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# Abstract


## Data-driven prediction of PVC flooring in the Swedish building stock

PVC flooring accounts for a significant share of PVC use in the construction sector and has great potential for recycling. Nevertheless, the actual recycling rate of PVC flooring spillage in 2018 was less than 20%, according to the national system for the separate collection and recycling of material residues from the installation of PVC floorings, developed by flooring manufacturer Tarkett AB and now used by all manufacturers in the flooring industry. To improve the sorting and recycling process of old PVC flooring it is necessary to identify where the material is located and evaluate its recycling potential. Such information is crucial for demolition waste recycling companies and flooring manufacturers to improve recycling practices for PVC flooring and then use the recycled PVC materials in the new flooring production. The challenge is to find out in which buildings there is PVC flooring and when it was installed which will indicate when it is planned to be dismantled and replaced. Since the PVC flooring manufactures do not keep track on where their products are laid such information is lacking. The best source of information that was made available for the researchers appeared to be the public building owners´ maintenance plans. Therefore, it was decided to focus on the presence of PVC flooring in public preschools as an example.

By combining data from maintenance plans with national building registers, the PVC flooring in the Swedish preschools have been forecasted.

The project results show an example how limited data sources can be used to predict presence of materials in larger stocks and is therefore expected to contribute to a climate-neutral supply chain with recycled PVC flooring. Based on the results of this study, dialogue, recommendations and guidelines can be developed for the flooring industry, the waste and recycling industry and the Swedish real estate and construction sector.


Key words: PVC flooring, recycling potential, data-driven prediction

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# Content

# Preface

This study has been carried out based on a project idea from RISE and was carried out in collaboration between researchers at RISE and representatives from the flooring manufacturer Tarkett and the recycling company Ragn-Sells. The purpose was to explore whether machine learning models can be used to predict in which buildings there is PVC flooring and estimate when it should be replaced and thus be available as a resource that can go back into the production of new PVC floorings. The project has been financed with support from Vinnova, the Swedish Innovation Agency, for which we are very grateful. We would also like to thank people from the municipal school administrations who assisted with information from maintenance plans as well as the managers of the preschools who received us during the site visits that were made in Gothenburg in the early summer of 2023 to verify that the information of PVC flooring in the maintenance plans corresponded to reality.

# Summary

This research project delves into the challenges and opportunities for achieving a more circular construction and real estate sector, focusing on the recycling potential of PVC flooring in the Swedish building stock. The primary aim is to increase material recycling and contribute to a more sustainable and circular flow of materials in the building industry.

The construction and real estate sector's push towards circularity faces obstacles due to a lack of discussion on the material quantities required for large-scale circular flows. The scattered nature of materials and the absence of control over their content and quality pose challenges. Waste management routines and legislation often do not incentivize sorting from renovation and demolition projects. To facilitate circular flows, materials need to be kept clean, analyzed before dismantling, and accompanied by environmental inventories.

The study addresses this challenge by developing a data-driven method to predict the recycling potential of PVC flooring in the building stock using preschools as a case building category. By combining data from building maintenance plans and Swedish building registers, the study estimates that nearly 900,000 square meters of PVC flooring exist in the Swedish preschool stock. Predicting that PVC flooring laid after 2011 constitutes about 9%, recycling this portion could save 3040 tonnes of $CO_2$.

However, challenges remain in predicting when and where PVC flooring will be dismantled. The study suggests collaboration between property owners, manufacturers, and end-users to track and prepare for material replacement. The use of building information management models and digital twins is proposed for future information accessibility.

The flooring manufacturer Tarkett sees the developed method as a basis for estimating material quantities and types in building stocks, aiding in preparation for reuse or recycling. The study exemplifies how limited building-specific information can predict material presence on a larger scale. The method can be applied to various materials and products with available training data.

The study concludes by emphasizing the importance of logging specific material information in digital logbooks for new buildings. However, challenges exist in synchronizing this information with national property registers, especially for existing buildings. Limited knowledge of in-situ PVC flooring makes material recovery and quality assurance challenging. Despite limited material data, the study shows the feasibility of estimating material presence.

In summary, the research project provides valuable insights into predicting and assessing the recycling potential of PVC flooring in Swedish building stock using preschools as an example. It highlights the need for improved data transparency and collaboration among stakeholders to achieve a more circular and sustainable construction and real estate sector.

