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Adaptation of circular design strategies based on historical trends and demolition patterns

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Abstract. With new knowledge on current trends in construction and demolition, circular design strategies can be adapted to recent developments in construction, thereby providing knowledge about the potential for reducing global warming, resource consumption, and the amount of construction waste. By examining data from public registers on historical demolitions and building statistics, it is possible to examine the patterns in demolished buildings to uncover which building factors may influence whether buildings are demolished or renovated. In the following, data from demolitions in Denmark will be linked to data for newly built and existing buildings. The results show that factors initiating demolition are distributed differently between high- and low-population areas. Furthermore, the increase in new forms of construction means that circular design strategies such as reuse, recycling, and adaptive reuse can only cover a small proportion of the need for new construction.

1. Introduction

The construction industry is responsible for about 40% of all anthropogenic CO_2 emissions [1] and produces 34% of the all waste in OECD countries [2]. Construction is therefore an important focus area in reducing global warming, resource consumption, and the amount of waste. By maintaining and renovating buildings, it is possible to extend their lives, thereby avoiding demolition and reducing the need for the construction of new buildings. However, due to the scientific focus on new construction, there is a lack of knowledge concerning why some buildings are being demolished [3] instead of renovated or transformed, and to what extent these demolitions can provide circular construction materials and elements to cover the need for materials to carry out new construction. In several contexts such as LCA (life cycle assessment), it is assumed that buildings will be demolished when they reach a certain age. In relation to the environmental impact, therefore, a building's year of construction is decisive in deciding when it should be demolished. Studies show that other building-specific factors than age may be more significant concerning whether buildings will be demolished: for example, the number of floors or type of materials may be more determining factors [4]. Other relevant factors may be economic, such as the cost of housing and the potential net salvage value of the building [5]. A reduction in the local population may also lead to a declining need for housing, resulting in a larger number of vacant buildings needing to be demolished [6]. At the same time, the existence of vacant buildings in an area often has a significant impact on local sales prices for housing, leading to a greater risk of more vacant buildings and final demolition [7]. By applying circular design strategies when renovating or transforming buildings at risk of demolition, it is possible to contribute local social, economic, and global environmental benefits [8]. Alternatively, former industrial buildings can also be repurposed through adaptive reuse, thereby reducing the need for new materials. However, if a building cannot be beneficially preserved from an economic, social, or environmental point of view, it is still essential to consider circular strategies such as urban mining and still attempt to achieve environmental or economic benefits from demolishing the building by recycling or reusing the materials. By examining data from public registers on historic demolitions and building statistics, it is possible to examine patterns in the demolished buildings to uncover which factors may influence whether buildings are demolished and how we can adapt circular design strategies. This is possible by gaining access to high-quality data from Danish municipalities regarding annual rates of demolition, which can then be linked to public data on building registrations. The data can then be used to answer the following questions: i) Are trends in new construction and demolition evenly distributed between cities and sparsely populated areas? ii) Does the demand for housing mean that other building types will be demolished? And ii) Can materials from demolition realistically meet our need for new construction materials?

2. Methods

2.1. Data collection

Data on new construction, extensions, and existing buildings are extracted from the data portal by Statistics Denmark. The following databases have been used: i) BYGB34 [9], ii) BYGV22 [10], and iii) BYGB12 [11]. The BYGB12 database is an annual inventory of the number of buildings in Denmark from 2010 to 2021 divided by area, building use, area interval, and ownership. BYGV22 is a statement of construction activity per quarter from 2006 to 2021, separated by the number of buildings, and new construction areas and extensions divided by area, building use, and construction time. To calculate the size of the existing building stock, BYGB12 data from 2011 to 2021 for the total existing building area were used, divided by area, year of construction, and building use. This study only includes the above-basement floor area from BYGB12. Data for calculating demolition rates have been extracted from the Danish Building and Dwelling Register (BBR). BBR was established in 1976 and is the Danish national register that contains information about all Danish buildings and their technical facilities. BBR is publicly available and can be accessed through various online portals for single properties, regions, and nationally. As there is no portal for accessing data on demolition in BBR over a longer period, for this particular research the BBR administrator made an extract of all demolition cases reported by municipalities with associated historical BBR information on the demolition cases. The dataset contains 152,300 cases of demolition completed in the period from February 2000 to June 2020.

