean variation in such spatial conditions across an urban landscape that permits support of well-being through different pathways. Topodiversity emerges from the natural landscape, the street network's topological configuration, and the distribution of destinations (Figure 3).

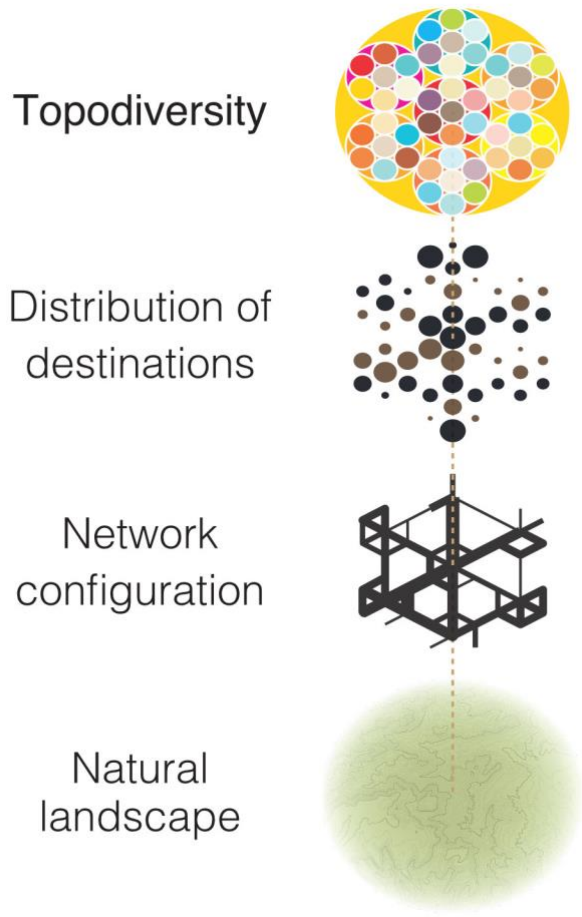

Figure 3. Topodiversity refers to variation across an urban landscape in spatial conditions for support of well-being being through different pathways. Topodiversity emerges from the natural landscape, the street network's topological configuration, and the distribution of destinations.

Consideration of topodiversity at both the city scale and neighbourhood scale can guide a paradigm for resilient urban well-being. The contrasts that emerge in Nordic cities between the central and peripheral areas suggest that the densification paradigm has seen increased topodiversity on the city scale but decreased on the neighbourhood scale in central as well as peripheral areas (Paper 4 showed that there might be less need for concern for areas of intermediate centrality). Resilient urban wellbeing requires equal concern for the foreground and background networks and for increased neighbourhood topodiversity in central as well as peripheral areas. However, neighbourhoods should not strive to be replicas of each other, which is both undesirable and an impossibility, as their relative locations necessarily provide them with different

spatial conditions. This thesis revealed negative experiences to be notably similar to each other, giving clear indications of the kinds of environment that hinder well-being and should consequently be avoided or transformed. Given that such environments are avoided, it seems likely that more topodiversity entails more possibilities for people to actualise well-being benefits through different pathways.

Urban planning strategies for resilient urban well-being should consider the system components from which topodiversity can emerge. Two complementary approaches are (1) restructuring of the movement network and (2) redistribution of the destinations. Strategies should moreover be informed by the three guidelines (balance residential and daytime populations, avoid extreme concentration of movement flows, and have accessible natural settings) so that they contribute to topodiversity. Here it is crucial to emphasize that no urban landscape is a clean slate. Because urban planning always has to and should adjust to an existing context, there is no inherent ranking between the guidelines. While conditions at one place might present opportunities for synergies between two or all guidelines, they might be in competition with each other somewhere else. Thus, even though the examples of strategies below are presented in a general way they might not make equal sense for all cities and be especially relevant for Stockholm where most experiential evidence in this thesis is from.

An important strategy is ensuring redundancy in city-wide movement. Reducing the need to rely on the most central areas of a city when traveling across it addresses the movement guideline in these areas. Many peripheral areas could benefit from more through-movement and within-neighbourhood-movement being concentrated to certain routes, addressing the balance guideline by creating a foundation for daytime population along these routes. Crucially, restructuring of the network should not just focus on options for movement but be informed by how topology relates to actual human movement. Pre-industrial market towns could perhaps function as inspiration (cf. Hillier & Hanson, 2009), with the aim of creating a wider span of spatial conditions that what currently exists in most sprawling suburban landscapes.

