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Abstract. One of the current dominant strategies proposed for sustainable urban development is densification. UN Habitat prescribes a density of over 150 inhabitants per hectare to realize the UN Sustainable Development Goals. While some authors advocate the very reasonable benefits of density, others emphasize the potential drawbacks. The main goal of this paper is to provide a systematic review of international research on urban density and its potential benefits and drawbacks for sustainable urban development. 1208 articles were selected from Web of Science and after the screening of abstracts, 330 papers were found eligible to be included in the quantitative synthesis. Results show that the effects of densification that dominate literature are transport related studies (41%), followed by studies focusing on economics (14%), social effects (12%) and human health (11%). Least studied effects are resource efficiency (1%), service (3%) and urban environment (4%). Positive correlations with higher density are reported for transport and economics, while ecology, social impact and health show mainly negative correlations with higher density. The findings reported are generic as similar trends are found in North America, Asia and Europe and only minor differences in outcome are found in studies using different measures of density, unit or scale of analysis.

1. Introduction

The compact city approach is since the 1990s the main planning strategy to cope with the fierce competition between land uses as a result of global urbanization and is regarded as one of the main strategies for sustainable urban development [1]. It is argued to provide, through densification and compact building, several environmental gains, especially related to the reduction of greenhouse gas emissions, innovation and economic growth [2]. However, there are also negative effects associated with higher density, not least when it comes to environmental degradation [3]. Importantly, great inconsistencies have been identified in the methodologies and techniques used to describe the built environment, including a great disparity in scales [3]. This make current studies on urban densification difficult to compare and does not allow for any cumulative progress, suggesting that the currently most prevalent planning approach for sustainable urban development lack enough scientific foundation. Hence, although current urbanization rates require some form of densification, there is need for a better understanding of its trade-offs. This paper therefore aims at providing an overview of positive and negative effects of densification and the degree of scientific consensus. A systematic review is used to collect an evidence base that covers, as broadly as possible, the theoretically relevant links between

density and corresponding environmental, social and economic effects. By including all outcomes related to density, this paper contributes to a recently published review paper where only environmental outcomes are considered [3]. We further restrict our sample to empirical studies published in peer reviewed journals included in Web of Science, which guarantees scientific rigor. Here, the current paper deviates from another recently published review [2] where mainly other search methods were used.[5] We do not impose geographical restrictions in the search for articles nor any time limit. Further, various geographic scales of analysis are covered from neighborhood to cross-region comparisons.

The objective of the current review is to evaluate the effectiveness of higher density (i.e. as means) to arrive at more sustainable urban development (i.e. the goal). The main research question is therefore: *Is there scientific evidence that high density solutions contribute to more sustainable urban development, one of the United Nations sustainable development goals (SDG), ´Sustainable cities and communities´ (SDG11)?* We do not address this question directly, but through the effects of densification such as good health and well-being (SDG3), inequality (SDG10), climate change and its impacts (SDG13), and biodiversity (SDG15). The reported outcomes are in a next step categorized in terms of their contribution to sustainable urban development. In most cases, this is rather straight forward such as preserving limited resources – a fundamental sustainability principle, while 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[6].

The outline of the paper is as follows. In the next section, the method for the systematic review is explained. In the third section, the quantitative synthesis is discussed guided by four research questions. The last section discusses these findings in relation to sustainable urban development by highlighting the areas of consensus and ambiguity. This will be used to define recommendations for practice and an agenda for future research.

2. Method

For the systematic literature review, we follow standard best-practice approaches as discussed in [4]. From a systematically selected sample of studies in the field, both an overview can be gained of the outcomes discussed (i.e. environmental, social and economic) as well as the consistency in the results and their magnitude. In short, the process of the analysis consists of three steps: first, search for articles according to an a priori search strategy; second, filtering out of obviously irrelevant ones; thirdly, reviewing the final sample following a pre-defined method. Web of science is used as first source, which guarantees double peer-reviewed material. As we do not want to steer the search towards specific outcomes, we focus the search on keywords related to the *topic* urban density (and synonyms). To exclude literature that discusses non-urban issues, keywords such as urban and city are added and to make sure we only include studies that are based on quantitative empirical data to arrive at conclusion, we add keywords to search for this specific *type of studies*. The search is further limited to peer-reviewed studies and English language, which means that a language bias has been introduced into the search. 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).[7] This resulted in a total amount of 1208 papers. In the next step, 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