2.2. Data-handling

To investigate demolition trends, the annual demolition rate (see equation (1)) for different construction periods and different building uses is calculated.

$$\mathrm{DR}_{x,y} = \frac{\mathrm{D}_{x,y}}{\mathrm{E}_{x,y}} \tag{1}$$

Where DR is the demolition rate in year x for construction period y. $D_{x,y}$ is the total floor area demolished in year x for construction period y. $E_{x,y}$ is the total floor area of the existing building stock on the first day of year x for construction period y. To calculate the demolition rate for building use, y represents the specific building use instead of the construction period.

In the analysis, the national data represent a sparsely populated area, although the national dataset also contains data for densely populated areas. To represent a densely populated urban area, an area called the Copenhagen region has been defined from the database. This area is defined by combining data for Copenhagen municipality with data for sixteen densely populated surrounding municipalities: Frederiksberg, Dragør, Tårnby, Albertslund, Ballerup, Brøndby, Gentofte, Gladsaxe, Glostrup, Herlev, Hvidovre, Høje-Taastrup, Ishøj, Lyngby-Taarbæk, Rødovre, and Vallensbæk. There have been ongoing

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restructurings in BBR and to the requirements for registration. We therefore assessed that before 2011 there were too many errors and deviations to make an accurate overall dataset for demolition. In addition, datasets from Statistics Denmark on existing buildings have only been compiled since 2011. As a result, 2011 was chosen as the start year for the study.

3. The existing building stock

In 2019, Danish building stock had a total area of 749,496,000 m^2 [9] divided into 4,474,174 buildings [11]. The building stock in the Copenhagen region accounted for 13.5% of the total building stock in Denmark in 2019. Of that total, housing accounts for the vast majority in square meters, with a total share of 45% nationwide. In the Copenhagen region, the share of housing is much larger, at 61% of the total building stock in the region. Multi-family houses account for a large part of the housing, whereas single-family houses make up the largest housing share (see Figure 1) nationwide.

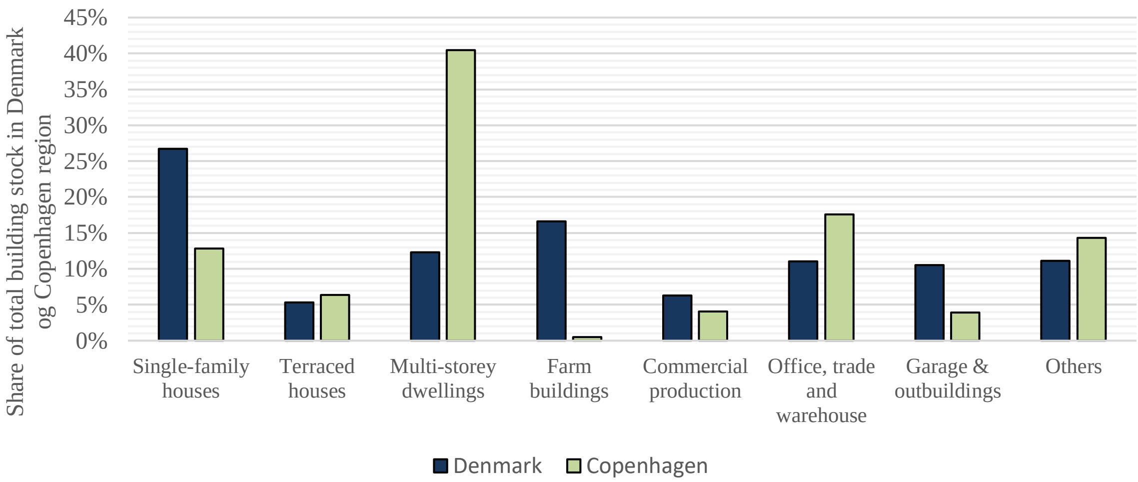

Figure 1. Distribution of building area in relation to different building uses in Denmark and the Copenhagen region in 2019.

