SECTOR-WIDE CIRCULARITY ASSESSMENT FOR THE CONSTRUCTION SECTOR

ROSKILDE

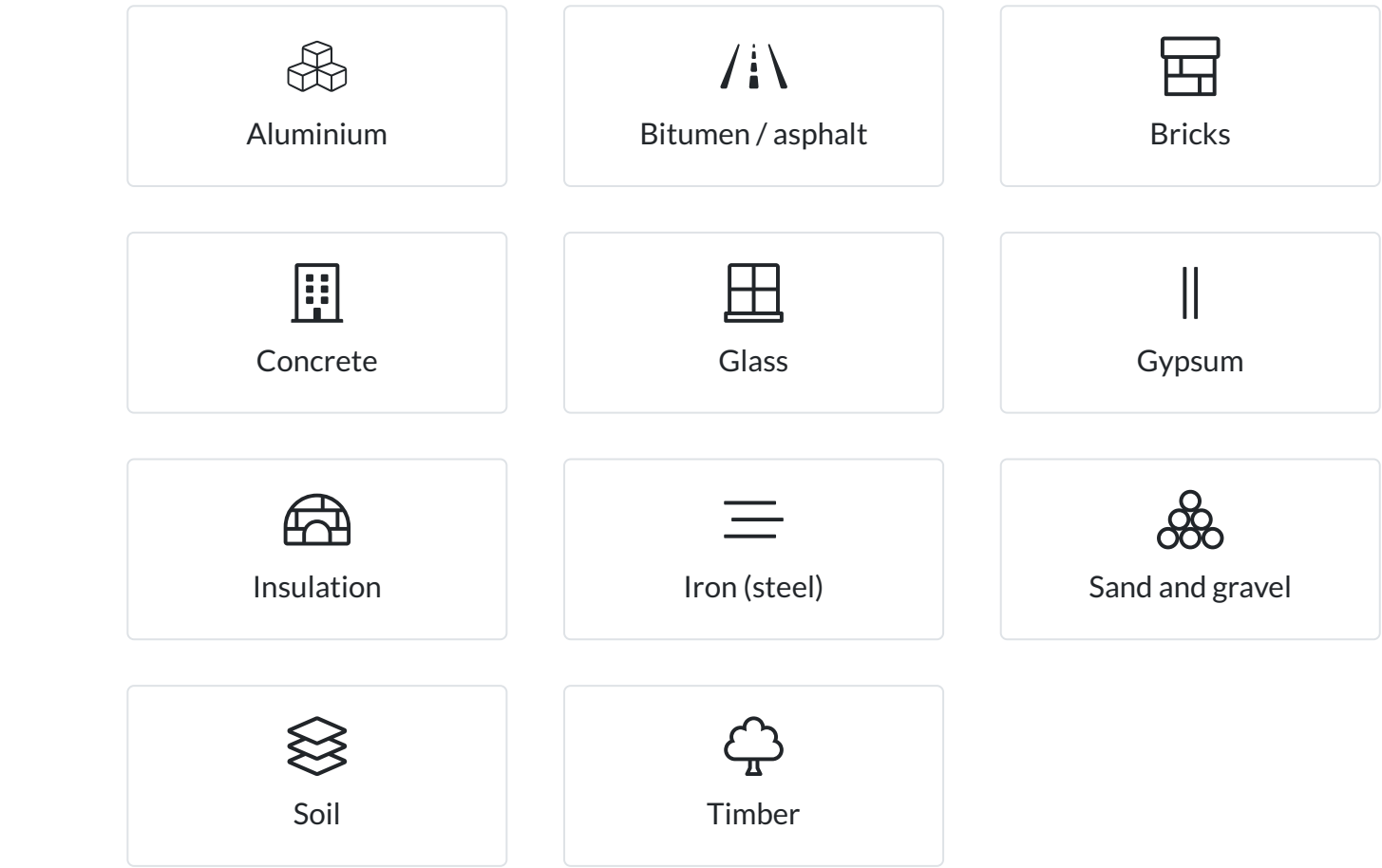
CITYLOOPS

METABOLISM OF CITIES

Introduction

The EU Horizon 2020 funded CityLoops project focuses on closing the material loops of two central sectors of any city in terms of material flows, societal needs and employment, namely the construction and biomass sectors. Due to their sizes, they represent a considerable opportunity for cities to transform their metabolism and economy towards a more circular state.

Within this project, seven European cities, amongst those also the City of Roskilde are planning to implement demonstration actions to kickstart their circularity journey. To better understand what the current circularity status quo is, as well as the impact of these actions, and the efforts needed to transform their sector, a Sector-Wide Circularity Assessment method was developed. This method combines a circular city and circular sector definition, a material flow and stock accounting method, as well as circularity indicators. The sector itself was defined in terms of a number of representative materials that make up a large share of the sector and associated economic activities. The construction sector is made up of 11 materials, depicted as icons here, which were studied along the entirety of their supply chains. Altogether, these elements help to set a solid knowledge and analytical foundation to develop future circularity roadmaps and action plans.



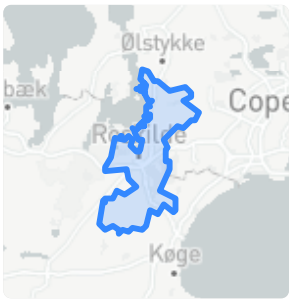
The assessment was carried out by the cities themselves after receiving extensive training in the form of courses on data collection (construction and biomass) and data processing. Numerous additional insights can be found in the individual Data Hubs of each city.

This current Sector-Wide Circularity Assessment report provides contextual information on the city and the economic sector under study. It then illustrates how circular these sectors are through circularity indicators and a Sankey diagram. Finally, it analyses and interprets the results, presents the limitations from the data used and offers recommendations about how to make this sector more circular.