[5] Less than 10% in this review of the selected papers were selected through Web of Science, while one third of the paper were collected through Google Scholar and one third was recommended by colleagues working in related fields.
[6] An interpretation has been made on basis of contemporary mainstream discourse on sustainability.
[7] We added another set of keywords to make sure that we include environmental studies that often use the term urban gradient instead of density. These search terms were TS=("urban gradient" OR "urban rural gradient" OR "urban to rural gradient") AND TS=(empiric*).

dense urban forms); exclusion criteria were density in relation to certain materials, species, trees, etc.
- *Type of study*. The papers should use quantitative empirical data to prove the relation between density and the outcome; 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 is reduced, first, based on their title, which resulted in a reduction from 1208 to 509 papers. Second, the same criteria are used in the reading of the 509 abstracts, which reduced the number of full articles to be included in the final review to 330.[8] To arrive at a quantitative assessment of the positive and negative effects of densification, the reading of the full articles is guided by a series of research questions. The main question is whether higher densities contribute to sustainable urban development. This is in first instance done by noting the actual correlation between density and a specific outcome; the results are either positive and significant, negative and significant, or insignificant. A positive correlation means that when density increases, the measured outcome values also increase. This is in some cases 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, the negative correlation can still have a positive effect on sustainable urban development, such as an increasing density that is negatively associated with CO_2 emissions, which still means that it contributes positively to sustainable urban development. We know from earlier reviews [2,3] that evidence is not similar across different outcomes (e.g. transport vs health related outcomes) or across different continents, which brings us to the first two research sub-question:

1. What is the scientific evidence that density contributes to sustainable urban development and how do the results vary across various outcome categories?
2. Is the scientific evidence different across various continents?

Further, there are strong indications that the methods used in studies, such as scale and type of density measure, affect the outcome [3]. This is of high importance when such knowledge is to be translated into planning recommendations such as UN Habitat's recommendation for higher density for sustainable urban development [5]. This brings us to two additional research sub-question:

3. How is the relation between density and measured outcome affected by the type of density measure such as population density, built density or land cover used in the study?
4. How is the relation between density and measured outcome affected by the unit and its resolution such as e.g. address, generated grid of 10m or census tract on 2-digit postcode level used for the analysis?

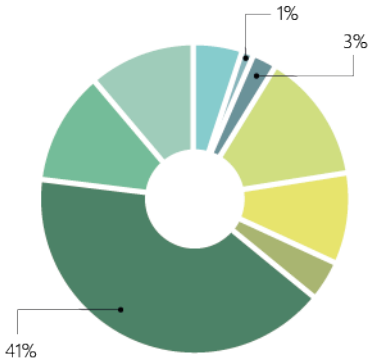
The results are presented based on the selected full articles where an article is duplicated in case it studies various outcomes or uses various measures for density.

3. Quantitative synthesis of results

The outcomes identified in the reviewed articles are grouped in nine main categories (Figure 1). It should be noted that these categories are defined posteriori, based on the article reviewed for this paper and a parallel reading of comprehensive plans in Sweden [6]. The latter study aims to give an overview of the

[8] At the time of writing of this paper, 179 full articles are included. The additional 151 articles will be included in the presentation at the conference.

claimed benefits of densification in Swedish urban development practice. The identified main categories are further divided into sub-categories.