4. New construction

The amount of new construction in Denmark peaked in 2008 at 9,428,614 square meters. From 2008 to 2011 there was a 48% annual decrease in new builds (see Figure 2). After 2011, new construction in Denmark began to increase, but in 2019 was still 22% below the peak level of 2008. In the Copenhagen region, the trend is different than in the rest of Denmark. In the Copenhagen area there has been much more growth in new construction since 2011, which means that in 2019 74% more new construction in square meters was built compared to before the financial crisis of 2008. In 2019, new construction in Copenhagen accounted for 17.5% of total new construction in Denmark, even though the existing building stock in Copenhagen only accounts for 13.6% of the country's entire building stock. This means that new construction in Copenhagen is higher than in the rest of the country. Concerning the expansion of existing buildings, overall there has been a decrease in the total area of extensions in Denmark generally and in Copenhagen specifically. Nationally, the annual floor area of extensions has decreased by 58% from 2006 to 2020, and in Copenhagen by 48%. While the expansion of existing buildings fell over the period, the area of new buildings increased, which could indicate that new construction is being preferred over extensions of existing buildings. Therefore, we should ask whether this also means that demolition subsequently replaced by new construction is preferred over extensions of existing buildings.

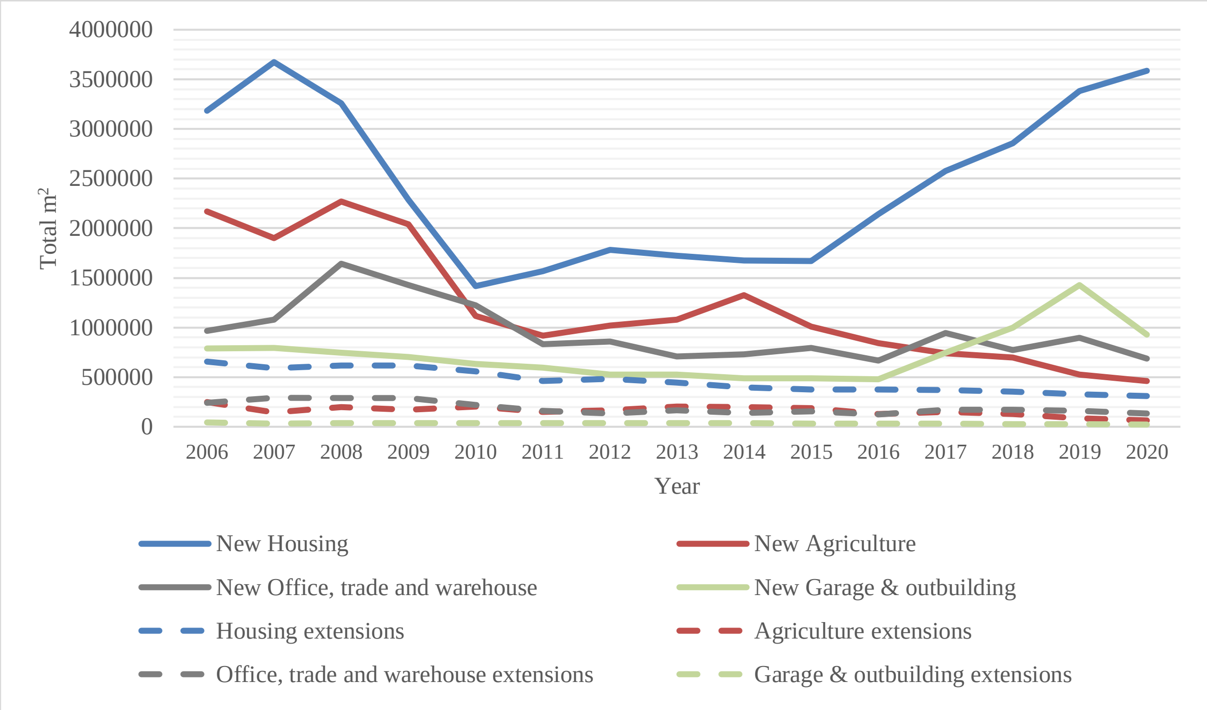

Figure 2. Overview of the annual square meters of new construction and extensions in Denmark from 2006 to 2020.