As for the location of destinations, the evidence from this thesis strongly suggests that redistributing daytime activity away from central towards peripheral areas can be a powerful strategy to promote well-being. Such planning goes against the fundamentals of the densification paradigm. Yet, it would again conform to the balance and movement guidelines in both central and peripheral areas. The COVID-19 pandemic might have pushed discourse somewhat in this direction, as some authors have entertained the notion that it might uproot the densification trend (Batty, 2020; Nathan & Overman, 2020). New pro-environmental habits for mitigating the climate crisis (Linder, Giusti, Samuelsson, & Barthel, 2021), e.g. around remote working, could create an excess of office space in central areas (Naor, Pinto, Hakakian, & Jacobs, 2021) that opens up possibilities to increase topodiversity there, perhaps even by constructing new natural settings that improve these areas with regards to the nature guideline.

Strategies that increase topodiversity in both central and peripheral areas could shift upwards baselines in urban landscapes' ability to support human well-being. Topodiversity entails greater possibilities to use the urban landscape as a resource, for example for accessing local job markets (Legeby, 2013) or for coping with the psychological demands of urban life (Korpela et al., 2018). Although it remains to be verified by research, topodiversity could entail experiential diversity in individuals, which makes them happier (Heller et al., 2020). The same strategies dovetail with global sustainability pursuits, as fulfilment of the balance guideline could enable active modes for much day-to-day transportation. A still open question is if fulfilment of the movement and nature guidelines could make urbanites more willing to refrain from energy-intensive travel (e.g. long-distance flights) by dampening the need to regularly travel out of stressful neighbourhoods (cf. Czepkiewicz et al., 2018).

Strategies that increase topodiversity could also make well-being more resilient to crisis. Better fulfilment of the balance guideline in peripheral areas likely leads to redundancy in services that people rely on during crisis, such as grocery stores and health care facilities. Better fulfilment of the movement and nature guidelines in central areas means redundancy in possibilities for restoration that seem to be just as important (Paper 5).

How can strategies for increasing topodiversity be actualised in concrete projects? An important lesson from the experiences with modernism, and which Jacobs (1961) best put into words, is the dangers of radical interventions in complex systems that are based on mechanistic thinking, especially if they disregard existing spatial dynamics. Greater understanding of geographical contexts could instead help adaptive management of the urban landscape in response to internal dynamics and external drivers, akin to what has been suggested through the "urban tinkering" approach that advocates a diversity of small-scale urban experiments to stimulate innovation and enhance adaptation or transformation in response to crisis (Elmqvist et al., 2018). This does not mean that the landscape's ability to support well-being will always change gradually in response to such projects, because there might be critical transitions along the way. While the literature on social-ecological systems have mostly focused on unwanted critical transitions, urban systems could undergo desirable critical transitions resulting from gradual change of the landscape, such as in the case of dramatic increases in bicycle use in Copenhagen in recent years (Kaaronen & Strelkovski, 2020). Digital technology producing immediate feedback from urban inhabitants in terms of their behaviour and experiences in places should help reveal the best locations to intervene in the system in concrete projects (cf. Lerner, 2014).

Budding method for research and practice

A paradigm for resilient urban well-being requires research and practice to engage more with configurational and complexity thinking. This thesis has made contributions to analytic methods through Paper 1, Paper 4 and Paper 5 that combine PPGIS with other methods in ways informed by an understanding of urban environments and well-being as a complex adaptive system.

Operationalising this theoretical point of departure would have been next to impossible until recently. However, digital tools now enable measuring human behaviour in and experiences of urban landscapes while also producing large datasets for quantitative analysis. A recent paper identified a progression of three phases in PPGIS analysis: exploration (descriptive analysis), explanation (analysis of relationships), and prediction (generalization to other contexts and/or future realities) (Fagerholm et al., 2021). In Paper 4, I sought to produce explanations that consider cross-scale interactions, by combining topological relations between places with the experiential precision of the PPGIS data. I have also sought to produce generalizable predictions by correcting for exogenous effects through spatial regression in Paper 1 and Paper 5. However, to my knowledge, no one has yet applied in research a model of urban environments and subjective well-being as a complex adaptive system that combines topological spatial analysis with spatial regression.

Despite planning practice by definition being concerned with predicting future realities, it has unlike research mainly relied on PPGIS for exploration (Fagerholm et al., 2021). A shift in planning practice towards greater attention to explanation and prediction has been called for (Ibid.). Explanation and prediction are skill-intensive activities whose uptake by planning practice can be aided by user-friendly planning tools that model urban space as a complex adaptive system, such as "Urban calculator" (Berghauser Pont, Stavroulaki, & Marcus, 2019b). Integration in urban planning tools of complexity-based descriptions of urban space with spatially explicit experiential or behavioural data would not only enable prediction of well-being outcomes, but also make prediction uncertainties a decision support.