Category	Amount of articles	Percentage
Technical infrastructure	9	5%
Resource efficiency	1	1%
Service	5	3%
Economics	23	14%
Climate & ecology	16	9%
Urban environment	7	4%
Transport	70	41%
Social	20	12%
Human health	19	11%

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

The first category, *technical infrastructure*, includes aspects related to capacity of e.g. water and sewerage that changes when more housing units are added to an area. The three other sub-categories are surface water management, energy, and road and rail infrastructure. The second category, *resource efficiency*, covers the effective use of existing natural and land resources. It should be noted that we only include the resource ´land´ here in general terms and the resource ´natural areas including agricultural land, nature and forests´. The more economically driven resource efficiency argument is found under the category *economics*. The next main category is *service*, including the sub-categories accessibility to service; the customer base of commercial and public service; presence and accessibility of recreational green; and housing. The subsequent category *economics* includes three sub-categories: labor productivity (including innovation), property values and public finances. *Ecology* includes three motives: biodiversity, mainly focusing on topics related to species diversity; ecological quality, which relates to ecosystems and their stability over time; and climate related issues in general. *Urban environment* is the category that groups all topics that describe the spatial qualities of the built environment. It covers the following four sub-categories: mixed land uses, cultural and esthetic qualities, micro-climate, and spatial qualities such as proximity. *Transport* is the category with most sub-categories. We distinguish three different modalities (public transport, pedestrian & bicycle, and car); sub-categories that relate to the use of these transport modes (car ownership, trip distance, choice of modality, and general travel behavior); energy use related to transport; and emissions related to transport. A last category is travel safety where especially traffic accidents are in focus. The subsequent category is *social impact*. Here we distinguish issues related to well-being, social interaction, social equity, and crime. The sub-category well-being or quality of life focuses on the individual, while the sub-category social interaction concerns the meeting and interaction between individuals. The last main category, *human health,* includes topics such as walkability and obesity, and psychological health, including stress and problems related to for instance sleep. Noise and air pollution are included as separate sub-categories as they represent the top two in disease burdens among environmental factors in Europe [7].

The full article reading shows that most articles are written by first authors with an affiliation to a department of architecture and/or urban planning (40%). Almost the same number of papers is written by authors from non-spatial disciplines such economics and medicine (37%), followed by authors with an affiliation in geography (12%), and civil engineering (7%). When comparing the outcomes in all studies with the outcomes in papers written by first authors with an affiliation to a department of architecture and/or urban planning, a slight deviation is found; more articles focus on transport related outcomes of densification and impact on service, while fewer articles address economics, ecology, and resource efficiency. This might be explained by the fact that mobility and service are traditionally central

to urban planning, while economics and ecology (including resource efficiency) are mainly studied within their own disciplines.

The outcome studied most often is transport, representing 41% of the articles in our sample (Figure 1). This is striking, but not surprising. The now seminal publication by Newman and Kenworthy [8], which showed a strong correlation between population density and energy consumption related to transport, has not only influenced the debate on urban development, advocating the compact city concept, but is also the most cited work in this field of research [3]. Five other outcomes of densification that are discussed relatively often are economics (14%), social (12%), health (11%) and ecology (9%).

3.1. Does densification contribute to sustainable urban development?

While half of the studies report a positive relation between density and sustainable urban development, one third of the studies show a negative relation and 12% of the studies show that density does not play a significant role. Densification has thus both advantages and disadvantages. When looking at the various outcome categories separately, we get a clearer picture of what these advantages and disadvantages are (Figure 2). Studies on the effects related to transport, economics, service and technical infrastructure more often report positive correlations, especially for transport related outcomes and economics. The ecological, social and health effects of higher densities are for the most part negative and outcomes categorized as urban environment are more often negative than positive.

The distribution of studied outcomes is highly uneven, as we have discussed above. This unbalance remains when we look at some of the sub-categories (Figure 3). Transport related studies focus mainly on sustainable modes of transport (public transport and active modes, together 37%), followed by private car as mode of transport (14%), trip distance by car (14%), and car-transport emissions (16%). Fewer articles study density in relation to traffic safety and travel behavior (9% and 10% respectively). 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 (52% of the papers om economics), followed by the relation of density with public finances (17%) and property values (13%). Studies on the social impact of densification focus primarily on well-being (45%) and less on social interaction (15%), crime (10%) and social equity (5%).