When the total area of new builds is split into different building uses (see Figure 2), a different pattern emerges regarding the various building uses, one that deviates from the general trend. The increase in new builds is mainly driven by constructions of new dwellings, which accounts for 46% of all new construction in Denmark in 2019 and has been increasing since 2010. On the other hand, new construction of farm buildings and offices, shops and warehouses has declined since the financial crisis of 2008, indicating a declining demand for these building types. The new construction of garages and small buildings also declined in the past, but it experienced a significant increase since 2016. New constructions of garages and small buildings accounted for 19.5% of all new construction in 2019, even though this building use only accounts for 10% of the total existing building stock. In Copenhagen the same trend is seen, but here garages and small buildings make up only 4% of the entire building stock.

5. Demolition

5.1. Demolition rates for different building uses

Nationally, the average demolition rate (i.e. $DR_{x,y}$ as estimated using equation (1)) was 0.24% from 2011 to 2019, and 0.19 % for the Copenhagen region. Concerning the factors that can lead to decisions to demolish, Figure 3 show some general tendencies whereby the demolition rates for housing are substantially lower than for buildings with industrial applications. Moreover, the demolition rate for industrial construction in densely populated areas tends to be substantially higher than the average demolition rate for industrial buildings in Denmark. Here, it is especially production buildings that are at greater risk of being demolished if they are located in urban areas.

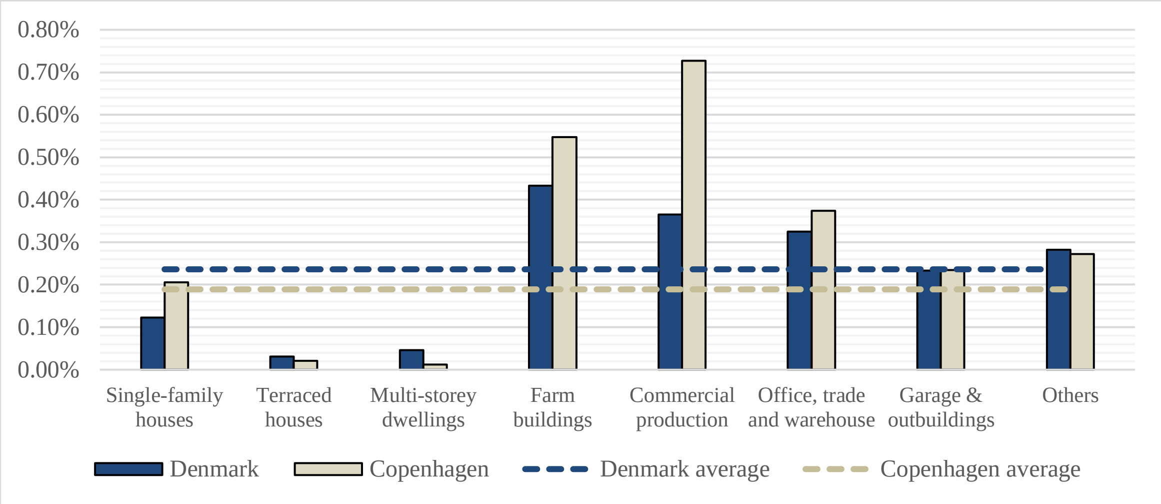

Figure 3. Average demolition rates for different building uses in Denmark and the Copenhagen region from 2011 to 2019.

