Systematic review and comparison of densification effects and planning motivations

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Systematic review and comparison of densification effects and planning motivations

SPECIAL COLLECTION: URBAN DENSIFICATION

RESEARCH

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ABSTRACT

Do higher urban densities contribute to more sustainable cities and communities? This paper examines the effectiveness of higher density (as a means) for achieving sustainable urban development (the goal) following three lines of enquiry. First, a systematic review of the scientific literature (n = 229 peer-reviewed empirical studies) is presented on the effects of urban density. Second, the motivations for increasing urban density are studied in a systematic review of Swedish planning practices based on the comprehensive urban plans in 59 municipalities. Third, these two studies are compared to find matches and mismatches between evidence and practice. Although positive effects exist for public infrastructure, transport and economics, there are also considerable negative environmental, social and health impacts. This creates a challenging task for urban planners to assess the trade-offs involving densification and accommodate current urbanisation rates. Some topics are found to be over-represented in research (transport effects), seldom discussed in practice (environmental impact), and misaligned when comparing motives and evidence (social impact). Furthermore, for some topics, urban density thresholds are found that are important because they may explain some of the divergences in the results between studies.

PRACTICE RELEVANCE

The transfer of knowledge from research to planning practice is a serious concern as planning strategies are not aligned with scientific evidence. Planning practice in Sweden is more positive about the contribution of higher density to sustainable urban development than the results of empirical studies warrant. The largest deviation is found in relation to the social impacts of higher density where the planning arguments are not aligned with the evidence. Several reported negative effects of densification (*e.g.* water management, recreational infrastructure, biodiversity) are not sufficiently accounted for in Sweden's

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planning policy and strategy. The narrow planning focus on decarbonising cities and densification needs to be broadened to ensure cities are resilient against the effects of climate change and include mitigation strategies to reduce negative social, environmental and health impacts. The findings can be used to develop evidence-based planning strategies. Other countries can apply this process to assess their planning strategies.

1. INTRODUCTION

Density as a concept in urban planning and design was introduced in the second half of the 19th century to control fires, disease and social disorder that were argued to be related to high densities in industrialising cities (Berghauser Pont & Haupt 2010). As a result, planning controls were developed that prescribed maximum densities, for instance, through building ordinances (Churchman 1999). Today, high densities are judged by many to be the best response to counter current problems such as climate change, land consumption, urban sprawl and loss of biodiversity. The United Nations (UN)-supported Millennium Ecosystem Assessment (MA) (2005), UN-Habitat (2015) and US EPA (2017) argue for city compaction and densification as the pathway towards more sustainable urban development (Haaland & van den Bosch 2015). Densification is argued to provide several positive gains, especially related to the reduction of greenhouse gas (GHG) emissions, innovation and economic growth (Ahlfeldt & Pietrostefani 2017).

However, there are also known negative effects associated with higher density, not least when it comes to environmental degradation. Furthermore, inconsistencies have been identified in the methodologies and techniques used to describe the built environment in these studies (Gren *et al.* 2018). This makes current studies on urban densification difficult to compare and does not allow for any cumulative progress. It also suggests that the currently most prevalent planning approach for sustainable urban development lacks a solid scientific foundation.

The aims of this paper are:

- to provide an overview of the positive and negative effects of urban densification and the degree of scientific consensus based on a systematic literature review
- to understand the current motivations of urban planners in Sweden for advocating urban densification and
- to compare the motives expressed in Swedish planning practice with the scientific literature to identify matches and mismatches between the knowledge base and its application.

A better understanding of these trade-offs can improve sustainable densification. By including all outcomes related to density, this paper extends the findings of a recently published review paper where only environmental outcomes were considered (Gren *et al.* 2018).

The main research questions are:

- Is there empirical evidence that a higher density contributes to more sustainable cities and communities, as per Sustainable Development Goal (SDG) 11?
- How does this evidence match with the main motives used for densification in Swedish planning practice?

To answer these questions, two systematic reviews are conducted. Section 2 introduces a systematic literature review, followed by a quantitative and qualitative synthesis in Sections 3 and 4. Section 5 presents the second study, which examines the motivations for densification in Swedish planning practice. Section 6 compares the overlaps and gaps between the scientific evidence and planning practice. Section 7 describes the limitations of these two reviews. Section 8 summarises the main conclusions and discusses the impacts of these findings for both planning practice and research.

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2. SYSTEMATIC LITERATURE REVIEW: METHODS

To answer the first research question, a systematic literature review of empirical studies published in peer-reviewed journals was performed. This provided an evidence base that covered, as broadly as possible, the theoretically relevant links between density and environmental, social and economic outcomes. [1]

2.1 SYSTEMATIC REVIEW OF EMPIRICAL STUDIES ON THE EFFECTS OF DENSITY

The systematic literature review consists of three steps:

- a search for articles according to an *a priori* search strategy
- the filtering of obviously irrelevant ones using clearly defined inclusion and exclusion criteria and
- a review of the final sample by reading the full papers, following a predefined recording method.

2.1.1 Search procedure

The Web of Science was used as the first source, which guarantees peer-reviewed material. As the authors did not want to steer the search towards specific outcomes, the search was based on keywords related to the *topic* of 'density' (and synonyms). To exclude literature that discusses non-urban issues, keywords such as 'urban' and 'city' were added. To ensure only studies based on quantitative empirical data were selected, keywords to search for this specific type of studies were added. The search was further limited to the English language, which means that a language bias was introduced into the search.[2] The search resulted in 1208 papers.

2.1.2 Inclusion/exclusion criteria

The eligibility of papers was assessed based on titles and abstracts, using three inclusion and exclusion criteria:

- *Topic*: Density should be related to urban development including population density, dwelling density, residential density, *etc.*, as well as urban–rural gradient or sprawl (being the opposite of dense urban forms). Exclusion criteria were density in relation to materials, species, trees, *etc.*
- *Type of study*: The papers should use quantitative empirical data to investigate the relation between density and outcomes. Exclusion criteria were commentaries, review documents, case studies, (agent-based) modelling, qualitative studies, *etc.*
- *Outcome*: The papers should discuss a clearly defined outcome using a quantitative proxy or index. Exclusion criteria were articles without a defined outcome (often method development papers).

Based on these inclusion and exclusion criteria, the selection of articles was reduced in three phases. First, based on their title, which resulted in 509 papers. Second, the same criteria were used in the reading of the 509 abstracts, which reduced the number of full articles to be included in the final review to 330. After reading these articles, another 101 papers that did not fulfil all criteria were excluded in the third and final phase. The results presented in this paper are therefore based on a sample of 229 scientific papers, of which 29% are from North America, 31% from Asia and 22% from Europe. The other continents each represent less than 5% of the sample, but more often even less than 1%.

2.1.3 Research questions

To arrive at a quantitative assessment of the positive and negative effects of densification, the reading of the full articles was guided by a series of research questions. The main question, as stated in the introduction, is whether higher densities contribute to sustainable urban development. This was ascertained by noting the concluded relation between density and a specific outcome. Depending on the statistical method used in the empirical studies, this relation was noted as 'significant correlation' (positive, negative or non-linear), 'insignificant' (if no correlation was

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reported) or 'association' (positive or negative) between density and the studied outcome. A positive relation means that when density increases, the measured outcome values also increase. In some cases, a positive correlation between density and studied outcome is also positive in terms of sustainable urban development, such as an increasing density that is positively associated with people being more physically active. In other cases, a negative correlation can have a positive effect on sustainable urban development, such as an increasing density that is negatively associated with CO_2 emissions, which means that it contributes positively to sustainable urban development. Therefore, the contribution of higher density to sustainable urban development, besides the relation between density and outcome, was also noted. In most cases, this is rather straightforward, such as preserving limited resources—a fundamental sustainability principle. This is more challenging in other areas such as economics where in cases of a high level of ambiguity the contribution is defined as neutral.[3]

Besides the main research question, three additional sub-questions guided the review of the full articles:

- How is the relation between density and measured outcome linked to the geographical context?
- How is the relation between density and measured outcome affected by the type of density measure (the numerator of the density fraction)? This study differentiates between population density, residential density, working population density, dwelling density (*e.g.* number of housing units per area unit), floor space index (FSI) (*i.e.* floor area ratio (FAR) in the North American context; FSI and FAR are calculated by dividing the total built floor space by the area unit), building density, urban cover density (*i.e.* coverage, ground space index—GSI), density type (categorical, *e.g.* urban, suburban and rural neighbourhood), density index (composite, *e.g.* sprawl index), economic density (*i.e.* number of functions or activities per area unit) and perceived density.
- How is the relation between density and measured outcome affected by the area unit and its resolution (the denominator of the density fraction)? This study differentiates between the method to define the area unit (*e.g.* administrative, generated, morphological and ecological unit) and the resolution used, *e.g.* block (defined by streets), neighbourhood, district, city, region and country.