# 1 Introduction

## 1.1 Background

Recycling PVC materials from waste from renovated or demolished buildings is a promising opportunity to attain the climate-neural goal for the building sector. According to the EU EEA report (No 18/2020), the building sector accounts for the most significant share (around 69%) of plastic products with the longest product lifetime in Europe [1]. The plastic components made from fossil raw material generate a high carbon footprint in the production phase, as well as significant environmental impacts for solid waste handling from end-of-life buildings. Considering the negative environmental impacts and future potential taxation on fossil-based plastic, increasing the extent of reusing and recycling plastic-containing components becomes an inevitable step to close the loop [1]. Changing the business-as-usual linear value chain of plastic is also economically efficient to compensate for the growing need for fossil raw materials in production and reduce the risk of short of supply in new construction globally. Among plastic materials in buildings, polyvinyl chloride (PVC) based flooring attributes a large number of PVC wastes in the construction and demolition waste (C&DW) compared to other PVC products, such as window frames, pipes, cables, and packaging [2]. The first homogenous PVC flooring on a roll was manufactured in 1961 but the sales peaked from the 1970-tie to late 1990-ties [3]. In the 90s, PVC flooring accounted for 51% of total flooring sales in Sweden, showing its extensive use in the past construction [2]. Today PVC flooring has 25% of the market share of all flooring in Sweden. PVC flooring is used both in domestic and public environments, often in wet areas and in areas that should be easy to keep clean, such as school environments and care facilities, hospitals but also in big warehouses.

Although a national system for separate collection and recycling of material residue from PVC flooring installation was established by the Swedish Flooring Association (GBR Golvåtervinning), the annual PVC residue recovery rate was less than 20% in Sweden in 2018 [3]. A majority of PVC flooring collected as combustible waste was incinerated for energy recovery, which is the lowest level of waste hierarchy and resulted in an extra two tons CO2-eq per ton of PVC flooring recycled in Sweden [3]. A recent LCA study on PVC flooring showed that bathrooms with PVC flooring as a surface layer have a higher environmental impact than bathrooms with ceramics tiles flooring [5]. For example, the bathroom with PVC flooring contributes to an effect of 38 kg CO2 e/m2, the outer wall 18 kg CO2 e/m2, and the inner wall 11,5 kg CO2 e/m2 [5]. To address the issue of limited recycling of PVC flooring, improvements on waste sorting of flooring by waste handling companies and extending producer responsibility principle to general flooring manufacturers are needed. Old PVC floorings represent a considerable material resource. Nearly 150 million square meters of PVC flooring were installed in the Swedish building stock, corresponding to over 350,000 tonnes of potential raw material with a recycling potential, which corresponds to save approximately one million tonnes CO2 [4]. Based on statistics on installed PVC flooring, the remaining amounts was predicted considering a lifetime of 15-20 years for heterogenous floors in private environments and 20-30 years for homogenous and especially durable heterogenous floors in public environments [3].

However, there are challenges with recycling PVC flooring. Most importantly, the information on the presence and the extent of PVC flooring in the existing building stock is lacking. The building-specific information on flooring materials are not registered in the current national building database, making it hard to estimate the location and the extent of recyclable PVC flooring prior to renovation, deconstruction, and demolition works. In addition, the collection rates of PVC flooring are low, including a disconnecting recycling practice by individual manufacturers, a low adoption rate of the collection and recycling system in the sector, etc. [4]. To overcome these challenges, new knowledge on the historical use of PVC flooring in various building types in Sweden should be developed and transferred among the actors along the PVC flooring life cycle.

This information is critical to the Swedish Flooring Association and C&DW actors to be better prepared to collect, separate, and recycle PVC flooring. Meanwhile, it can also be advantageous for property owners or demolition companies to estimate the material assets in advance to plan for cost-efficient material recovery. By compiling information on PVC floorings from public pre-school owners´ maintenance plans in three Swedish cities, Stockholm, Gothenburg, and Kungsbacka, the information, including PVC flooring used in a majority of the pre-school stock in Sweden, will be covered. This specific part of the building stock is acting as an example how the methods can be used, provided that building specific information is available för a part of the stock. The usefulness of such empirical data and the data integration workflow have been proved in the Swedish context [6, 7]. From an urban mining perspective, the gained information can benefit infrastructure and production systems at the sectoral level by promoting secondary PVC sourcing from the building stock. New knowledge of potentially available PVC flooring in the building stock can also facilitate for PVC flooring producers to transform their business models and value chains toward circular development with the scientific basis for investment decisions. Today the producer Tarkett recycles about 270 tons of installation waste per year from its floors with known material content in its production. Recently, Tarkett has introduced that they also take back and recycle their homogeneous PVC floorings from 2011 onwards. The reason is that the floorings produced before 2000 contained the plasticizer DEHP which is considered as endocrine disruptors and floorings produced between 2000-2011 contained DINP which became subject to a permit in 2015 within EU. From 2010 Swedish flooring manufactures started to use DINCH as plasticizer, which is can be recycled as raw material for production [3].