In addition, the results show that for housing there is also a difference between Denmark and Copenhagen, the demolition rate for single-family homes being greater in Copenhagen than the national demolition rate for single-family homes. In contrast, the demolition rate for multi-family dwellings is as low as 0.01% in Copenhagen, or five times lower than the national demolition rate for multi-family homes.

5.2. Demolition rates for different construction periods

When the demolition rate is calculated over different construction periods (see Figure 4), two different and opposite trends emerge between Copenhagen and Denmark, where old buildings in Copenhagen are at much less risk of demolition than old buildings in the rest of Denmark. For buildings in Copenhagen built before 1909, the demolition rate is around 0.05%. After that, the demolition rate increases the younger the buildings are, reaching its maximum of 0.39% of the existing building stock for buildings built from 1950 to 1959, both for buildings demolished in the Copenhagen region and nationally. After that, the rate of demolition begins to decrease again.

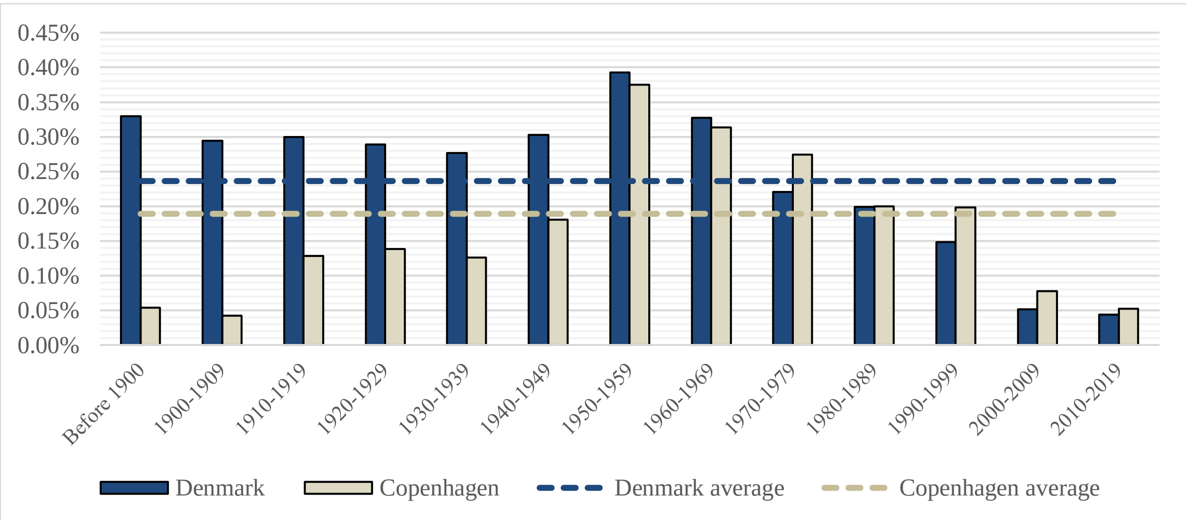

Figure 4. Average demolition rates for different construction periods in Denmark and the Copenhagen region from 2011 to 2019.

The demolition rate for old buildings in Denmark generally is substantially higher than in Copenhagen and is more evenly distributed over construction periods before 1950. After that, the demolition rate for new buildings falls more markedly at the national level than it does in the Copenhagen area. The results show that a building located in densely populated areas or rural zones is at equal risk of being demolished for buildings built between 1950 and 1969. In addition, the results of buildings before 1950 are at much less chance of demolition in the Copenhagen area than they are in the rest of the country. In contrast, the opposite is true for buildings built after 1970, which are at the most significant risk of demolition if they are located in the Copenhagen region.