The results are presented using a quantitative synthesis, where data are aggregated and summarised, and a qualitative synthesis, which involves interpreting the data by comparing the results of individual studies, relating them to each other, which leads to a new understanding.

The results are based on the selected 229 articles. An article is duplicated if it studies various outcomes or uses various density measures, area units and resolutions. The data and codings used for the review are available in the data file labelled 'scientific data related to the literature review' in the supplemental data online.

3. SYSTEMATIC LITERATURE REVIEW: QUANTITATIVE SYNTHESIS

Transport was the most frequent category studied in the final sample of 229 scientific papers (35% of all papers). This would have been even 49% if it also included energy consumption, GHG emissions and health effects related to transport. Papers that report on these effects were categorised as 'public infrastructure' for the studies related to energy consumption, 'environmental impact' for the climate effects of transport, and 'health effects' for the pollution linked to transport.[4] This large number of investigations into the relation between density and transport is striking, but not surprising. The now seminal publication by Newman & Kenworthy (1999), which showed a strong correlation between population density and energy consumption related to transport, has influenced the debate on urban development, advocating the compact city concept, and is also the most cited work in this field of research (Gren *et al.* 2018). The five other outcomes are 'public infrastructure' (12%), 'economics' (11%), 'environmental impact' (17%), 'social impact' (13%) and 'health effects' (11%) (***Figure 1***).

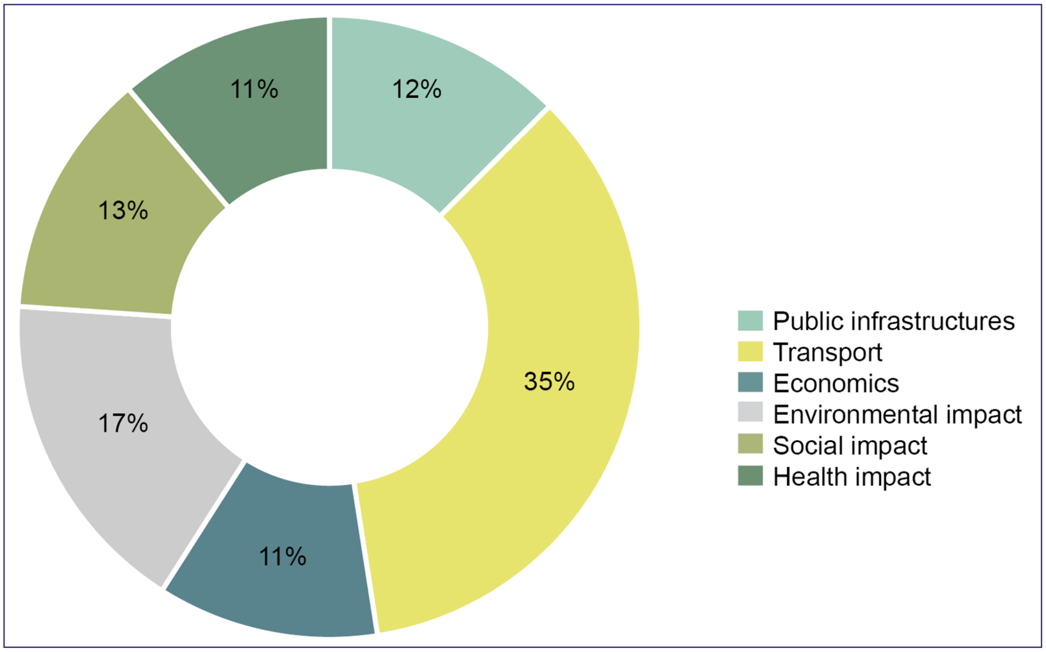

Figure 1 Distribution of the studied outcome categories discussed in the scientific papers.

Half the studies reported a positive relation between density and sustainable urban development, but almost one-third of the studies also showed a negative one. Thus, densification has both advantages and disadvantages. When looking at the various outcome categories separately, a clearer picture emerges of what are these advantages and disadvantages (***Figure 2***). Studies related to public infrastructure, transport and economics more often report positive relations with density, while environmental, social and health effects of higher densities are for the most part negative. Section 4 considers these outcomes in more detail.

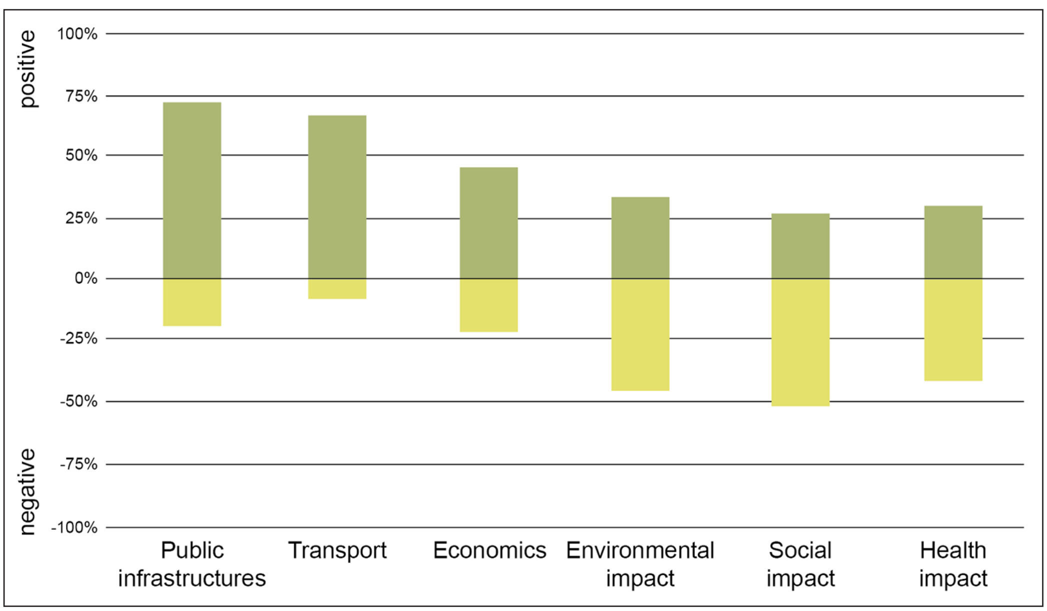

Figure 2 Reported relation between density and sustainable urban development where studies related to public infrastructure, transport and economics more often report a positive relation with density, while ecological, social and health effects of higher densities are for the most part negative.
Note: For further information, see the supplemental data online.

3.1 HOW ARE THE RESULTS AFFECTED BY THE TYPE OF DENSITY MEASURE?

The dominant density measure in all articles is population density (63% including residential and working population), followed by density type (10%) and FSI (6%). None of the studies measured density at an individual level using, *e.g.*, the amount of floor space per person (m^2/person) that could also impact wellbeing and health. Population density was used most frequently in transport studies (73%), followed by economics (72%). These two categories also use working population

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density more often (in 17% and 14% of the studies, respectively, while the average for all studies is 10%). Density type is used more frequently in studies related to health and environmental impact (in 21% and 24% of the studies of the studies, respectively, while the average for all studies is 10%). Due to the field-specific use of measures, it is hard to draw conclusions on the relation between the measures used and sustainable urban development, but the overall trends hold when looking at the results found for studies using specific density measures.