## 1.2 Aim and objectives

The project will systemize the information of PVC flooring records extracted from maintenance plans for existing public pre-school buildings, in particular Stockholm, Gothenburg, and Kungsbacka regions, and use the statistical outcomes to forecast the recycling potential of PVC flooring in the majority of public preschools in Sweden. The preschool stock acting as an example of how building stock analyses and machine learning methods can be used to predict presence of a specific type of material or product in the building stock, provided that building specific information is available for a limited part of the stock. The pre-study will form a basis of a PVC flooring dataset for knowledge exploitation from practical sides. Building such expertise and research capacity is fundamental to ensuring the quality of the recyclable PVC flooring and improving its residue collection and separation rates. The system analysis results will lead to technical recommendations for the PVC flooring waste management plan for future renovated, deconstructed, and demolition project.

The PVC flooring dataset will be maintained by the project partners, yet the analysis, results and recommendations will be disseminated to the building and real estate sector. Primary barriers to PVC flooring separate collection and recycling [4], including engagement from manufacturers and standard practice within the industry, can be addressed through providing more transparent quality assurance of recycled PVC flooring.

# 2 Materials and methods

In this section the data base with building specific information which the predictions will be based on, and the methods used for prediction, are described.

## 2.1 Materials

Currently, there is very limited information about building materials in governmental and municipal registers, and this includes PVC flooring. Therefore, the project had to begin by compiling various national and local registers into a standardised and common database. In this section, each dataset used in the project is described further, providing details on their sources and contents. Attempts were also made to utilize the TED procurement database, which is the online version of the “Supplement to the Official Journal” of the EU, dedicated to European public procurement [8]. However, it has been found that very few municipalities report purchases of floor laying services to TED, typically due to the small amounts involved. Even when such expenditures were reported, it was sometimes challenging to link these quantities to a specific building or property, which complicates building-specific analyses.

### 2.1.1 Energy performance certificate

From the start of 2009, it has been mandatory for apartment and commercial buildings to obtain energy performance certificates (EPCs), as stipulated by the Swedish Building Act (2006:985). Energy performance certificates (EPCs) are also required for detached houses at the point of sale or lease. These certificates are compiled by an independent energy specialist and are archived at the National Board of Housing. The purpose of creating energy performance certificates (EPCs) is primarily for energy conservation, however, some of the included parameters can also be utilized to predict materials, as demonstrated in the studies by Wu et al. [9], and Wu et al. [10]. The relevant building parameter is described in

Table 1 adapted from Wu et al. [10].

Table 1: Building parameters retrieved from energy performance certificates.

| Data specification | Measurement type |
|---|---|
| Municipality | Nominal [290 municipalities Stockholm, Gothenburg, Malmö etc) |
| Building category | Nominal [locals, multi-family building, single-family building] |
| Building type | Nominal [detached, gable, intermediate] |
| Construction year | Scales[N] |
| Heated floor area | Scales [m2] |
| Number of floors | Scales [N] |
| Number of stairwells | Scales [N] |
| Ventilation type | Nominal [exhaust, balanced, balanced with heat exchanger, exhaust with heat pump, natural ventilation] |
| Usage Percentage of Floor Area (%) | Ratio (%) |
| Matching key | String and numeric [Index] |

## 2.1.2 Property Register and Property Map

The Property Register and Property Map, managed by the Swedish Mapping, Cadastral and Land Registration Authority (Lantmäteriet), comprise a comprehensive collection of tables and geodata, all of which are available from the authority for research purposes. Key building parameters is presented in Table 2.