5.3. Demolition in relation to new construction and extensions

From 2011 to 2019, the proportion of demolitions in Denmark remained very constant, with 0.20-0.28% (see Figure 5) of the existing building stock being demolished annually. The year with the most demolitions was 2015, when 2,017,166 m^2 were demolished in Denmark, whereas 2013 was the year with the fewest demolitions, when a total of 1,444,495 m^2 were demolished.

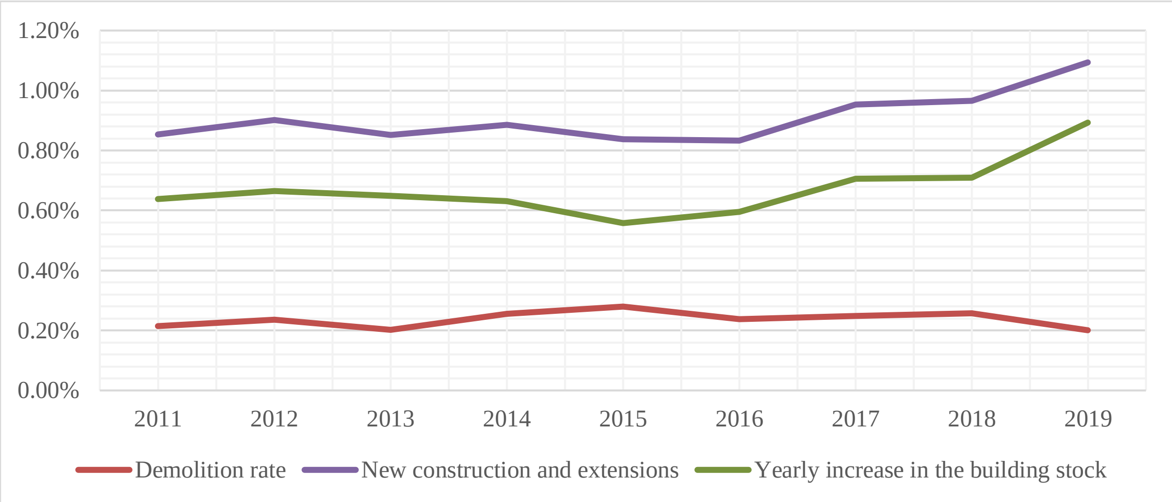

Figure 5. Development in the share of new construction, extensions and demolitions in Denmark in relation to the existing building stock from 2011 to 2019.

Over the entire period, the average demolition rate was around 0.24% of the existing building stock. On the other hand, an average of 0.75% new construction and 0.15% extensions was added to the existing building stock from 2011 to 2019. Thus, there is a growth in the existing building stock of 0.67% over the period when demolition is deducted. At the same time, the share of new construction is increasing, while the share of demolition is static. This can therefore be a problem concerning the recycling of building materials since the proportion of available materials from demolition is not increasing at the same rate as the need for reused or recycled materials for new buildings. Over the period 2011 to 2019, square meters demolished corresponded to 25% in relation to how many square meters were being built. In 2019 square meters demolished only corresponded to 18% of the total of new construction in square meters. In addition, there are a lot of materials from demolitions that are not suitable for either reuse or recycling because they contain harmful substances or provide limited opportunities for recycling. This means that demolition can only cover a small proportion of the materials needed for new construction. According to the Danish national inventory for construction waste in 2019, the recycling rate for construction waste was 36% [12] in 2019. This means that only 6.5% of the material requirements of new construction in 2019 could be covered from demolitions in the same year when recycling rates are added to the share of demolition if it is assumed that there is an equal relationship between material in a demolished square meter building and a square meter newly constructed building. Of course, this will not be correct in most cases and is therefore used only as a theoretical assessment of the magnitude of the potential for circular materials.