3.2 HOW ARE THE RESULTS AFFECTED BY THE UNIT OF ANALYSIS AND ITS RESOLUTION?

Most studies are based on administrative units such as census tracts or municipal boundaries (65%), followed by generated units such as grid cells, often used in geospatial analysis to combine datasets with varying administrative boundaries (13%) and morphologically defined units of analysis (13%). Very often the morphologically defined units are based on isochrones that depict the area accessible from a point within a certain distance or time threshold (often referred to as buffer zones). Ecologically defined units are underrepresented (4%), which might be explained by the fact that data are often not available for these units and, moreover, the unit is highly linked to environmental studies. Studies on economics primarily use administrative units of analysis (91%), while health studies use relatively often morphological units (27%). Studies based on administrative units of analysis more often report a positive relation with sustainable urban development. Again, this can also be the results of the more frequent use of units of analysis in certain types of studies (*i.e.* focusing on specific outcomes) such as studies on economics that primarily use administrative units.

The resolution of the unit of study is also important to ascertain the relevance of results to the scale level. If a study is based on data gathered on the unit resolution city, it is argued that one should not draw conclusions about the lower neighbourhood scale or higher scales such as regions. In the sample, most studies are based on data on the neighbourhood unit level (41%), followed by district (16%), city (12%) and regional level (10%). No significant differences were found in the results between these resolutions.

4. SYSTEMATIC LITERATURE REVIEW: QUALITATIVE SYNTHESIS

4.1 DENSITY AND PUBLIC INFRASTRUCTURE

Public infrastructure includes topics ranging from technical infrastructure such as roads and sewers, the energy efficiency of these infrastructure and surface water management, to the availability and accessibility of services including recreational infrastructure and housing. In general, the results reveal that a higher density provides advantages from a sustainability perspective for technical infrastructure, resource efficiency and service provision (***Figure 3***). The studies show a consensus that a higher density contributes positively to technical infrastructure in terms of investment costs, operational costs and efficiency. For instance, water service utilities with more customers were able to maintain a higher level of efficiency (Ananda 2014); similar results are reported for road infrastructure (Schiller 2007) and annual operational costs for energy and water infrastructure are lower (Du *et al.* 2016; Persson & Werner 2011; Pflieger & Ecoffey 2011).

A higher population density is also associated with a lower amount of electricity used for cooling and heating (Ko & Radke 2014; Mashhoodi 2018; Otsuka & Goto 2015; Rode *et al.* 2014; Wang *et al.* 2017) and transport (Banister *et al.* 1997; Du *et al.* 2016; Marique *et al.* 2013). But density is not the only variable of importance, because the socioeconomic status of the residents is as much an explanation for low energy consumption as is higher population density (Modarres 2013). Higher density neighbourhoods also have better accessibility to public and commercial services (Dave 2011; Lin & Yang 2006), people use services more frequently (Dempsey *et al.* 2012), and the services provided are more diverse (Adolphson 2010; Schiff 2015). This is important not only from an economic perspective, but especially because having accessible key services in the neighbourhood is important for vulnerable groups (Dempsey *et al.* 2012).

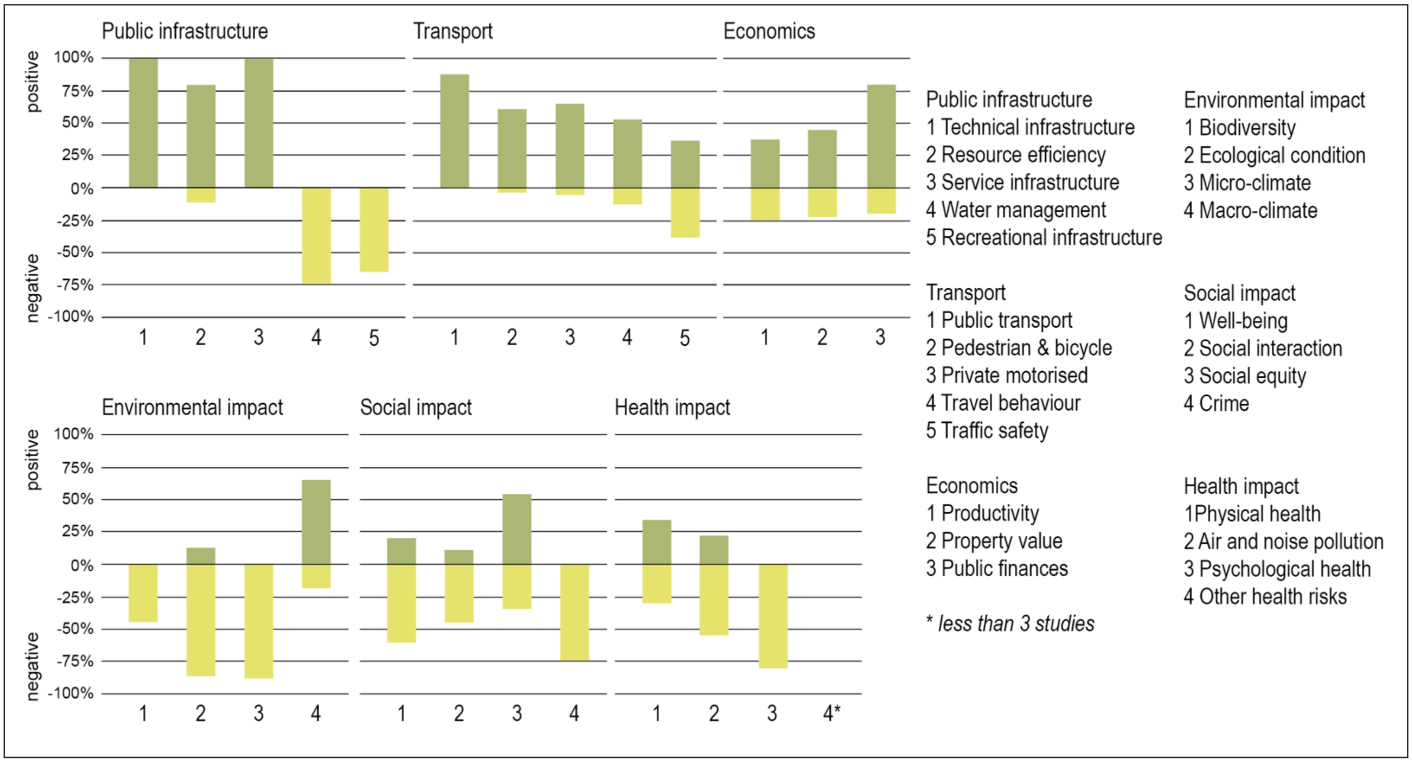

Figure 3 Found relation between density and sustainable urban development (level of the subcategories). *Note:* For further information, see the supplemental data online.

Higher densities do not create optimal conditions for surface water management (Kim *et al.* 2016; Li *et al.* 2016; Trudeau & Richardson 2016) and are a threat to the provision and quality of recreational (green) areas. In the case of water management, the lack of permeable surfaces is the main obstacle and may not be attributable to population density. When it comes to the availability of public and green space, a study in the UK reports that the use of, and perceived access to, recreational (green) spaces is relatively high across the different densities (Dempsey *et al.* 2012). In other words, despite the decrease in surface, the perceived access to green is not negatively affected. Further, a study from North America reports an increasing willingness to vote in referenda for the provision of open space, indicating that people care more about open spaces when population densities are higher (Kline 2006).

4.2 DENSITY AND TRANSPORT

Three different modalities are distinguished in the transport category: public transport, active modes of transport (*e.g.* walking and cycling) and private motorised transport (the car). The fourth subcategory relates to travel behaviour, including trip distance and choice of modality; and the last covers traffic safety.[5] There is strong consensus across the studies that higher densities contribute to an increase in the use of public transport (Houston *et al.* 2015; Renne *et al.* 2016; Sung *et al.* 2014) and active modes of transport (*e.g.* Ewing *et al.* 2016; Kim *et al.* 2018; Zhao *et al.* 2018a), while they reduce car ownership (Coevering & Schwanen 2016; Zhang & Zhang 2015) and vehicle miles travelled by car (*e.g.* Cervero 2002; Lee *et al.* 2014a).