Table 2: Building specific parameters retrieved from the Cadastral and Land Registration Authority.

| **Data specification** | **Measurement type** |
|---|---|
| Building area | Scales [m2] |
| Building width | Scales [m] |
| Building length | Scales [m] |
| Building category | Nominal |
| Building coordinates, x, y | Position |
| Building footprint | Geometry |

## 2.1.3 Preschool unit registry

The preschool unit register consists of all Sweden's preschools, their names, and addresses [11]. It also includes, among other things, the number of children enrolled in the school and the number of teachers. The school unit Register is maintained by the Swedish National Agency for Education and has been downloaded as open data. Key attributes of the register are presented in Table 3. Statistics Sweden (SCB) provides an open dataset [12] with coordinates that can be matched to the preschool unit register at the address level. This facilitates spatial joins with the preschool data, compensating for any inaccuracies in the address data.

Table 3: Information retrieved from the School Unit Registry.

| Data specification | Measurement |
|---|---|
| Ownership | Nominal |
| Activity code | Nominal |
| Name | Nominal |
| Address | Nominal |
| Number of children | Scales[N] |
| Number of child groups | Scales[N] |
| Average number of children per child group | Ratio (%) |
| Number of full-time positions | Ordinal [N] |
| Percentage of Full-time Positions with Preschool Teacher Degree | Ratio (%) |
| Percentage of Full-time Positions with Preschool Teacher Certification | Ratio (%) |
| Staff Density | Ratio (%) |
| Preschool coordinates | Geometry |

## 2.1.4 Inventory and Facility Planning Data on PVC Flooring

This section describes the data collection process, which was mainly conducted by compiling information from maintenance plans for public preschools in the municipalities of Stockholm, Gothenburg, and Kungsbacka.

### 2.1.4.1 Stockholm

Data from the City of Stockholm was obtained from SISAB, which is the municipal owner of school properties in Stockholm. The data consisted of inventories of PVC floorings intended for replacement as part of SISAB's efforts to reduce the presence of hazardous chemicals in preschool environments. The surveyed preschools were permanent facilities; temporary structures such as pavilions were not included. Only occupancy rooms (Sv: vistelserum) were included, which corresponds to approximately 50% of the total area. The conclusion of the inventory made 2017 showed that approximately 37% of the floor area in the occupancy rooms had older PVC flooring that is not fulfilling today's requirements.

Table 4 describes the attributes found in the dataset.

Table 4: Information retrieved from SISAB, managing preschools in Stockholm municipality.

| Data specification | Measurement |
|---|---|
| Urban area name | Nominal |
| Address | Nominal |
| Area PVC flooring(PVC) | Scales [$m^2$] |
| Comments | Nominal |

#### 2.1.4.2 Gothenburg

Data from Gothenburg was obtained from Stadsfastigheter, which is the City of Gothenburg's property owner of public premises. The dataset received included management plans for PVC flooring in all buildings, for example, the quantity and when these are scheduled (which year) to be replaced in the future. From the action text, it was possible to discern which types of PVC floorings are to be replaced, for example, 2mm floors, 2mm non-slip with coved baseboards, as well as an estimated unit cost for performing the work and the materials. Table 5 shows the dataset more in detail.

Table 5: Information retrieved from Stadsfastigheter, managing preschools in Gothenburg municipality.

| Data specification | Measurement |
|---|---|
| ID Administrative Unit | Nominal |
| Address | Nominal |
| Building id | Nominal |
| Measure/Action id | Nominal |
| Measure/Action description | Nominal |
| Year | Scale[N] |
| Quantities | Scales [$m^2$] |
| Floor number | Scale[N] |
| Room id | Nominal |
| Room name | Nominal |

### 2.1.4.3 Kungsbacka

Data regarding flooring was collected from the municipal management system of Kungsbacka which included most of the public buildings in the municipality. The dataset also included various floor types such as "Rubber," "Ceramic Tiles," "Linoleum," "Wood Flooring," along with their respective areas and the specific floors and rooms where they were installed. Table 6 describes the attributes found in the dataset.

Table 6: Information retrieved from municipal management system of preschools in Kungsbacka municipality.

| **Data specification** | **Measurement** |
|---|---|
| Region | Nominal |
| Floor material | Nominal |
| Area/Campus | Nominal |
| Building | Nominal |
| Floor | Nominal |
| Category | Nominal |
| Room type | Nominal |
| BRA Area (Swedish: Bruksarea, English: Gross floor area) | Scales [$m^2$] |
| NTA Area (Swedish: Nettoarea, English: Net area)" | Scales [$m^2$] |

## 2.2 Methods

Data integration was made by using Feature Manipulation engine (FME), a specialized spatial Extract, Transform, Load (ETL) tool. This approach is based in methods established in studies such as those by Johansson et al. [13] and Eriksson and Johansson [14]. The overall data integration schema is shown in Figure 1, and the extracted data sources are described in detail in Section 2.1.