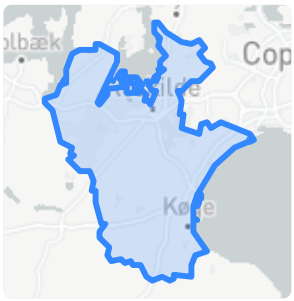
(The italic texts in this report were written by Metabolism of Cities' Aristide Athanassiadis and Carolin Bellstedt. They provide relevant general information and serve as connecting elements of the single report parts.)*

Urban context

To contextualise the results of the sector-wide circularity assessment, this section provides population and land use information data of the city. In addition, population and area of the city under study, as well as its corresponding NUTS3, NUTS2 and country were included. Data for these scales were added to better understand how relevant and important the approximations are when downscaling data from these scales to a city level.

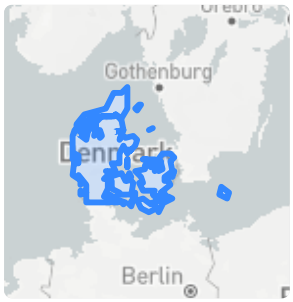


Roskilde
88,989
212 km^2



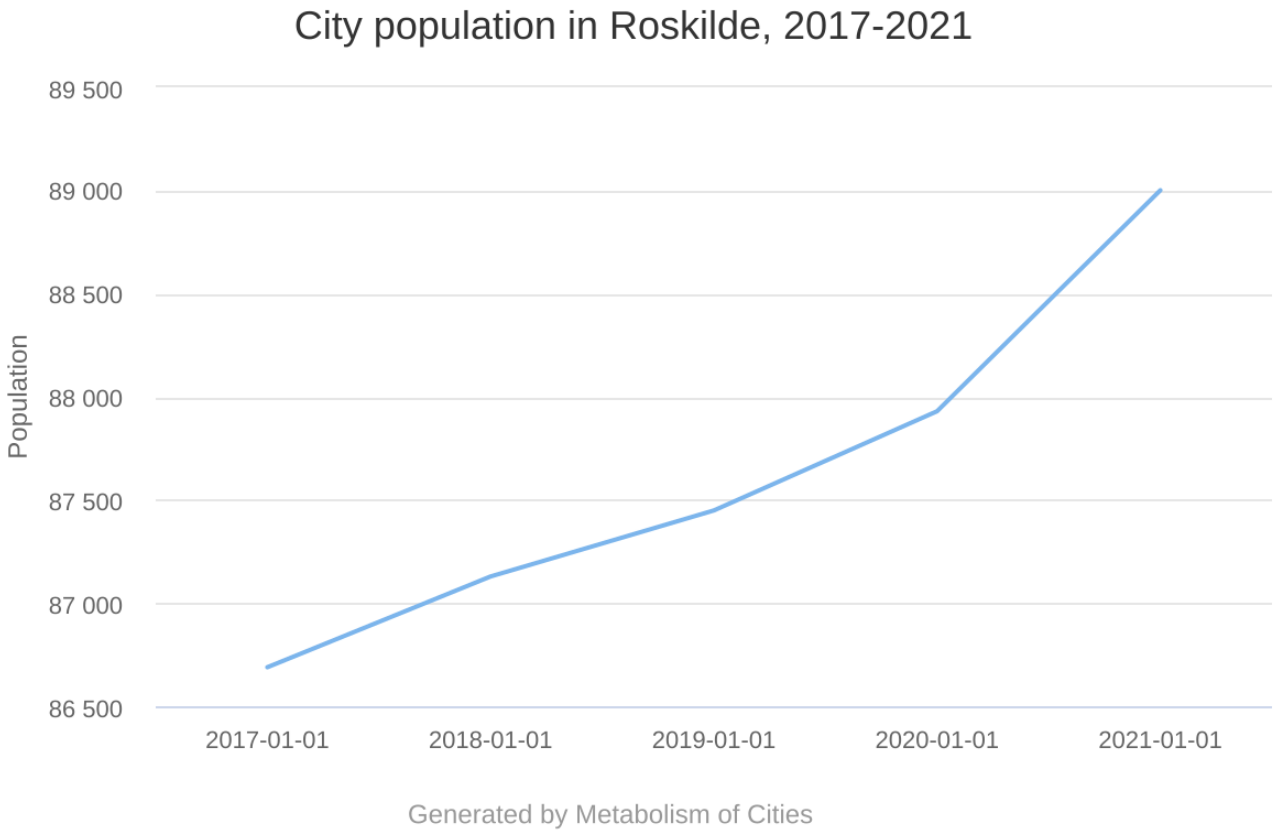
Østsjælland
253,321
808 km^2

Sjælland
2,659,634
9,789 km^2



Denmark
5,850,189
42,933 km^2

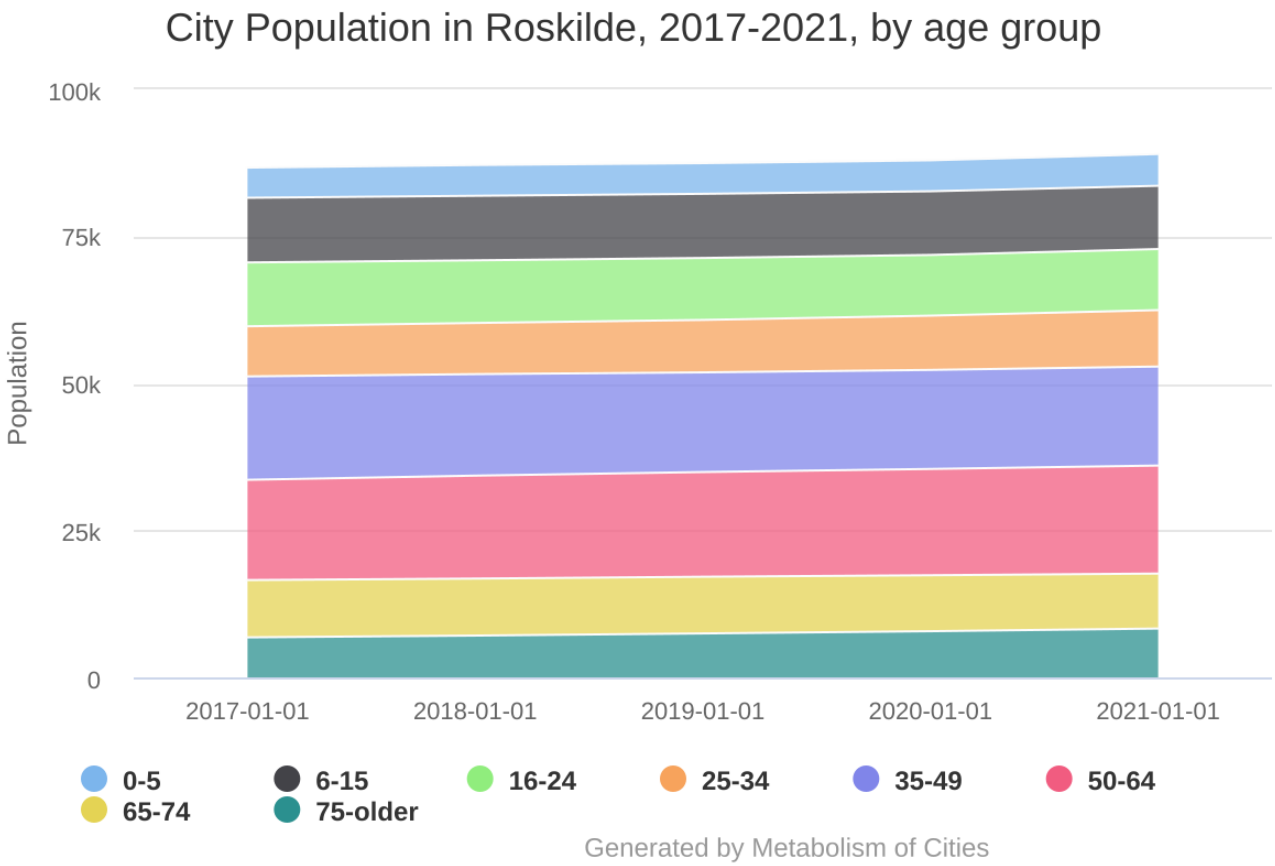
Population of Roskilde