The results also highlight some details that are important. First, commuting trips are more strongly related to density than recreational trips. Most studies on public transport ridership investigate commuting, and only one article reported on weekend ridership where no significant relation with density was found (Lin & Yang 2009). The same insignificance was found for recreational bike ridership (Sun *et al.* 2017). However, a higher population density decreases the likelihood of owning cars (*e.g.* Chen *et al.* 2008; Karathodorou *et al.* 2010), which significantly influences non-work-related trips (*e.g.* Lee *et al.* 2014a; Salon 2009). Second, car trips are more dependent on high density at the trip destination (Cervero 2002; Lee *et al.* 2014a), while the density at the home location (origin) is in some cases shown not to be significant at all (*e.g.* Ding *et al.* 2014; Li & Zhao 2017). On the other hand, cycling and especially walking are more strongly affected by high density at the location where the trip starts: at home (origin) (Lin & Chang 2010; Tabeshian & Kattan 2014). Third, there seems to be a density threshold above which the positive effect of

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higher density on reduced car trips and increased walking and bicycling starts to diminish. Eom & Cho (2015) indicate that the odds of taking walking trips increase as residential density increases, but once the density exceeds a certain level (in this study, between 10,000 and 15,000 persons/km^2), this effect declines. Their study on car usage shows that residents living in the lowest density areas were 3.38 times more likely to take the car, but this gradually decreases to become insignificant beyond a threshold of around 20,000 inhabitants/km^2. It should be noted, however, that studies also highlighted huge cultural differences between mode choices (Buehler 2011), even after controlling for dissimilarities in socioeconomic factors and land use.

Average trip distances and commuting duration are lower for residents living in high-density areas than for those living in low-density areas (Akar *et al.* 2016; Ralph *et al.* 2016). Engelfriet & Koomen (2018) reveal that this is mainly the case when economic density increases, while they could not report significant correlations between commuting distance and residential density. Raux *et al.* (2011) report a negative correlation between density and commuting duration. The reason for these contracting findings might be explained by two opposite effects that, depending on the strongest, result in a positive or a negative effect. Although spatial proximity to amenities reduces travel time, congestion following from density increases travel time. When the latter is stronger, this results in a negative correlation between density and travel time.

The combined results of eight studies on the relation between density and traffic safety are inconclusive, with half the studies reporting a negative and the other half a positive impact. Three studies report that urban density has a statistically significant direct effect on traffic safety, *i.e.* fewer accidents and traffic fatalities occur (Chen & Zhou 2016; Dumbaugh & Rae 2009; Najaf *et al.* 2018). However, two other papers report the opposite and show that an increase in population density yields an increase in traffic accidents (Gladhill & Monsere 2012; Iwata & Managi 2016). In a systematic review on multifunctional streets, a similar discrepancy was highlighted by Stavroulaki & Berghauser Pont (2020) who argued that the number of crashes indeed increased, but their severity and the number of fatalities decreased in more central locations because of the lower vehicular speeds.

4.3 DENSITY AND ECONOMICS

Studies on economics are primarily about the agglomeration effects of densification, such as higher productivity, employment rates, profits or number of entrepreneurs, companies and innovations (60% of the papers on economics), followed by the relation between density and property values (26%) and public finances (14%).

There is strong consensus on the positive role of density on productivity and innovation, but some studies also emphasise that densities that are too high can shift the ratio between agglomeration benefits and diseconomies related to traffic congestion and/or environmental pollution (Sedgley & Elmslie 2011; Zheng 1998). The positive effect of higher density relates to an increase in productivity as a result of an agglomeration effect or economy of scale (*e.g.* Ciccone 2002; Fallah *et al.* 2011; Jennen & Verwijmeren 2010). This is not equal across all markets as some studies point out (Abel *et al.* 2012; Cruz & Teixeira 2015; Morikawa 2011). For instance, the positive effects for the creative, knowledge-based service industries are considerably larger than those for the manufacturing and retail industries. Furthermore, agglomeration benefits can result in a reduced interest to invest in training and innovation (Brunello & De Paola 2008), as well as a diminished start-up activity (Di & Vuri 2010; Hans & Koster 2018).

Property value is positively affected by density (Ding 2004; Liu & Jakus 2015; Nase *et al.* 2016), although it is also pointed out that proximity to parks, lakes and open spaces is beneficial for property prices (Asabere 2014; Nilsson 2017). This might also explain the non-linear relation reported by Nilsson (2017) in which density was perceived as a disamenity beyond a certain threshold level.

There is a consensus on the benefits of higher density for public finances. The per capita costs of providing public infrastructure such as roadways, other transportation, sewers, waste collection, housing and community development, parks, education and libraries decreases as density increases (*e.g.* Carruthers & Ulfarsson 2003; Cubukcu 2008; Edwards & Xiao 2009). However, higher density is also associated with higher costs for public safety, such as costs related to traffic accidents and an increase in crime (Iwata & Managi 2016). As a result, reduced expenditures for public services as highlighted above may be offset by increased expenditures on public safety.

4.4 ENVIRONMENTAL IMPACT OF DENSITY

Within the category environmental impact, the effects of density are distinguished for biodiversity and ecological conditions as well as microclimate impacts and climate change effects on the macro-level.

There is consensus about the negative impact of higher densities on biodiversity due to lower habitat suitability in urban areas compared with rural areas (Li *et al.* 2016), including a lower richness and abundance of forest species (Villasenor *et al.* 2014). Moreover, it is reported that genetic diversity and population size decrease over time in high-density areas. An exception is found for 'urban adapters', species that thrive in urbanised areas (Rochat *et al.* 2017). Further, housing density correlates with higher shares of impermeable (sealed) surfaces that, in turn, have a negative impact on overall environmental conditions (Shaker 2015). This is confirmed for streams (Alberti *et al.* 2007) and natural water in general (Bressler *et al.* 2009), as well as for the increased levels of dissolved inorganic nitrogen fluxes (Lee *et al.* 2014b). The negative impact of higher density on biodiversity at a local scale might have positive effects at the regional scale. Barbosa *et al.* (2010) address this scale dependence in the biodiversity–human correlation and report a positive correlation between population density and endemic species richness at the regional scale which disappears at more local scales. Total species richness, however, was reported to be positive across scales.

Most papers on the microclimate investigate the urban heat island effect, measured as increased land surface temperature, and all report that the more built-up the urban area, the higher its temperature (*e.g.* Balazs *et al.* 2009; Christen & Vogt 2004; Kamruzzaman *et al.* 2018). Besides lower permeability and greater population density, lower tree canopy cover is also considered to be an important explanatory variable (Trlica *et al.* 2017; Zhao *et al.* 2018b). The role of vegetation is therefore important, and because of the collinearity between these two variables, it is often difficult to determine whether cooling effects are caused by lower density or higher green cover (Yang *et al.* 2011). This also indicates that higher density could be mitigated by higher tree coverage.

Besides these negative environmental effects of density, there is strong consensus that residents living in communities with a higher density emit fewer GHG emissions from both cooling and heating (Norman *et al.* 2006; Qin & Han 2013; Son *et al.* 2018) and transport (*e.g.* Cao & Yang 2017; Travisi *et al.* 2010). In relation to transport, this is especially true for passenger vehicle emissions, while the results for truck-related emissions are inconclusive (Iwata & Managi 2016). Further, Ottelin *et al.* (2014) report higher overall emissions for metropolitan dwellers in comparison with lower density areas, which is explained by the significantly higher emissions from air travel, a factor ignored by all other studies. This highlights the need to include all transport modes when studying GHG emissions.

Thus, the reported impacts of a higher density on biodiversity, ecological conditions and the microclimate is primarily negative, but scale dependency in the biodiversity–human correlation associated with displacement effects needs to be considered as well. Effects related to climate change are positive because of reduced GHG emissions, often related to reduced car mobility. However, despite the reduction per capita, the *overall* levels increase in more urban areas simply because more people live in those areas (Wang *et al.* 2018; Zhou & Wang 2018). Finally, carbon sequestration that could help to reduce the overall CO_2 levels was shown to be lowest in developed urban areas and highest in rural areas (Li *et al.* 2016). In other words, denser areas have less capacity to mitigate the higher emissions.

4.5 SOCIAL IMPACTS OF DENSITY

To synthesise the social impact of higher density, a distinction is made between wellbeing, social interaction, social equity and crime. The subcategory wellbeing or quality of life focuses on the individual, while the subcategory social interaction concerns the meeting and interaction between individuals.