6. Adaptation of circular design strategies

These results show a difference in demolition trends between densely and sparsely populated areas. In densely populated areas, newer buildings were at greater risk of demolition than older ones. This could be important knowledge concerning the environmental impact of circular design strategies for existing buildings. In life-cycle assessments, generic life-times for buildings are usually used in calculating the remaining lifetime of the building. However, the results in this paper suggest the relevance of considering remaining life-times differently, depending on whether the building is located in sparsely or densely populated areas. Concerning circular design strategies, the results demonstrate the potential for adaptive reuse, since there is a decreasing demand for industrial buildings, which also accounted for a large share of the demolitions. With circular design strategies, such as adaptive reuse, these industrial buildings can be transformed into dwellings, avoiding demolitions while reducing the demand for the construction of new housing. In the case of adaptive reuse, it will primarily be the load-bearing construction elements that are preserved, which are also the building parts that are often most difficult to recycle and reuse offsite. This is in contrast to conventional demolition, where, for example, concrete from the demolition of industrial buildings is down cycled to replace gravel. However, adaptive reuse requires industrial buildings located in areas where there is a demand for housing, as in densely populated areas. Unfortunately, our results showed that farm buildings located in sparsely populated areas accounted for a large part of the demolition. In cases where adaptive reuse is not advantageous due to a falling demand for buildings, circular strategies such as urban mining offsite reuse and recycling of material from demolition may be necessary in order to avoid having a lot of vacant buildings. If a more substantial proportion of buildings are renovated or transformed with adaptive reuse, it will also mean that the proportion of available materials from demolitions will decrease. In order to meet the very large need for materials for new construction, circular design strategies are needed that reduce the need for new construction. For instance, building smaller units or using environmentally friendly low-carbon materials will not reduce the amount of materials significantly, but will lower the environmental impact.

7. Limitations and assumptions

This study only includes new construction and extensions since it was not possible to obtain data on renovations. Nonetheless, renovations are a circular method of avoiding demolition. Renovations both generate construction waste and require new materials. Because only 36% of materials are recycled, renovations will mean a much greater need for new materials. Demolition can cover about 6.5% of the need for new materials in new constructions, a value that would probably be lower if the material needs for renovations were included. However, this will require a greater degree of registration of how many square meters are being renovated per year and the type of renovation. Also, it must be taken into account that the material intensity can vary between demolished buildings and newly built buildings and therefore the 6.5% can vary based on which types are demolished and which types of buildings are built so the 6.5% should be seen as a general average consideration of the entire building stock, This study does not cover materials intensities for buildings, so the actual material quantities may differ because the material intensity will vary for different buildings per m^2. A thorough study of the material intensities of Danish buildings is needed before it will be possible to calculate material flows. However, by stating the inventory as ‘per square meter’, it will be possible later to include material intensities. The results give an impression of the trend in and size of supply and demand.

8. Conclusion

By combining high-quality building data from Danish building registers, this project has defined and tested trends in new construction, existing buildings, and demolition that can affect circular design strategies. This showed that factors influencing demolition decisions are distributed differently between densely and sparsely populated areas. The age of a building is often described as an essential indicator of when it will be demolished, but our analysis of demolition data showed that newer buildings were at greater risk of demolition in densely populated areas. In contrast, the opposite trend occurs nationally, where it was older buildings that were at the greater risk of demolition. In addition, the results also showed a large proportion of industrial buildings being demolished but a decrease in new constructions of industrial buildings. In contrast, there was a significant increase in new housing construction, but a very low demolition rate of housing so there is a basis for transforming more industrial buildings into housing through circular design strategies such as adaptive reuse. At the same time, significant increases in new construction mean that circular design strategies such as reuse, recycling, and adaptive reuse can only cover a tiny part of the need for new housing. This means that there is a great need for other sustainable strategies, such as reducing the need for new construction or using low-carbon materials, in order to reduce global warming, resource consumption, and the amount of generated construction waste.

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