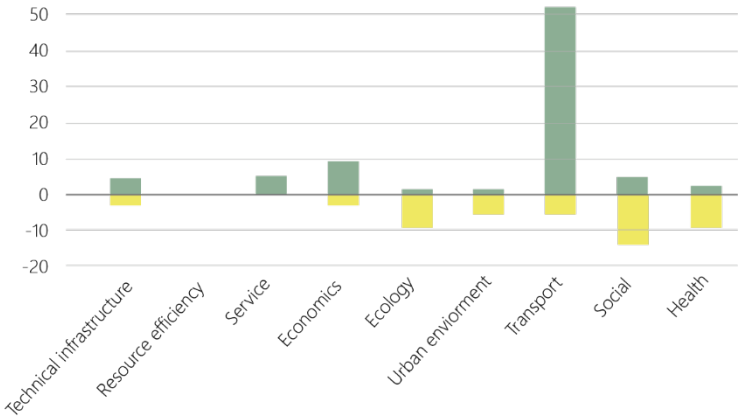


Figure 2. Main outcome categories where the amount of outcomes deemed positive for sustainable urban development are depicted in green and negative ones in yellow.

Figure 3. Distribution of the studied effects of density: From left to right: outcomes related to transport, economics, and social effects.

The top-20 of most frequently studied sub-categories (Figure 4) show that the choice for active modes of transportation is most often studied and categorized as contributing positively to sustainable urban development. Next sub-category is labor productivity, an economic argument to densify. The third most often studied outcome is physical health[9] that shows an ambiguity in its contribution to sustainable urban development. This is a surprising finding as it is often argued that higher density contributes to more walkable neighborhoods and thus, it is assumed, positive health effects. Based on our findings, we can indeed confirm the positive relation between density and the choice of more active modes of transport. However, the review also shows that this does not prove that it automatically contributes positively to physical health. The following three sub-categories are transport related and report a primarily positive contribution of density in terms of reduced car usage, car-related emissions and motorized trip distance. The next two sub-categories, well-being and ecological conditions, show a mainly negative effect on sustainable urban development.

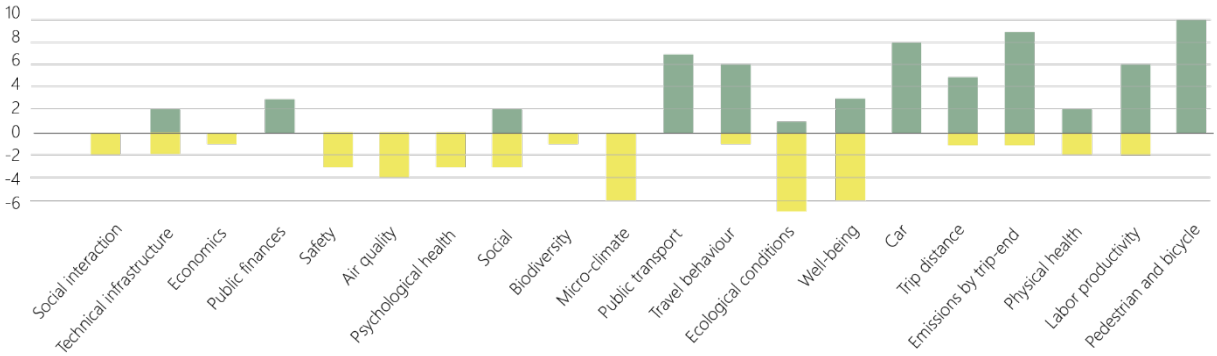


Figure 4. Top-20 of studied outcomes where the amount of positive effects on sustainable urban development are depicted in green and negative ones in yellow.

3.2. Is the scientific evidence different across various continents?

Of all empirical studies included in this review, 40% is conducted in North America, followed by Asia (29%) and Europe (23%). The other continents are underrepresented, representing less than 5% of the sample and more often less than 1%. In general, more positive effects of density are reported in the

[9] The total number of papers is 11, but only 4 reported significant positive or negative effects (see appendix).

North American studies (54%) compared to Europe (41%) and Asia (37%), which might be related to the fact that North American cities have lower densities in general.