Data source

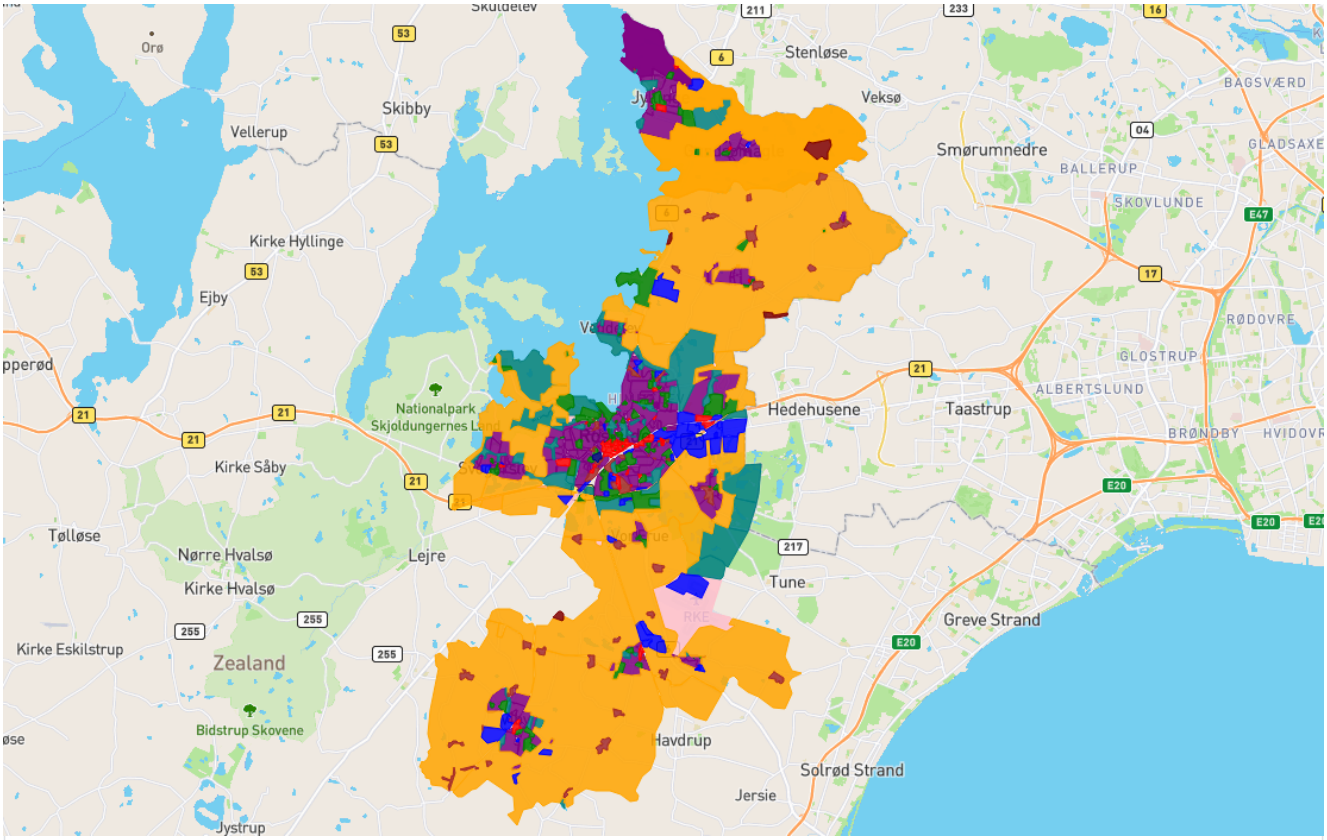
Roskilde municipality is characterised by a steady increase in population, namely by 2.67% from 86,689 inhabitants in 2017 to 89,001 in 2021. Roskilde is a popular settlement municipality and the city's relocation rate has been continuously increasing, for example by 1,200 people from 2019 to 2020. Expressed in households, there were a total of 40,102 in 2020. Roskilde municipality is characterised by a population that is largely represented by the fact that there are more than twice as many with a long higher education as in the rest of the Region Zealand. Also measured in short and medium-term higher education, Roskilde Municipality is above Region Zealand. Roskilde University attracts a number of new citizens every year and a portion of those stay in the municipality when they start working. This is balanced by a growing portion of elders in the population, since the number of deaths are increasing.