Emerging research questions

In this section I outline three directions for future research centred around questions that emerge from the results of this thesis and other recent research.

The first direction is to seek to better understand trade-offs and synergies in urban landscapes' respective relationships with well-being and energy efficiency. Transportation is a major aspect for addressing urban energy efficiency (Creutzig et al., 2016). Fulfilment of the balance guideline is likely to promote less energy-intensive active transportation in day-to-day life. Fulfilment of the movement and nature guidelines might mitigate the need for urbanites to engage in more energy-intensive leisure travel (cf. Czepkiewicz et al., 2018). In other words, there is a potential win-win situation in achieving pro-environmental travel habits (Linder et al., 2021) and well-being among urbanites. Incorporating smartphone applications (Donaire-Gonzalez et al., 2019; MacKerron & Mourato, 2013) or GPS trackers in combination with surveys (Heller et al., 2020) to monitor people's movement and subjective well-being over time can answer: *What are the relationships between urban environments, travel habits, and well-being?*

Dense built structure is more energy efficient than sprawl in terms of building energy savings (Creutzig et al., 2015; Güneralp et al., 2017). This aspect is, in contrast to transportation, conceivably in competition with the

well-being guidelines, at least beyond some density threshold. However, there is a lack of understanding of how spatial configuration influences where such a threshold is and how severe the competition is. Integration of building energy modelling in a GIS environment (Ali et al., 2020) can fill this gap by addressing the question: *What urban forms best combine energy savings of high-density built structure with the guidelines for promoting well-being?*

The second direction is to delve deeper into how topodiversity relates to the possibilities for individuals to promote or maintain their well-being through different pathways. Urban inhabitants report higher levels of happiness when they experience different and varied places in their day-to-day life (Heller et al., 2020). Yet, people tend to stick to a limited set of places they revisit often in their day-to-day life (Alessandretti, Sapiezynski, Sekara, Lehmann, & Baronchelli, 2018). Paper 5 shows that sustainability, environmental justice, and urban resilience all demand having places that support well-being close to where one lives, in a local activity space (cf. Hasanzadeh, Laatikainen, & Kyttä, 2018). Paper 4 shows that some neighbourhoods better than others achieve a diversity of experiences across people. However, it is unknown what urban landscapes allow individuals to actualise a diverse local activity space that support their well-being. By tracking individuals' subjective well-being and movement in and out of places over time, research could answer: *What kind of topodiversity in urban landscapes enables local activity spaces leading to a diversity of experiences promoting well-being in individuals?*

The third direction is to further research on the urban landscape as a slow variable. I have considered homes and daytime activity places as the two most important kinds of destination in cities. However, I was unable to quantify relocation of daytime activity. I also did not include any data relating to the street network and spatial configuration in Paper 3. Extending this analysis to include daytime population and street network data in addition to data on homes and natural settings allows for better proxies of population-wide exposure to urban environments over time. It could even allow estimating commute length and mode of transportation, which are important factors for mental disorder risk (Wang et al., 2019). The overarching question for this research direction is: *How has the spatial distribution of residential and daytime populations and the street network co-evolved to alter the urban landscape's ability to support well-being?*

Conclusion

21st century human civilization is mainly and increasingly urban (United Nations, 2019). Making it one that is also healthy, resilient, and less taxing on the planet is a challenge that urban scholars and urban planners urgently need to address. This thesis highlights how the challenge can be addressed in a Nordic context. To conclude and based on the results of the five papers that comprise this thesis, we must firstly do away with the compact-green or urban-rural dichotomies that still dominate urban sustainability discourse, because these align poorly with how urban environments relate to well-being. Second, we must keep track of cross-scale spatial and temporal dynamics to appreciate how urban landscapes' support of well-being in day-to-day life can be undermined by slow changes such as residential migration over the course of decades, even if the physical urban structure does not change radically over the same period. Third, the best way to strengthen urban landscapes' support of well-being is not by pursuing a universal formula to replicate everywhere, but through transformation of some environments that challenge well-being for lots of people.

Thesis results reveal that a paradigm in urban discourse that answers to the challenge above requires that configurational and complexity thinking permeate research and planning to a larger extent than traditionally. This paradigm should avoid merely highlighting the uniqueness of places through descriptive methods. It should equally avoid merely attempting to reduce urban phenomena to universal laws. Instead, it should be situated in the realm of "weak replicability" (Goodchild & Li, 2021) where attempts are made to explain and predict geographic processes but where it is also recognised that spatial heterogeneity is a fundamental feature of such processes. A critical part of the thesis research was to develop spatial analysis methods along these lines that allowed synthesis of results that offer qualitative guidelines for urban designers and planners. Key redesign guidelines for neighbourhoods that challenge well-being are that they should (1) have a balance of residential and daytime populations, (2) avoid extreme concentration of movement, and (3) have accessible natural settings. These guidelines do not represent an exhaustive solution for every context, but rather represent examples of the kind of knowledge generation needed for making complexity thinking practicable in concrete planning.