### 2.2.1 Establish a national database

The initial step undertaken was to match all of Sweden's preschools from the SCB database using the property register's address table and entrance table. In cases where an incorrect or unmatched address was provided, a spatial join was employed between the address point and the building area. In this manner, each preschool identified in the SCB data was assigned a UUID.

The second step undertaken involved matching the SCB's geodata on schools with the school unit register to obtain additional information regarding the number of child groups, total number of children, and preschool teachers, which can provide a measure of how the locals are utilized. This was achieved through a match based on addresses, and also through spatial matching, using the address points of each dataset as starting points.

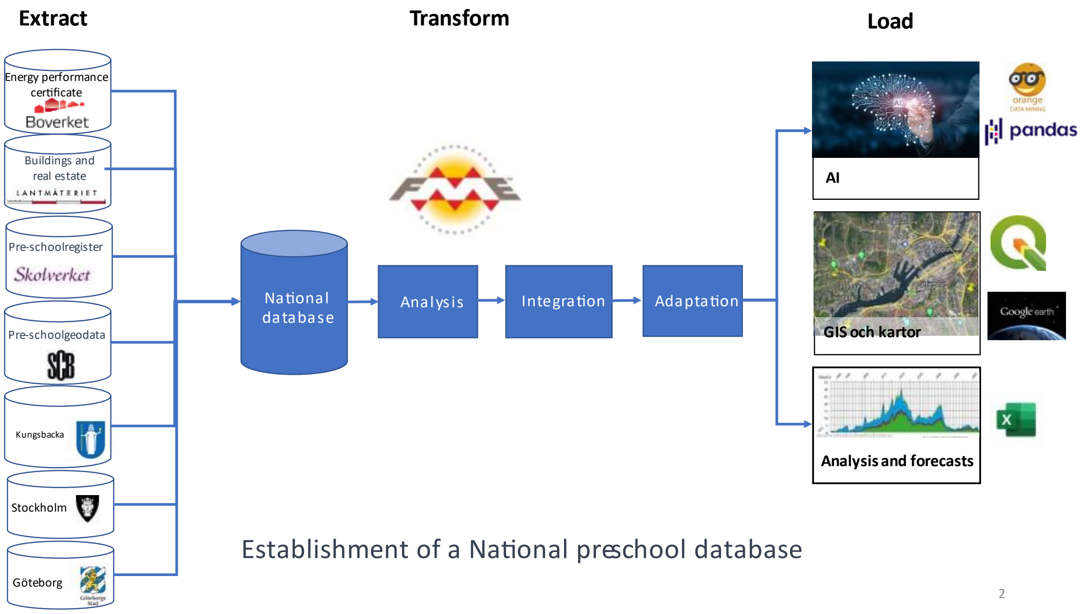


Figure 1: Establishing of a national database through extraction and matching of register data, based on addresses and spatial information.

In the first and second steps, a preschool table was created with all preschools along with a UUID, enabling the possibility of matching these data sets with the Swedish National Board of Housing, Building and Planning's energy declarations and the property register. The initial steps were necessary as there are no purpose codes or type codes specifically for preschools. In the third step, the identified preschools were matched with building, assessment, and ownership tables from the Swedish Land Survey. Unfortunately, municipal preschools often do not receive an assessment value, year of renovation, or valuation year, likely because they are not subjected to the same taxation as, for example, commercial locals. However, from the register it was possible to obtain the building parameters from the building tables from poverty and EPC register.

In the fourth step, local data from the municipalities of Kungsbacka, Gothenburg, and Stockholm were adapted. In all cases, there were no national building IDs available; however, the preschools were primarily matched based on address. If there was no match, the addresses were geocoded to a geographic point, which was then used for a spatial join with the building area to obtain a UUID.

The total area of PVC flooring in Stockholm was aggregated at the building level. However, in their PVC floorings inventory, only approximately 50% of the floor area of each building was examined. As a result, the PVC areas for the Stockholm data were multiplied by 2. In Kungsbacka and Gothenburg, the PVC flooring area, originating from a local register, was aggregated from each room to the building level.

When the database was analyzed, significant differences were observed in the amount of heated floor area per child across various municipally owned preschools. This variation seemed to correlate with the building's purpose. Consequently, a method was developed to address these variations, with its results presented in Table 7.