As can be seen in the graphic below, the population is comparatively young with about 40.6% (2021) of them being 34 years and younger, while the largest number of people are in the 50-64 year olds age group.


City Population in Roskilde, 2017-2021, by age group
100k
75k
50k
25k
0
Population
2017-01-01
2018-01-01
2019-01-01
2020-01-01
2021-01-01
0-5
6-15
16-24
25-34
35-49
50-64
65-74
75-older
Generated by Metabolism of Cities

Data source

Land use



Data source

The municipality is characterised by a mixed land use. Agriculture and nature fills up a significant part of the landscape. Low rise dwelling areas also dominate the land use. In 2021, there will be a special focus on changed land use, nature conservation and increased biodiversity on municipal land, cooperation on afforestation, further development of the nature areas close to the city, and improved access to nature.

Economic context of construction sector

This section puts into perspective the economic context of the sector under study. It describes how many people are employed in this sector, as well as who the main actors involved (from all lifecycle stages for the sector's materials) are.

	GDP (monetary value, in kr.)	Employees
Roskilde	708,000,000	3,113
Østsjælland	1,739,000,000	7,700
Sjælland	18,635,000,000	82,500
Denmark	40,375,000,000	178,505

The construction sector in Roskilde

The construction industry plays a key role as the second largest industry in the municipality and contributes to the economic activity overall. The construction industry accounts for 13% of the total industry. The construction sector of Roskilde is characterised by many small to medium sized companies in the construction sector. Most are associated with rawmaterial production and typical craftmen.

The actors of the construction sector

Data source

The primary actors associated with material flows in the construction sector are: Nymølle, Roskilde Sten & Grus ApS, Munck Asfalt, Betonelement, DK Beton, and ARGO.

Extraction

A number of actors that deal with extraction of raw construction materials can be found in Roskilde. As seen on the map, there are a total of six companies present, most of which are gravel pit operation sites. Nymølle Stenindustrier A/S and Roskilde Sten & Grus ApS are the largest companies by employees with around 70 and 45 people respectively in 2019, whereas the other four companies have less than five employees. The so-called "Hedehusene" gravel pit (see image), though in the municipal boundaries of Roskilde and operated by Nymølle, is the largest gravel pit of Denmark. In 2020, about 2 million tonnes of gravel were excavated from that site. For over 100 years, gravel has been sourced from this area with different levels of quality that the Danish construction and infrastructure industry are dependent on. These gravel deposits have been deposited by huge meltwater rivers during the last ice age and cover a vast area from Roskilde west and all the way to Hedehusene in the east, containing an unusually high content of stones. Therefore, the municipality is well suited to produce a wide range of high quality sand, gravel and stone products to fit many different purposes, e.g. foundation, road construction, construction projects, as well as a contract for asphalt and concrete production (Nymølle Stenindustrier A/S 2019).

Data source

Compared to Nymølle, Roskilde Sten & Grus ApS has not been in operation for so long, but also already for three generations. What began with the discovery of sand in their agricultural field in the 1970s and the initial operation of a gravel pit in Himmelev is nowadays a family-owned company that has excavated several areas in the vicinity of Roskilde. Since 1999, the primary

excavation work has been at Øde Hastrup Vej (Roskilde). The area has since grown and the third generation, Anders Jensen, has taken over the day-to-day operations. The gravel pit delivers both for the very large construction and building projects, for the small craftsman, gardener, mason and contractor as well as for the private homeowner who has the opportunity to bring their own trailer and pick up materials (Roskilde Sten & Grus ApS 2021).

Manufacturing

The construction material related manufacturing industry in Roskilde is limited to two materials: bitumen/asphalt and concrete. For all other materials (aluminum, bricks, glass, gypsum, insulation, iron (steel), timber), there are no companies registered to be dealing with those in the municipality.

Asphalt

The main bitumen/asphalt company in terms of employees is Munck Asfalt with 27 people (2019). Founded in 1995, their business revolves around the manufacture of asphalt and the construction of roads and motorways. At the "Sjælland - Asfaltfabrik Svogerslev", the asphalt plant which is located between Svogerslev and Lejre, approx. 8 km west of Roskilde, new asphalt is mixed in a batch operation with a 4 tonne mixer and a capacity of approx. 240 tonnes per hour. The site also has a crushing plant that receives old, broken asphalt and electric slag for crushing.

Next to Munck Asfalt, there is also the Dansk Støbeasfalt, with officially 9 employees, which has existed under this name since 1986 and was owned and operated by Vagn Rask for 25 years. Since then, Dansk Støbeasfalt has had an administration and factory in Roskilde. Since the end of 2011, the company has been owned by and operated as a subsidiary of the DAB Group AB, which handles membranes, sealing layers, cast asphalt and concrete renovation. The local subsidiary itself focuses on casting asphalt and moisture insulation (Dansk Støbeasfalt 2021).

The third company registered in Roskilde municipality to handle asphalt is Sjællands Emulsionsfabrik I/S (SE). SE is a production company that produces various bitumen based products. Typically, the products are used in the production and laying of asphalt. Other areas of application for SE products are, for example, gluing, grouting, moisture protection, impregnation and sealing. (SE 2021).

Concrete

As for concrete, there are two actors, namely Betonelement and DK Beton.

Betonelement is a subsidiary of CRH Concrete A/S, which manages several brands and employs approximately 1,300 employees in 11 factories throughout Denmark. CRH Concrete A/S is part of the international group CRH plc (approx. 80,000 employees in 30 countries). The Betonelement company is located in the south of Roskilde municipality, in Viby Sjælland, where it has the production site, as well as the headquarters of Betonelement and CRH Concrete A/S. There, it produces concrete and lightweight concrete with a special focus on concrete building

elements that it also designs and installs as a service. Betonelement supplies all types of elements, from prestressed structures, over facades, walls, columns and beams, to complete solutions in both industrial, domicile and residential construction. Since recently, they can also deliver filigree decks, double walls, tunnel elements and prestressed bridges (Betonelement 2021).