These guidelines can also be seen as part of a new urban discourse centred around the notion of *topodiversity*. Topodiversity refers to variation across an urban landscape, similar to how biodiversity refers to variation in ecosystems. More precisely, topodiversity means variation in spatial conditions emerging from the natural landscape, the street network's topological configuration, and the distribution of destinations. The thesis research found support that topodiversity permits support of well-being through different pathways, and that increasing topodiversity within neighbourhoods could enhance their contribution to well-being. Topodiversity could furthermore make this contribution more resilient since it allows behavioural adaptations to impacts

on well-being in day-to-day life, such as the ability to escape a busy street and seek refuge in a park or going down to the local square to nurture a sense of connection on a lonely day. It similarly allows adaptation during crisis, for example through safe and easy access from the home to both grocery stores and restorative natural settings.

Between the years 2017 and 2040, the urban regions of the Nordics are projected to grow with 1.2 million people (Gassen & Heleniak, 2019). Housing these people by creating new sprawling urban landscapes would not only intensify the cities' environmental impacts (Pan et al., 2020), but might according to Paper 2 also be detrimental for the inhabitants' mental health. Yet, cramming them into already urban landscapes through infill development would not only serve to further disconnect inhabitants from the biosphere (Andersson et al., 2014; Giusti, 2019), but might according to Paper 1, Paper 4 and Paper 5 erode these landscapes' ability to contribute to experiential well-being. The three guidelines put forth here could safeguard that development steers away from both scenarios. They are means towards ensuring topodiversity in neighbourhoods within an overall spatially contained urban form, and reveal the possibility of future urban landscapes where people to a higher degree have experiences promoting well-being, run lower risks of mental illness, put less pressure on the planet through the habits of their daily life, and can better draw on the landscape as a resource to cope with crisis.

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Thank you

I want to thank the cosmos, for the luck of living in a time and place where you can be paid to pursue the answers to the questions you find most fascinating. Throughout the years of being a PhD student, whenever I have taken the time to reflect on my situation it has been obvious to me that I could not have wished for a better job. It troubles me that most people are not as lucky as I have been.

I want to thank my supervisor, Stephan Barthel, for excellent supervision and relationship building, professionally and socially. Through a rare combination of vision and pragmatism you reminded me to lift the gaze from the details and connect them to the bigger picture. I also want to thank my co-supervisor, Anders Brandt, for making me appreciate the value of the geographic approach (arguably the world's oldest branch of systems thinking), and for providing valuable advice and feedback at key moments in the thesis work process.

I want to thank Noah Linder, Matteo Giusti, and Johan Colding. I am very fortunate to have such good friends and dynamic thinkers as colleagues. I also want to thank everyone else in the Sustainability Science group at University of Gävle, for creating an inspiring academic environment with a bright future ahead of it.

I want to thank Clive Sabel, Tzu-Hsin Karen Chen, and Rikke Dalgaard for your hospitality during my time at Aarhus University in Roskilde and for the stimulating scientific collaborations it yielded.

I want to thank my co-authors, especially Garry Peterson, Ann Legeby, and Terry Hartig. In addition, I also want to thank Lars Marcus. You provided crucial contributions to the papers in this thesis that helped it reach whatever scientific standing it has in the end.

I want to thank the group of PhD students at Stockholm Resilience Centre, especially Laura Elsler, Ami Golland, and Patricia Villarubia, for including me in and making me feel at home during your social and academic activities.

I want to thank Adrian for making me rediscover how remedial it can be to run (and for a 16-year-old friendship that gets better and better). I also want to thank all my other friends. I am convinced that the joy I have mostly felt in undertaking this thesis project would have been greatly reduced, had I not had so much fun outside of work.

I want to thank Marta, for coming into my life and lighting it up in the middle of social distancing and a period of intense work. How can it be that I have only known you for a year and some months? It feels like a lifetime. I love you.

Lastly, I want to thank my family. My sister Klara, the kindest person I know, and my brother Ville, wise beyond his years. And my parents, Karin and Claes, that have always encouraged my curiosity and wholeheartedly supported me in whatever I have undertaken. Even if I sometimes feel that I have bit off more than I can chew, the deep-seated security that it will be alright in the end are thanks to you. I love you all.

Papers
Associated papers have been removed in the electronic version of this thesis.
For more details about the papers see:
http://nbn:se:hig:diva-27137