More than half the studies report a negative impact of density on wellbeing, while only 12% report a positive effect. In most cases, the negative wellbeing effects are based on studies using quality-of-life indicators (*e.g.* Baldassare & Wilson 1995; Fassio *et al.* 2013; Kytta *et al.* 2011), but in some cases more specific indices are used, such as children's stress (Schwirian *et al.* 1995) and nuisance (Cao 2016). The quality-of-life indicators often include multiple dimensions (Fassio *et al.* 2013), but in the end they all come down to the same question: How satisfied are you with your life?

Besides quality of life, social interaction also shows primarily negative correlations with density. One might expect a positive effect given that people living in proximity could find interaction easier. However, the results of the review do not confirm this, and density has been shown to affect social interaction positively in only one study and negative in almost half the studies (the others report a neutral or non-linear relation to density). For instance, how often a person talks with or visits their immediate neighbours tends to be lower, not higher, in high-density areas (Brueckner & Largey 2008; Jun & Hur 2015; Nguyen 2010). Furthermore, density is not positively associated with 'community', including perceptions of safety, social interaction and stability (Dempsey *et al.* 2012). Only one paper found statistically significant direct positive effects on opportunities to meet new people (Mouratidis 2018), and two papers present inconclusive findings on the link between density and social interaction (Dave 2011; Freeman 2001). Interestingly, some papers on both wellbeing and social interaction report a non-linear relationship with density (Bramley *et al.* 2009). Wellbeing, social interaction and group participation tend to improve as density increases up to a medium level, and then fall off at higher levels.

In relation to social equity, half the papers indicated a positive association with density, but the findings are at times contradictory. The first positive effect reported is that higher densities correlate negatively with price polarisation (Antoniucci & Marella 2018). In other words, in cities of higher density, a smaller disparity between housing unit prices in the centre and the suburbs was found. However, another study reports that housing affordability decreases when density increases (Lin & Yang 2006). It might be that housing prices increase in general in denser cities, which reduces affordability without affecting polarisation. This reflects the more vulnerable position of low-income households in higher density environments, as was confirmed by a study where the most important predictor of social equity is the proportion of social housing. It seems that this offers the opportunity to ameliorate some of the negative effects that the market would otherwise deliver to low-income groups in denser cities. Furthermore, it is shown that higher incomes grow more quickly in denser cities, suggesting a disproportionate agglomeration of incomes in the highest income categories (Sarkar *et al.* 2018). Another study partly confirms this, but displays that the relationship between density and income segregation follows a quadratic function, first rising, then falling, as densities increase (Pendall & Carruthers 2003). In other words, segregation is low in low-density regions, highest for moderately dense regions and somewhat less high in high-density regions.

The relation between crime and density exhibits a negative trend, with an increase in population density yielding an increase in crime (Dave 2011; Iwata & Managi 2016; Lin & Yang 2006). However, the negative relationship is only significant if the neighbourhood or dwelling is *perceived* as crowded with people, but not when density is measured (Dave 2011). The low number of papers in this category means caution should be applied to these results. Furthermore, all results are based on Asian studies only, which makes it hard to state whether these findings are true in other contexts as well.

4.6 DENSITY AND HEALTH

Studies on the health impact of density are divided into the effects on physical health, health related to air and noise pollution, psychological health, and other health risks such as accidents and natural disasters. The studies on the effects of density on physical health can be subdivided into those related to obesity and physical activity, on the one hand, and other physical health issues such as loss of fertility, lung cancer and heat vulnerability, on the other. The studies that report a positive impact of higher density are almost all related to the first group, in which increased density is associated with lower rates of automobile use and higher rates of walking, which in turn is associated with a lower Body Mass Index (BMI) (Frank *et al.* 2010; Pendola & Gen 2007; Yamada *et al.* 2012). It can be concluded that a higher density has a positive impact on health when it comes to activating the population to walk more, which, in turn, reduces BMI and obesity-related health problems. It is merely functional walking that is affected by density and not recreational walking, where the importance of mixed land uses is emphasised to promote walking, in addition to high density (Chaix *et al.* 2017; Forsyth *et al.* 2007; Frank *et al.* 2004).

A negative impact of density on physical health is reported in four studies that indicate increased heat vulnerability (Kim & Ryu 2015), a higher death rate in relation to epidemics (Li *et al.* 2018), lower fertility rates (Sato 2007) and a higher risk for lung cancer (Xu *et al.* 2018). Wang *et al.* (2016) showed, however, that it is traffic and not density that plays a significant role in predicting lung cancer incidence. Thus, higher densities in combination with *lower* motorised traffic volumes might not have a negative impact on lung cancer. Studies that especially investigated air pollution and related health impacts show that air pollution concentration increases when density increases in line with the earlier discussion on GHG emissions (Choi 2018; Clark *et al.* 2011; Li *et al.* 2016). However, other studies indicated that an increase in population density is associated with a significant decrease in the concentration of pollutants, and emphasise that this might be explained by the amount of green areas also present (Choi 2018; Yuan *et al.* 2018) and the availability of public transport (Mou *et al.* 2018).

There is strong consensus on the reported negative impact of density on psychological health. Hence, high-density neighbourhoods have more people with stress-related health problems or depression (Chen *et al.* 2015; Dave 2011; Fassio *et al.* 2013). Noteworthy is the variation in the role of two density measures in one study where the first describes the intensity of the building bulk using FAR (FSI) and the second described building coverage ratio (GSI) (Knoell *et al.* 2018). Contrary to the authors' assumptions, the results disclose that using FSI in the statistical model decreases the correlation compared with using GSI. This means that the compactness of the built fabric or the lack of open space plays an important role, while FSI and building heights play a relatively small role in explaining perceived urban stress.

5. SECOND STUDY: DENSIFICATION MOTIVES IN SWEDISH PLANNING PRACTICE

5.1 INTRODUCTION

To answer the second research question: How does this scientific evidence match with the main motives used for densification in Swedish planning practice?, a second systematic review was performed using comprehensive plans. The objective of this second review is to investigate which motives are used in relation to the intended urban development and, more specifically, in relation to density. Motives are identified by searching for arguments that are used with a clear semantic relation to density. In other words, the aim is to uncover the motives used for or against densification.

Comprehensive plans are used as source material because they guide urban development in the Swedish planning system. They describe how each municipality intends to use its land and how national and regional goals of significance for sustainable development are taken into account.[6] The Swedish case is chosen because it is often discussed as a showcase for sustainable urban development (with examples such as Hammarby Sjöstad and Norra Djurgårdsstaden). The focus on one country allows for a comparison of plans developed under comparable circumstances (reasonably common juridical, political and cultural frameworks), but with varying population densities. Both the reviews (literature review and the review of comprehensive plans) were conducted parallel to develop and synchronise the categories of effects and motives, which in turn allows the results of the two reviews to be mirrored. The results of this comparison will be presented in Section 6.

5.2 METHODS: SYSTEMATIC REVIEW OF MUNICIPAL COMPREHENSIVE PLANS

For the systematic review of Swedish comprehensive plans, a representative sample of 59 plans from the total 290 municipalities in Sweden was selected.[7] The review includes comprehensive plans for the period 2000–19 (85% are less than 10 years old). As density is a strategy more often discussed in larger cities, and these are much fewer in number, all municipalities with more than

100,000 inhabitants are included. This includes the three largest municipalities with more than 300,000 inhabitants (Stockholm, Gothenburg and Malmö) and 13 municipalities with between 100,000 and 300,000 inhabitants. Of the 274 smaller municipalities (with fewer than 100,000 inhabitants), a random selection of 43 municipalities is included in the final sample. The results of the review are assessed using *a priori* defined questions. This allows for a systematic and transparent assessment of the comprehensive plans that can be discussed with a high level of objectivity. The following sub-questions are used to review the comprehensive plans systematically:

- Which motives are used in relation to densification?
- Is the expected outcome deemed to be positive or negative for sustainable urban development?
- Is there variation in the results between municipalities with different population density?