DK Beton is the other company manufacturing concrete in Roskilde. While a national supplier with 17 locations that supply ready mix concrete, two of those sites are in the municipality, namely in Roskilde and Gadstrup. The company delivers both traditional concrete, floating / vibratory and set concrete in all strengths. Floor concrete, curb concrete, joint concrete and gravel concrete are also part of their supply. daily concrete delivery. Their customers range from private individuals to large contractors.

Retail and wholesale

There was no information provided on the companies registered in Roskilde that are operating in the retail or wholesale related to the construction sector. Oftentimes, the manufacturing companies are engaged in direct sales to other companies or contractors, thus skipping the step of a retail middle person. Moreover, even if the company names are known, it is generally very difficult to obtain data on sales volumes of materials. Therefore, the actors of this supply chain stage are disregarded.

Use

As for the actors in the use stage, the share of companies or private persons employing construction materials for construction or renovation work is unknown. Although there are permits for such work, it is not stated who carries it out, no less which materials and quantities for it are employed. In all likelihood the number of actors, especially in the form of small companies, is quite large. However, there is no overview of those. Even if there was, the local contractors' shares of doing work within the boundaries of the municipalities vs. outside of it and those who aren't registered in the municipality, but still conducting work in it are unknown.

Waste collection and treatment

The four main actors dealing with waste collection and treatment in Roskilde are all concentrated to the east of the center of the municipality, in industrial areas, close to highway 21. ARGO, an I/S waste company that treats waste for citizens and companies in nine Zealand municipalities, dominates waste processing in Roskilde. The company's primary task is to ensure that waste is converted into resources. The prioritisation is as follows: reuse before recycling before energy utilisation before landfill. As much waste as possible must be reused and recycled, and energy utilisation must take place in an environmentally sound manner and with the greatest possible benefit in the form of electricity and district heating. In Roskilde, ARGO operates two sites: a recycling center and a combined heat and power plant (CHP) called Energitårnet (energy tower), whose construction was finished in the end of 2013. The energy tower rises as a landmark for Roskilde and is surpassed only by the monumental cathedral. The CHP, which cost 1.293 billion kroner (166.6 mio. Euro), uses the waste that cannot be reused or recycled and with a utilisation

rate of close to 100 percent, generates heat for the production of electricity and district heating. The district heating is sold to the transmission company VEKS, whose transmission network extends from Roskilde to Copenhagen and along Køge Bay to Køge.

Data source

Aside from ARGO, there are three other actors: Solum Roskilde A/S, Hedehusene Product Handel A/S, and Stena Recycling. These primarily deal with waste collection, the two latter ones especially with iron and metals, which they also trade.

Indicators

To monitor the progress of this economic sector towards circularity, a number of indicators were proposed and measured. Altogether, these indicators depict several facets of circularity of the sector. As such, they need to be considered in combination rather than in isolation when assessing circularity. In addition, these indicators can be compared to other cities or spatial scales (such as the country level). However, this has to be done with great care and use of the contextual elements in the previous sections of the report. Finally, the value measured from these indicators can be traced over time to track the sector's progress towards circularity.

Indicator number	Indicator	Value	Unit
34	Domestic material consumption (DMC)	3,160,939.04	Tonnes/year
39	Circular Material Use Rate	9.01	%
48	EU self-sufficiency for raw materials	1.01	%
55	EOL-RR (End of Life Recycling Rate)	13.99	%
57	Amount of sector specific waste that is produced	683,520.42	Tonnes/year
58	End of Life Processing Rate	30.00	%
59	Incineration rate	1.75	%
61	Landfilling rate	25.03	%

The domestic material consumption (DMC) is calculated by adding "Domestic extraction used" to "Imports" and subtracting "Exports". For Roskilde, it amounts to 3,160,939 tonnes and 35.52 tonnes per capita. This value is quite high compared to the total DMC of 13.4 tonnes per capita for EU-28 in 2019 and still higher relative to the 24.98 tonnes per capita, in all of Denmark. However, those latter two also do take into account the **total** DMC and not just the materials used in the construction sector. Since it goes beyond the scope of this work to determine the share of construction materials in the total economy, it will not be further assessed. There are two main aspects that influence the DMC: (1) Probably the exported amount of extraction is under accounted for, meaning that not all that is extracted locally is also used locally, but likely

transported to and used in other regions and (2) the “use”, which was indirectly determined through this high extraction value becomes very high in return, especially since the exports are not that high. These uncertainties are definitely a shortcoming.

The CMU value of indicator 39 stands at 9% and compared to the 12.4% for EU-28 in 2019 and 7.6% for Denmark, seems to be in line. However, since this indicator also includes the DMC, it must be assumed that the value is negatively affected as well. Another difficulty that is added to this indicator is that it was originally designed for metals. Since now materials from different categories are bundled up, it skews the image of the circularity of materials.

The EU self-sufficiency for raw materials indicator is very low with 1.01%. Unfortunately, there is no national value to compare it to. And since the data completeness was lacking in terms of differentiation of the single materials, this indicator couldn’t be calculated for them individually to determine the various self-sufficiency levels.

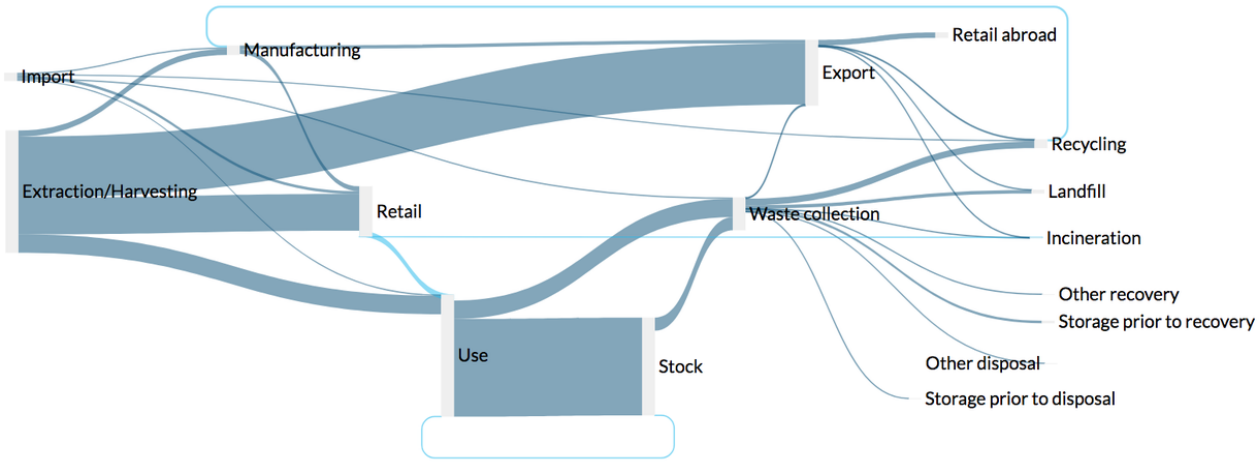
The EOL recycling and processing rates are still considerably low with about 14% and 30%, respectively. While 27% of materials are still subjected to disposal and 73% to recovery, the efficiency of recovery could still be improved. There is however uncertainty in those values, as the amounts derived from recycling had to be estimated.