The bulk of studies in North America concerns transport (51%), followed by economics (13%), ecology (10%), health (10%), and social impact studies (9%). In Asia, transport dominates as well (41%), followed by social impact and health studies (each 14%), ecology (10%), and economics (8%). Europe has the least transport studies in comparison to North America and Asia (only 25%) and has an equal number of studies related to economics (also 25%), followed by social impact studies (16%), health (13%), and the urban environment (8%). In other words, the same categories are studied most frequently in all three continents but Europe deviates from the other two with less focus on transport. Further, in North America, studies on mode choice, trip distance and travel behavior dominate, while in Asia, studies on emissions related to transport dominate and in Europe, the studies focus mostly on sustainable modes of transport and travel behavior.

The strongest positive relation between density and sustainable urban development that is reported in all studies relates to transport. In North America, transport related studies report a primarily positive relation to sustainable urban development (74%). In Asia and Europe, the number of transport related papers are fewer and the reported effect on sustainable urban development is a bit weaker in Asia in comparison with North America but stronger in Europe. In the North American studies, positive contributions to sustainable urban development are also reported for technical infrastructure and economics. Studies related to ecology, social impact and human health show a negative impact in line with the results where all studies are included. This trend is repeated, but more strongly, in the two other continents; positive results are found in relation to transport and economics, while negative effect are reported in relation to ecology, social impact and health.

3.3. How are the results affected by the type of density measure?

The dominant measure used to calculate density in all articles is population density; 50% of all studies use this measure, followed by density type[10] (14%) and Floor Space Index [11] (8%). There are some patterns in the data worth to note such as the even greater dominance of the use of population density in transport studies (63%). Further, working population density is mainly used in studies related to transport and economics, while FSI is more frequently used in studies related to social impact. 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 it seems that the overall trends found hold when we look at the results found for studies using specific density measures.

3.4. 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 (61%), followed by generated units such as grid cells, often used in geospatial analysis to combine datasets with varying administrative boundaries (19% of the articles use generated units). Morphologically or ecologically defined units of analysis are underrepresented (6% and 4% respectively), which might be explained by the fact that data often is not available for these units. Further, not surprisingly, the ecologically defined unit of analysis is most often used in studies related to ecology, while the morphological unit is used in transport and social impact related studies. Studies on economics primarily use administrative units of analysis. Noteworthy is that 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.

To know at which scale level the results of an analysis have relevance, the resolution of the unit of study is also important. If a study is based on data gathered on city level, it is argued that one should not

[10] Density types is a diverse category such as urban, suburban and rural neighbourhood types, but have in common that they are based on density measures that are grouped in different classes.

[11] Referred to as Floor Area Ratio in the North American context. FSI and FAR are calculated by dividing the total built floor space by the area unit (e.g. plot, block or neighbourhood).

draw conclusions on the lower neighborhood scale or higher scales such as regions (the so called MAUP problem) [9]. In our sample, most studies are based on data on neighborhood level (37%), followed by district (22%), city (12%) and regional level (11%). We did not find significant differences in the results between these resolutions, which means, contrary to our hypothesis, that results can be interpreted as generic, independent of the resolution used.

4. Conclusions and discussion

Almost half of the studies included in this review focus on transport where higher density is shown to correlate with more sustainable modes of transport and less greenhouse gas emissions and thus to contribute positively to sustainable urban development. The second most studied outcome is economics that, again, has demonstrated positive contribution to sustainable urban development. Negative effects have been found in relation to ecology, social impact and human health. Some exceptions to this can be found in the sub-categories physical health and social well-being but results here are inconclusive. Similar outcome trends are found in North America, Asia and Europe with some minor differences where North American studies generally present more positive results. Similar minor differences were found when comparing differences in outcome of studies using different measures of density, units or resolutions. This means that findings presented are to a large extent generic, which is important when knowledge is to be transferred to planning practice. However, the review also highlights the need to shift the focus away from transport related research to less frequently studied outcomes and especially the ones that show deviating results such as well-being and physical health. The strong dichotomy between, on the one hand, the positive effects of density on transport and economics and, on the other hand, the negative effects for ecology, social issues and human health is striking. It also formulates a challenging task for urban planners to balance these two spheres (the system and the lifeworld), while at the same time acknowledging the need for some form of densification to handle current urbanization rates.

Acknowledgments

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