To answer the first sub-research question, a search was performed for 'density-motive' couples in the comprehensive plans. This was performed in two steps. First, the search function was used to find the keyword 'density' as well as related terms such as 'dense' and 'densification' and some opposing terms for dense such as 'sprawl' and 'dispersed'.[8] Second, a coupled motive was registered if a motive was mentioned in the same sentence or paragraph and clearly linked to density. The motive must have a clear semantic relation to the keyword density to be included in the analysis. The search does not include any results from images, captions, maps, illustrations or headings. To answer the second sub-question, the motives are categorised as having a positive or a negative contribution to sustainable urban development. For the third sub-research question, correlation analysis was used to find trends between the number of 'density-motive' couples and the municipalities' population density (inhabitants/ha). A simple comparison of means was used to describe numerically differences in the motives used in municipalities of varying population density.[9]

5.3 FINDINGS

In the 59 comprehensive plans, the keyword density (and similar terms) was used 3298 times, whereof 905 times it was accompanied with a motive (*i.e.* 27% of total usage has a motive). In more than three out of four cases (76%) the stated motives support the argument that higher density contributes to sustainable urban development. How often different motives are used is shown in ***Figure 4***, which depicts the dominance of the category public infrastructure (38%) and a rather low usage of environmental motives (5%). The next most frequently used motive is transport related (19%), followed by arguments related to economics (13%), social motives (12%) and health (12%). The motives used for densification are in most cases positive, except for motives related to its environmental impact and health (***Figure 5***).

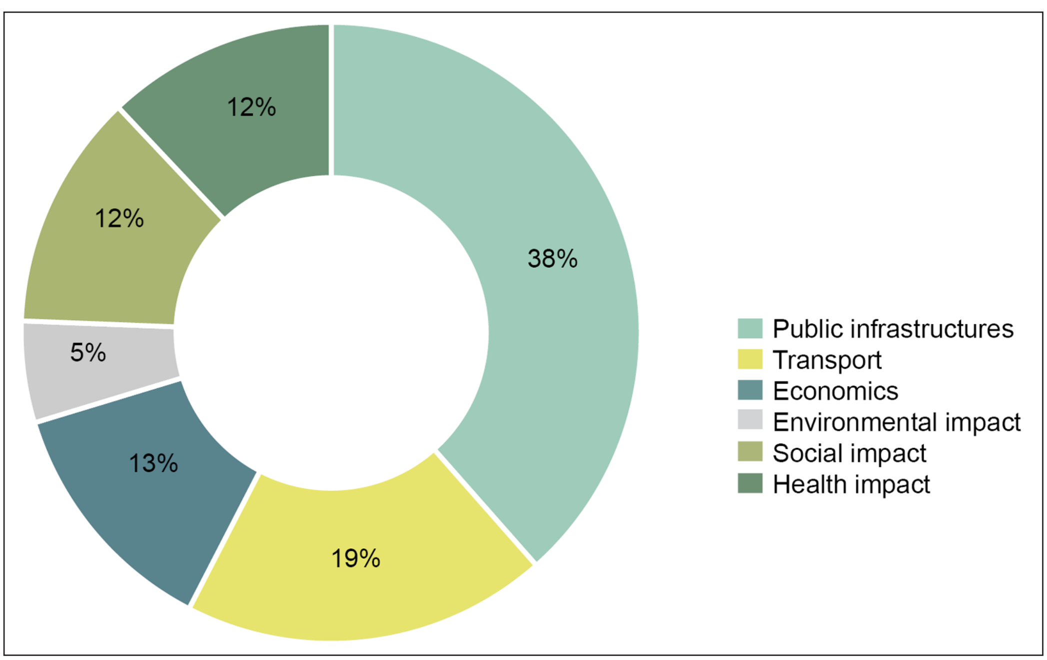

Figure 4 Distribution of the motives related to the density used in 59 Swedish comprehensive plans.

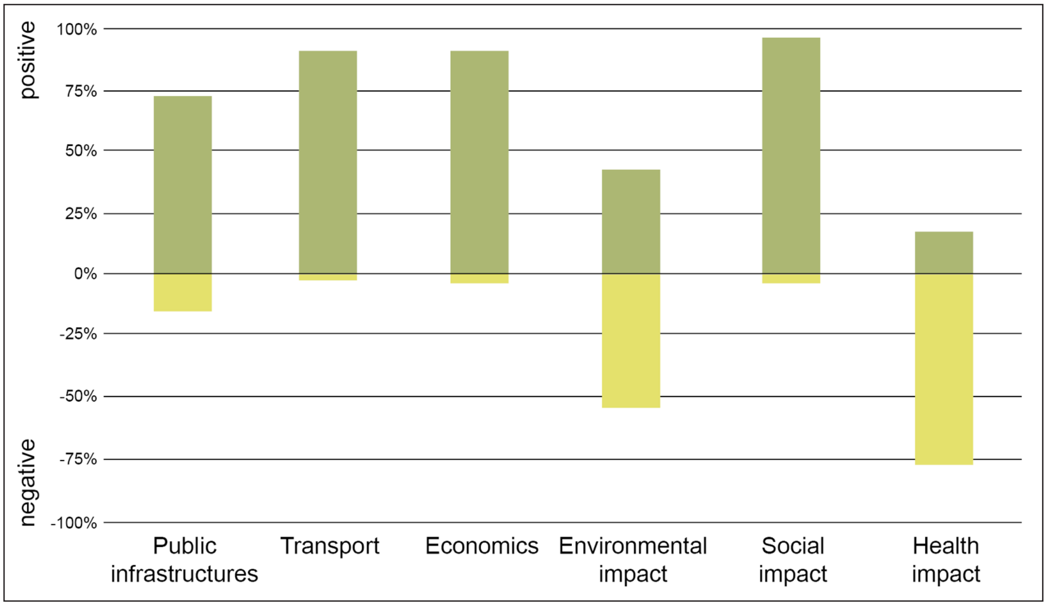

Figure 5 Argued contribution of higher density to sustainable urban development in 59 Swedish comprehensive plans.

Note: For further information, see the supplemental data online.

For public infrastructure, the most frequent mentioned motives are the presence of and/or access to services (34%), resource efficiency (including safeguarding land outside cities, 25%), followed by the presence of and/or access to recreational green spaces (18%) and technical infrastructure (15%, *e.g.* roads, sewage, housing, *etc.*). For transport-related motives, three-quarters of the cases are about promoting sustainable modes of transport. The argument is that higher densities will contribute to more people using public transport or choosing more active modes such as walking or cycling. The other motives are related to car usage and travel behaviour (10% and 16%, respectively). Traffic safety is not discussed in relation to density. When economics are discussed, most of the arguments relate to public finances and labour productivity (63% and 34%, respectively). Arguments related to land and property values are largely absent (3%). Arguments related to the environmental impact of density are little discussed, with half the motives being about climate change effects (42%). Social impacts occur frequently, especially related to social interaction and crime (51% and 34%, respectively), but wellbeing and equity are less often referred to (3% and 12%, respectively). Health arguments related to density are mostly limited to noise and air pollution (87%), while other physical and psychological health effects are rarely discussed (2%).

The most often used motive in favour of higher density is the presence of and/or access to services (13% of the total amount of motives), mostly associated with a positive contribution to sustainable development. The second most frequently used argument is the role of density is resource efficiency (10%). Other popular positive motives are related to public transport (8%), public finances (7%) and social interaction (6%). A frequently addressed negative effect of higher density is noise pollution (10%). Also, the presence of and/or access to recreational green space is relatively often used as an argument for densification (43%) or as a risk associated with densification (37%). Other frequently stated negative effects of densification are negative health effects related to noise and air pollution (7%) and problems related to surface water runoff (3%).

5.3 DIFFERENCES BETWEEN MUNICIPALITIES

Population density correlates positively with the frequency a motive in relation to density is mentioned in the comprehensive plans (0.28, $p = 0.035$). In other words, more urbanised populated municipalities more often discuss density with a motivation in their comprehensive plans.

The comparison of means shows that more densely populated municipalities more frequently use motives related to the presence of and/or access to recreational green (the mean within this category is 1.61 times higher than the mean of the full sample) and promoting active modes of transport (1.14), while municipalities of lower density more frequently highlight public transport as a motive for densification (0.35). Also, the presence of and/or access to services is mentioned more frequently in the lower dense municipalities (0.64) as well as public finances, resource efficiency and social interaction (between 0.75 and 0.78). The other motives are either equally often used or the numbers of motives were too few to compare means.