The incineration rate is very low with only 1.75%. This is somehow surprising, as there is an incineration plant close by in Høje-Taastrup. On the other hand, construction waste materials are usually not subjected to a large extent to those facilities.

Finally, the landfilling rate is still quite high at 25%. The numbers came from the waste statistics and can be considered reliable, thus there is no uncertainty there. Either the municipality really still landfills quite a lot of waste, or the values are influenced by a lack of classification or differentiation of waste use on landfills as “alternative daily cover”.

Visualisations

Measuring circularity is a data heavy exercise. Numerous datasets were collected and visualised throughout the sector-wide circularity assessment process. To synthesise these findings, a Sankey diagram illustrates how material flows from the studied economic sector are circulating from one lifecycle stage to another. The height of each line is proportional to the weight of the flow. This diagram therefore helps to quickly have an overview of all the materials flows that compose the sector and their respective shares. The flows that are coloured in light blue in the Sankey diagram, are return flows. This means that they flow in the opposite direction of the lifecycle stages and are subjected to reuse, redistribution, or remanufacturing. Their size relative to the others is a good indication for the materials' circularity.



Data source

The Sankey diagram builds of course on the collected data that also the indicators have been derived from. Therefore, it needs to be taken into account that the previously discussed data quality influences also the quality and informative value of the Sankey diagram. In addition to the data quality, so-called allocation values also have an impact on the data behind the visualisation. These allocation values were employed to estimate the amounts of materials that "flow" between the single lifecycle stages, since these relationships and quantities were in most cases unknown, except for waste collection going to waste treatment.

Overall, the Sankey diagram for Roskilde shows that quite a lot of materials are moving around in the construction sector system. The share of materials for and from **extraction** really dominate the graph. About 30% of the materials (2 million tonnes) are extracted in the form of sand and gravel by one company, Nymølle Stenindustrier A/S, alone. The main share of it is subjected to export for retail outside of the municipality, while the other shares go to manufacturing, retail and direct use.

Compared to export, **import** plays a significantly smaller role. (It should be noted that the data quality and estimations of imports do have an impact on the image here, see the data quality section above.)

Manufacturing sees an inflow of materials from recycling and **retail** is fed with new materials from extraction, import and manufacturing, as well as secondary materials from incineration and use. This latter return flow from use back to retail could be surplus materials from construction sites that are labelled for reuse.

Going forward in the diagram from left to right, it can be seen that there is a data gap from the outgoing materials from **retail** to all other lifecycle stages. This reflects on the gap in the data availability described above.

Use is being fed by imported and extracted materials, although the majority would likely origin from retail, which can only be assumed due to the data gap. Most of the materials from use end up in stock, as constructed materials. While it may seem that quite a significant amount (677 kt) of the **stock** goes to waste collection and a little bit gets reused, this is only true in terms of the data of flows. It might seem that a lot of buildings and infrastructure get demolished again, but this of course isn't the case. It is just that the Sankey diagram does not depict the stocks, the materials that stay in a system for over a year, but only the flows from the single stages.

While the **waste collection** node does receive most materials from the stock, it also gets inflows from imports and use. The diagram shows that the main share of materials leaves to **recycling**, which is also fed by imports and which has a comparatively large outflow as return flow to manufacturing. As for the other waste treatment options, **landfill** is quite high and very similar in size to **storage of materials for recycling**. Finally, a significant stream is from **export** to **retail abroad**.

Data quality assessment

Numerous datasets were collected and considered in the sector-wide circularity assessment. In some cases, datasets were not available for some materials or for some lifecycle stages for the studied sector. Therefore, estimations need to be done by looking at data at higher spatial scales (region or country). This section qualitatively assesses how reliable the data used is.

Data quality

Before describing data gaps and assumptions, the overall data quality is considered. It is expressed through four data quality dimensions that are depicted in the data quality matrix: reliability, completeness, temporal correlation, and spatial correlation. Each dimension has its own criteria for the ranking of high (green), medium (yellow) and low (red), which is based on this Pedigree report and shown in the table below. There can be additional explanations in some cells, as supporting information.

Rating	*Reliability*	*Completeness*	*Temporal correlation*	*Spatial correlation*
high	*Reviewed or measured data*	*Data exists for all of the single materials and their respective economic activites*	*Data less than 3 years difference to the time period of the data set*	*City-level data*

Rating	*Reliability*	*Completeness*	*Temporal correlation*	*Spatial correlation*
medium	*Estimated data*	*Data exists for most single materials and most economic activities*	*Data less than 6 years difference to the time period of the data set*	*Regional-level data (NUTS 3)*
low	*Provisional data*	*Data exists for the sector only for the Life Cycle Stages*	*Data less than 10 years difference to the time period of the data set*	*NUTS 2 and country-level data*

Data quality matrix

Lifecycle stage	Reliability	Completeness	Temporal correlation	Spatial correlation
Extraction/Harvesting				
Manufacturing				
Retail	no data			
Use				
Stock				
Waste collection				
Landfill				
Incineration				
Recycling				
Imports				
Exports				

As can be seen in the data quality matrix above, the overall quality of the data is relatively high. The temporal correlation is very good for all lifecycle stages (LCS), as the data was almost always from the reference year (2020) or from 2019. The spatial correlation is still fairly good. However, it does suffer, especially in manufacturing where national data was used and in use, imports and exports where NUTS3 level data were employed. The reliability of the data is ok. For around half of the LCS, the data was measured, while the other half was estimated or provisional. Finally, the completeness of data scores medium for all LCS. This is mostly because the data either only exists for some single or for some economic activities, but not both and not all materials are differentiated.

Data gaps and assumptions

Aside from data often being available, there were still some gaps in local data or the data was not in the right form. The following paragraphs describe how sources, assumptions, and calculations were used for each lifecycle stage.

Extraction

The data for extraction was obtained from the Danish statistics on "RST01 Extraction of raw materials in Denmark by region and type of raw material", which has data for the years 2006-2020 and where it was used for 2019. Since it was only an amount for all construction materials, the coefficient 1.9 from the Eurostat Handbook was used to convert from cubic metres to tonnes.

Manufacturing

The manufactured amounts were derived from the Danish national statistics called "VARER3: Manufacturers' sales by main SITC groups". The relevant materials were selected and then calculated in tonnes with a conversion sheets for conversion from DKK 1,000 to tonnes. Thereafter, employment numbers in that sector were used as a proxy to downscale the values for Høje-Taastrup. Since the materials are only on a 2-digit level, they are considered medium in terms of completeness for the data quality.

Retail

In the case of retail, the data gap could not be closed. The issue around data in that area and level was confirmed by a recent study entitled "Cities as organisms: Urban metabolism of the four main Danish cities" (p.3), which stated that "it should be noted that inflows of construction materials and goods could not be quantified due to unavailability of public data at the city level." It goes on in saying that "data on construction material inflow is difficult to obtain at the city level, if existing at all. Worth mentioning here is the current development of dynamic built environment stock studies that might help get a better understanding on the size of construction material flows entering cities" (p. 13). Their findings could be confirmed for the inflows represented by the lifecycle stages of retail and use, for which it could either not be obtained at all or it was estimated indirectly, respectively (see "use").

Use

As mentioned under "retail", data for the use lifecycle stage could only be derived indirectly, namely by applying the DMC (Domestic material consumption) formula (Domestic extraction used + Imports - Exports). With the help of the imports and exports data, it was calculated how much materials were used. Since the imports and exports data is from NUTS3 level and it can be considered a rough estimation, the score in the data quality matrix is low for reliability accordingly.

Stock

The amounts for stock came from a report called "Prognose for sekundære råstoffer" *(English: Forecast for secondary raw materials)* which was carried out for the municipalities of Høje-Taastrup and Roskilde in 2021. The report provides information on a forecast for the expected production of recyclable (secondary) raw materials of concrete and bricks from buildings, as well as concrete, asphalt and gravel from paving that result from demolition and renovation projects. The values could be used as they were.

Waste collection and treatment

The data for waste collection and treatment were extracted from the Danish "Affaldsdatasystemet (ADS)" *(English: waste data system)* by the municipality, using the sources of ""Affaldsproduktion i Danmark fordelt på kilde og kommune (R026) (Branchegruppe)" *(English: Waste production in Denmark by source and municipality (R026) (Industry group))* and "Affaldsproduktion i Danmark fordelt på behandling og kommune (R019) (R/D)" *(English: Waste production in Denmark by treatment and municipality (R019) (R / D))*. The data is for 2019 and in tonnes, so it could be used directly. In principle, the completeness of waste data is also pretty good. The issue here is that although it is detailed per material, it is not known by which economic activity or lifecycle stage they are produced.

Imports and Exports

For imports and exports, national road freight transport data for unloading and loading regions (NUTS3) respectively, from 2019 were used. The data is in tonnes, so it doesn't suffer in quality through conversion. However, an estimation needed to be made for the share of materials used in construction. For this, it was estimated that 80% of the materials for selected categories from the NUTS3 imports are used for the construction sector. The same applied to export.

To summarise overall, the data gaps stemmed from:

- Some data only being available on a national level and not a municipal level.
- Large amounts of data being unavailable due to lack of reporting and/or trade secrets.
- Certain data that is available, but only behind a paywall. It was not possible to access this data, because it required to be extremely precise about exactly what data needs to be retrieved. As the SCA process and method were still under development, a precise enough

formulation of which data was needed was not possible to be conveyed to a level that was satisfactory to those who were to retrieve the data, during the time when the people in the municipality had resources to do so.

Data analysis

This section analyses the Sankey diagram developed in the previous section. It discusses and interprets the results for the sector-wide circularity assessment. It also reflects on how the current demonstration actions fit within the bigger picture of the sector, as well as how they could be upscaled to accelerate the transition towards a more circular sector.

Insights on status quo of the construction sector

This report provides a lot of information on the construction sector, its size, actors and materials handled in the municipality of Roskilde. Based on that it can be summarised that the construction sector plays an important economic role in the municipality. Various actors and industries are represented here, including some national and international companies. Many of the local companies have been in the municipality for well over 50 years and consistently brought business to and made available job positions in the region.

It was seen that the area is also well suited for extraction of sand and gravel due to its geological history. Since not all of the materials are needed locally, a lot of those are exported.

The current situation of the construction sector with regards to its circularity is hard to determine due to limitations in data availability and quality. The direct reuse of materials is quite low and while the amount of waste subjected to recycling is high, the recycling efficiency is not known, which would help in determining the amount of secondary materials available. It is, however, already commendable that there is a focus on waste sorting, though mostly in the interest of removing hazardous substances from the waste stream and recycling non-hazardous materials lower on the waste hierarchy than where they started.

Overall, the municipality still has a long way to go to make the material flows of their construction sector more circular.

Connection to and upscaling of demonstration actions

The municipality of Roskilde has three demonstration actions (DA) planned to showcase its intent to encourage circularity in the construction sector in Roskilde.