6. COMPARISON OF THE RESEARCH EVIDENCE BASE AND PLANNING MOTIVES

The most often used motive in Swedish comprehensive plans relates to public infrastructure (38%), while this category is not so well studied (12%). This does not necessarily mean that the motives used are not supported by the evidence. A single study may, for instance, provide sufficient results to influence a number of practices, but it might also highlight a need for more research on these topics. For recreational infrastructure, the empirical studies show that despite the decreasing surface area for recreation, the perceived access to recreational areas is not decreasing, while it is considered being of lower quality. Also, planning practice discusses recreational infrastructure in both positive and negative terms (*cf.* ***Figures 3*** and ***6***). Within the subcategory resource efficiency, the most frequently used argument relates to safeguarding land outside cities. However, this is little studied, probably due the obvious relation between the two. Energy efficiency, on the other hand, is more frequently studied but is not discussed in the comprehensive plans.

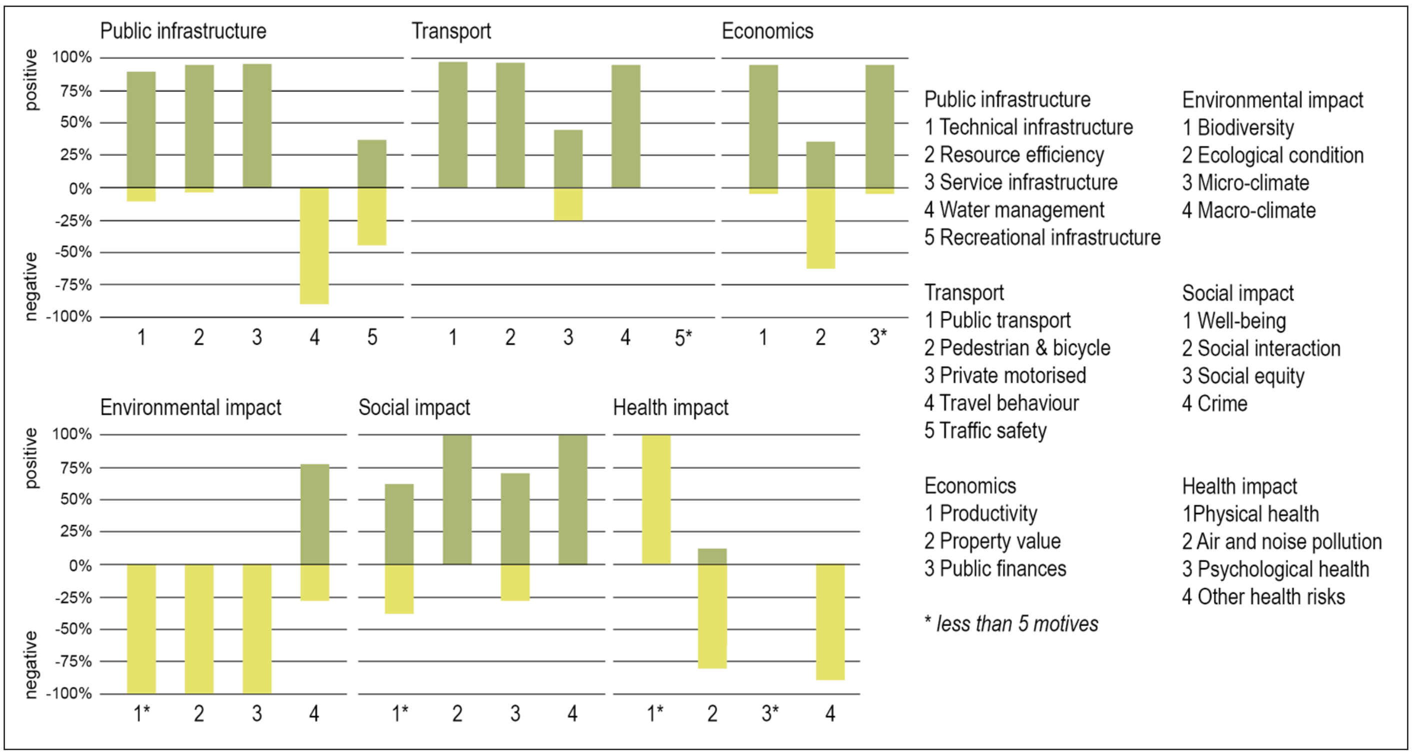

Figure 6 Argued contribution of higher density to sustainable urban development in 59 Swedish comprehensive plans (level of the subcategories).

Note: For further information, see the supplemental data online.

The category that is empirically studied most frequently is transport with a strong alignment between the studies showing that higher density correlates with more sustainable modes of transport (public transport and active modes of transport increase and car usage decreases). This is also an argument frequently used in Swedish planning practice in favour of densification. Transport is thus an example where findings from research align with practice. However, there is one exception. The only topic not addressed in the comprehensive plans in relation to density is traffic safety. Low vehicular speed has been highlighted as the most important variable that in combination with high density might increase the number of crashes, but their severity and the number of fatalities decrease.

Another well-studied but little-discussed topic in comprehensive plans is the environmental impact of density. Only 5% of the planning arguments relate to this, while 17% of the research studies report on it. Higher densities negatively affect biodiversity, ecological conditions and

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the microclimate, which is infrequently acknowledged in planning practice. The only positive environmental impact of higher density is reduced GHG emissions per capita, which is highly related to reduced car mobility. However, while the per capita emissions decrease in more urban areas, the absolute levels can increase locally with a negative health impact. This is an example of divergence between local and global effects that was discussed earlier in relation to biodiversity.

Economics is a topic well studied in relation to density and frequently used as an argument for densification. However, the motives used in practice often relate to public finances, while empirical studies more frequently focus on productivity and property values.

For the two subcategories health impact and social impact, three severe inconsistencies and/or problems with knowledge transfer were observed. First, inconsistencies were found between the proven effects and the motives, *e.g.* social interaction and crime. Second, comprehensive plans ignored certain topics where there is evidence for negative density effects, *e.g.* wellbeing, physical and psychological health. Third, a lack of empirical studies exists on some of the frequently used arguments, *e.g.* noise pollution and other health risks.

7. LIMITATIONS

Some methodological choices used in these systematic reviews might have caused biases in the results. First, the reliance on Web of Science may have excluded relevant research. Second, the search term 'dens*' (*i.e.* density, densification, dense) that is used may have caused a bias in favour of studies on the positive role of densification, whereas the problem of low density (sprawl) is considered less. Further, the review of Swedish planning documents is obviously limited and could be extended with other cases. However, this paper does not claim to represent all European countries, or countries around the globe. It aimed to exemplify how the current planning paradigm on densification is interpreted in a country such as Sweden.

The categorisation of motives and the effects of densification was developed in an iterative manner by the researchers working on the two systematic reviews and driven by the data presented in the articles and comprehensive plans, respectively. Obviously, the grouping could have been done in other ways. It would, for instance, be interesting to distinguish between local and global effects, as well as between individual and collective gains or benefits. The usage of subcategories allows others to redefine the main categories or adjust the categories proposed in this paper. One of these adjustments in the paper pertains to the main category 'transport'. In this paper it includes all transport modes, travel behaviour and traffic safety, while energy consumption and emissions related to transport are not included. These are categorised as 'public infrastructure' and 'environmental impact', respectively. This choice and others can be easily adapted to other research questions by aggregating the subcategories differently. The database of source material (the 229 articles) can also be used to find articles that present results from one continent (*e.g.* 67 results for 'Europe'), use a specific measure for density (*e.g.* three results for 'vertical density') or articles that combine a set of such search terms.

Lastly, the effects of density are reported as trends (negative, positive, neutral and non-linear) without reporting on the size of the effect. This is important but requires a meta-analysis where the effects are quantified and then statistically combined. This paper chose to cover all outcomes of densification and it was therefore beyond its scope to include the accumulation of studies for each effect, but an obvious next step would be to perform such a meta-analysis.

8. CONCLUSIONS

The strong dichotomy is striking between, on the one hand, the positive effects of density on public infrastructure, transport and economics and, on the other, the negative environmental, social and health impacts. It is a challenging task for urban planners to balance these two spheres (the planning system and one's social and personal life), while at the same time acknowledging the need for some form of densification to handle current urbanisation rates.

The results reported in the empirical studies are for the most part consistent across the studies, *e.g.* the positive impact of higher density on public ridership and the negative impact of a higher density on the microclimate. Other results seem to be inconsistent across studies, such as the divergent findings in relation to traffic safety, productivity (economics), social equity and physical health. These might be the result of threshold effects (those that do not occur until a certain level), displacement effects (divergence between local and global effects) or cumulative effects when several mechanisms interact in different ways (additive, synergistic or counteracting), *e.g.* more intense traffic in areas of higher density that increases the risk for collisions, but lower speeds in these areas of higher density, which reduces the severity of injuries. In other words, depending on the effect studied, the number of collisions or the severity of injuries, the results are different. The combination of the quantitative and qualitative synthesis as presented in this paper is therefore crucial in providing both an overview and an insight into the detailed mechanisms at play.

Similar outcome trends are found in North America, Asia and Europe, with some minor differences, where North American studies generally present more positive results. The other continents are scarcely studied, which is striking because arguably the Global South is one of the places where excessive densification might be most harmful due to the lack of urban infrastructure to sustain it. Minor differences were found when comparing differences in outcome of studies using different measures of density, units or resolutions. This means that the findings presented are to a large extent generic.

In four of the six main categories, planning practice in Sweden is more positive about the contribution of density to sustainable urban development than warranted by the results of empirical studies. The largest deviation is found in relation to the social impact of higher density, where the arguments are not aligned with the evidence found in the empirical studies. In the Swedish municipal comprehensive plans, social interaction is argued to be associated positively with higher density, but findings from empirical studies show the opposite. The other three arguments in favour of higher densities (transport, economics and public infrastructure) are mostly in line with the effects reported in empirical studies, but practice is overoptimistic about these positive effects and does not discuss nuances that are important for urban design and planning. For instance, higher density is associated with lower car usage, which is both reported in the scientific studies and used as a motive for densification. However, the more nuanced truth is that density affects the number of functional car trips (*i.e.* commuting), while it is less clear how recreational trips are affected. Further, refinements about the difference between density at working and home locations are not often discussed in comprehensive plans, while this has been shown to be of importance for commuting and recreational trips, respectively. Yet another example relates to economics where the positive impact of higher density is not generally true for all economic markets; it is more advantageous for the creative, knowledge-based service industries than for manufacturing and retail.

Based on the comparison of findings in the two reviews, blind spots are identified. For practice, the limited use of environmental arguments is worth noting. The arguments employed are aligned with the scientific findings, so this is not a problem of inconsistency but of underrepresentation. The same can be said about the health impacts of higher densities where the comprehensive plans almost solely discuss health effects in relation to noise and air pollution, but give very little attention to other health effects such as the positive effects of density on walking and reducing obesity, and the negative effects of density on psychological health.

Blind spots can also be identified for the research community where motives for densification that are often used in practice lack scientific support. For instance, the safeguarding of agricultural and natural land outside cities is infrequently studied. Some health effects of density also need more research evidence, especially in relation to the risks related to noise pollution and other human health risks, *e.g.* floods, landslides, accidents during the transportation of dangerous goods. Another blind spot is the role of air traffic in relation to density which was only mentioned in one study when reporting an increase in air travel and corresponding emissions by people living in denser environments. Partly this might be the same phenomena of not including recreational trips

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when studying the effects of higher density, because business travellers account for only 12% of airlines' passengers.

The combined findings from the two reviews presented here can be used to formulate new research questions and planning strategies. A first line of enquiry is the earlier mentioned meta-analysis where displacement effects and density thresholds should be included. Second, density effects in the Global South should be studied empirically. Third, the narrow planning focus on decarbonising cities and densification needs to be broadened to make cities more resilient. Most of the reported negative effects of densification (water management, recreational infrastructure, biodiversity, ecological condition, microclimate, air and nose pollution, and psychological health) can be related to a lack of permeable green areas. However, the role of vegetation compared with density is difficult to determine because of the collinearity between the two variables, as some studies highlighted. It is therefore not known whether these trade-offs can be mitigated by increasing vegetation. This clearly sets a research agenda to investigate these two variables together and then develop planning strategies that include both densification and urban greening, in line with the conclusion in Gren *et al.* (2008). This combination can be used to define the lower and upper limits of density to frame an environmentally safe and socially just space in which humanity can thrive in line with the 'doughnut economics' proposed by Raworth (2018), but now as a model for transforming our cities.

NOTES

1 Preliminary results of both reviews were presented at the Beyond 2020 conference (Berghauser Pont *et al.* 2020; Haupt *et al.* 2020), where mainly the quantitative syntheses of the reviews were presented. Furthermore, at the time of the conference, only parts of the review were finalised, while the current paper presents the complete results. More precisely, 179 full articles were included in Berghauser Pont *et al.* (2020). The present paper includes the additional 151 articles.

2 The following keywords were used: TS = (dens*) AND TS = (urban OR city OR cities) AND TS = (empiric*) refined further through DOCUMENT TYPE = (article) AND LANGUAGES = (English). Further, another set of keywords is added to make sure environmental studies that often use the term 'urban gradient' instead of 'density' were included. These search terms were TS = ('urban gradient' OR 'urban rural gradient' OR 'urban to rural gradient') AND TS = (empiric*).

3 An interpretation was made based on the contemporary mainstream discourse on sustainability.

4 'Public infrastructure' includes aspects related to capacity (*e.g.* land, sewerage, but also energy, and road and rail infrastructure) and services such as commercial and public service, recreational green space and housing. The second category, 'transport', includes the different modalities public transport, pedestrian, bicycle and car as well as subcategories that relate to the use of these transport modes (car ownership, trip distance, choice of modality, general travel behaviour]). 'Economics' includes three subcategories: labour productivity (including innovation and entrepreneurship), property values (including housing prices) and public finances. 'Environmental impact' includes biodiversity, mainly focusing on topics related to species diversity; ecological quality, which relates to ecosystems and their stability over time; and macro- as well as microclimate topics. The subsequent category is 'social impact'. Here issues related to wellbeing, social interaction, social equity and crime are distinguished. The subcategory wellbeing or quality of life focuses on the individual, while the subcategory social interaction concerns the meeting and interaction between individuals. The last main category 'human health' includes topics such as walkability and obesity, but also other physical health issues such as loss of fertility, lung cancer and heat vulnerability. Health problems related to noise and air pollution are grouped separately because they represent the top two in disease burdens among environmental factors in Europe. The last two subcategories include psychological health and 'other health risks', including accidents and natural disasters.

5 Emissions and energy consumption related to transport are not reported here, but can instead be found in the category ecology (macroclimate) and infrastructure (energy efficiency), respectively.

6 The Swedish planning system consists of the regional plan, the comprehensive plan, the area regulations and the detailed development plan (Planning and Building Act). In the comprehensive plan, the municipality must present the basic characteristics of its intended use of land and water. The comprehensive plan is not legally binding but is used as guidance in the development of the detailed development plan and in the permit-granting process (see *https://www.boverket.se/en/start/building-in-sweden/developer/planning-process/*). Comprehensive plans are developed by municipalities that must consult with, among others, the county administrative board, regional bodies, neighbouring municipalities and citizens. The plan weighs and prioritises public interests against each other. Individual interests are not taken into account and, therefore, the content cannot be appealed against.

7 The plan here was to include 60 municipalities, but Örebro's comprehensive plan (part of the random selection) was excluded because the municipality has a digital plan with interactive maps, but no comprehensive text.

8 The plans are written in Swedish, therefore the following Swedish keywords were used for the search: *tät*, *förtätning*, *täthet*, *gles*, *hög exploatering* and *låg exploitering*.

9 This is expressed as a ratio between the mean population density for the whole sample and the means within each motive category. A number >1.0 means that the argument is more frequently used in denser populated municipalities, while <1.0 indicates the opposite (the argument is more frequently used in municipalities of lower density).

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COMPETING INTERESTS

The authors have no competing interests to declare.

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SUPPLEMENTAL DATA

Supplemental data for this article can be accessed at: *https://doi.org/10.5334/bc.125.s1*

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