- **DA 1: Demolition of Hall 11/12 area, preserving the building structure and facilitating reuse of CDW**
    - Hall 11 is a secondary building situated in the demonstration area. It will be demolished and materials from the demolition will be incorporated into other

construction projects. The function of hall 12 was and will remain a skate hall. Beams and pillars and the main steel structure of hall 12 will be preserved - therein lies the greatest savings in materials and CO2. The building will get a new roof, new façade and new interior. Hall 12 will be connected with a new multi-storey car park by a roof spanning 12 x 45 metres.
    - The buildings had a **pre-demolition screening** and **selective demolition** will take place, keeping reusable elements in storage for reuse in new buildings and creating material passports documenting their quality and possible use. A **virtual material bank** will be created through design for disassembly using Building Information Modelling (BIM) for information on regulations, quantities, material types, etc. LCA on selected materials will aid in decision making by revealing the carbon emissions impacts of different handling options. Roskilde will also try to implement circular soil strategies in the project by minimising soil movement and facilitating reuse on site.
    - A **material passport** will be created for selected materials from the demolished buildings. A virtual material bank is sketched and will be used for hall 11/12 - both for materials going out (in the selective demolition) and in the new, renovated hall. The first version consists of an Excel sheet for each material, describing its lifespan, what kind of testing it has to go through, and where it could end up in future uses.
    - The virtual material passport and databank are merged in one database. The circular procurement strategy includes use of the virtual material bank to source and supply secondary construction materials. The data is extracted from BIM models and kept in a database. Roskilde asks for the BIM in the tendering process for each building to be built at Musicon, to ensure such documentation is available for the future. Contractors need to provide a Revit/BIM model level of detail of each building with amounts/ types of materials.
- **DA 2: Construction of Car Park 2 'Indfaldet'**
    - Construction of Car Park 1 was finished in mid-2021. When Roskilde started digging in preparation for the car park, they discovered a large amount of concrete obstacles in the ground stemming from the site's concrete production function in the past. The concrete unearthed in CityLoops was kept on site and crushed into a mixed fraction. The mixed fraction was used for material layers below the concrete, replacing virgin gravel. Other concrete recovered from the digging was cleaned and crushed, to be mixed on site and used in new concrete. This has made a very positive business case.
    - A criterion in the tender for the new car park was that the developer foresee **design for disassembly**, including scenarios for future recycling. Consequently, a report was delivered by the contracted developer (MT Højgaard). They created the multi-storey car park with a steel skeleton, premade components assembled by bolts and a minimal use of concrete. They made calculations on CO2 for future reuse/ recycling and have documented the benefits on future use of materials from the car park. The local Parkour club is to finish/ furnish their area of the Car Park 1 with materials from the material bank at Musicon.
- **DA 2b: Construction of Car Park 2 'Pulsen'**

- The second multi-storey car park will be built as a steel structure, and Roskilde is involving the market in **risk model analysis and testing.** 100% recycled coarse fraction and 50% recycled fine fraction of recycled concrete will go into the foundation for Car Park 2. It's a new construction, so circular strategies such as design for disassembly will be added. Roskilde will create a physical construction material bank in the ground floor of Car Park 2. There will be a roofed passageway between this car park and hall 12. The refurbishment of the old library in Roskilde has released a total of 128 big bags of used roof tiles. These roof tiles will be reused in the new car park on the facades.

Recommendations for making the construction sector more circular
In order for the construction sector to become more circular, the **successes and methods** behind the actions striving for that need to be made as visible as possible. This will ensure replicability and that the barrier of knowledge gaps, in terms of how to build with circularity on a purely practical level, are reduced.

The municipality would also be greatly helped by **legal measures** that would incentivise circularity. These include higher fees for virgin resource extraction and higher fees for waste disposal. Greater possibilities of certifying and guaranteeing used materials are also essential to reduce the perception of risk associated with using used materials.

It can also be recommended to **increase engagement and collaboration with local players** that already have circular initiatives and solutions, for example:

- DK Beton already has a "circular concrete" product. According to their information, this material employs 20% recycled concrete aggregate, 100% recycled water and a filler that replaces up to 30% cement.
    - The municipality of Roskilde could support this business by promoting it and direct business there. In addition, it seems to be an opportunity to include this company in procurement processes, for when the municipality itself requires concrete.
- Solum Roskilde, who on their "Our DNA is circular economy" page state that they want to be a 100% circular company and already engage in partnerships for that. "The Solum Group has e.g. together with STARK and Golder developed the idea behind GENTRÆ, which is wood waste from construction sites that are converted into recycled wood for the same purpose, rather than as before, ending up as waste on incineration. An idea that has won a prize at the Realdania Circular Construction Challenge." They have something on CE, might be interested to share it.
    - Roskilde could support this company and their ambition by facilitating a get together of like minded companies to create the possibility for partnerships. A smaller way to provide assistance could be in the form of drawing attention to such projects, by sharing it on the municipality website or a newsletter.

Certainly, other **circular initiatives** could be discovered and mapped in Roskilde, or it could be learned from, adopted and build on the "14 Danish cases on resource efficiency in small and medium-sized enterprises", which can be a recommendation in and of itself. This would help with other **business potentials** e.g.:

- for higher value utilisation of materials: Development and testing of new concepts and business models as well as new and existing technologies and methods that support a higher value utilisation of materials
- of circular design and product development: Design of products and processes that underpin a more circular economy and new circular business models.
- of plastics recycling: Reducing and improving the recycling of plastics, including in particular plastic packaging across sectors as part of SMEs' exploitation of future business potentials in plastics recycling

It can also be recommend that the municipality guards and finds measures to **take care of local resources**. Although the area is predestined for extraction of construction materials, especially with its many gravel pits, these materials are nevertheless still finite. Recognising that private businesses engage in their extraction and that it is economically important, the resources should be sourced responsibly, as the avoidance of virgin materials use has the highest priority in a circular economy.

Finally, it is recommended that the **data availability and quality** are improved on, so that the region can determine its true potential of available resources and wastes per year. This way, the potential for upscaling the demonstration actions could be better analysed and a circularity process for the sector developed, containing main objectives and an action plan.

References

- Denmark
- Sjælland
- Østsjælland
- Population of Roskilde, 2017-2021 line graph
- Static land use map of Roskilde
- Static map of extraction companies in Roskilde
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