Table 7: Floor area per child for the different categories that were produced after the quality assessment.

| Type of pre-school | Mean m2 per child | Median m2 per child | Standard deviation | Number of units |
|---|---|---|---|---|
| Detached | 11.5 | 11.7 | 3.3 | 649 |
| In multifamily house | 208.1 | 115.7 | 345.8 | 189 |
| In school | 75.8 | 31.7 | 105.4 | 86 |
| In premises | 87.7 | 33.6 | 124.6 | 43 |

Heated floor area and other parameters from the energy performance certificate register are crucial for us to be able to predict and scale up the results to a national level, as the register contains the most suitable parameters for doing building specific analyses.

The method for classifying buildings based on their purpose/function involved using a combination of building purposes from the National Land Survey's building categories, the number of apartments, the proportion of residential area from the energy performance certificate register, and the area per child calculated from the heated floor area in the energy performance certificates, along with information from the school registry regarding the number of students in the specific school.

To verify the quality of the inventory, an estimation of the total number of municipally owned preschools was made and compared with buildings listed in the register. Table 8 shows that detached preschools had a high representativeness compared to other categories. The insufficient data quality for the other groups led to a focus on the detached type of preschool when estimating quantities of PVC flooring in Sweden.

Table 8: Representative of different types of pre-schools I the inventories.

| Type of pre-school | Available in inventories |
|---|---|
| Detached | 75% |
| In multifamily house | 15% |
| In school | 59% |
| In premises | 28% |

### 2.2.2 Site visits at preschools for data verification

In order to verify that the information of the amounts and type of flooring material stated in the maintenance plans received from the management organization corresponds to reality, some checks were made on site. This also gave the opportunity to make a judgement of the recycling potential. A number of preschools that according to the maintenance plans have PVC floorings were selected. The head of the preschool was contacted and asked if a site visit was possible. Seven preschools offered to host the team for a visit in May 2023. The assessment of the type of flooring, and a rough estimate of the quality in each preschool was made by a representative from the flooring manufacturer. The results are showed in Table 9.

Table 9: Estimated amounts of PVC and linoleum flooring at site visits at seven preschools in Gothenburg.

| Preschool | Estimated PVC at site | Type | PVC according to maintenance plan | Estimated linoleum at site |
|---|---|---|---|---|
| A | 100-150 sqm | IQ Optima (old) | 202+76 | 300 sqm |
| B | 100 sqm | IQ Optima | 294 | 150-200 sqm |
| C | 500 sqm | IQ Granit (possible to recycle) | 398 | |
| D | 500 sqm | IQ Granit (possible to recycle) | - | 1000 sqm |
| E | Small amount | Zero-PVC free (not possible to recycle) | 125 | 100 sqm |
| G | Small amount | Not identified | 260 | 800 sqm |
| H | Small amount | IQ Optima | 315 | 500 sqm |

The results from site visits prove that there is a coherence in data from the public managers' databases and what was found in the buildings. The difference between the amounts estimated at site and amounts according to maintenance plan can be due to many factors, such as: amounts were not properly measured but only roughly estimated at the site visit, all rooms were not accessible due to ongoing activities, preschools were located on the same estate as other public premises i.e. homes for elderly.

# 3 Results

The results section is divided into two main parts: firstly, a national estimation of the floor area covered by PVC floorings in preschools, achieved by extrapolating local data from public preschools in Kungsbacka, Stockholm, and Gothenburg with national data. The second part employs artificial intelligence to identify preschools likely to have significant amounts (over 150m2) of PVC flooring.

## 3.1 National estimation of PVC flooring in preschools

In this study the focus is on estimating the amount of PVC flooring in detached preschools, since the other types of preschools are difficult to isolate and predict since the building areas are shared with many other building usages like school, residential and commercial activities.

### 3.1.1 Total numbers of pre-schools by type

The method to classify preschools which is described in section 2.2 was used to estimate areas of detached preschools. Table 10 indicates that detached preschools are the most common type of preschool in Sweden. Additionally, multifamily buildings and schools are commonly used to accommodate preschool facilities.

Table 10: Number of preschools in each category.

| Type of pre-school | Number of units |
|---|---|
| Detached | 6 402 (62,3%) |
| In multi-family house | 1 798 (17,5%) |
| In school | 1 052 (10,2%) |
| In premises | 819 (8%) |
| Mismatched | 200 (1,9%) |
| **Total** | **10 271** |

The most common type of preschool is the detached preschool built in the 1960s and 1970s, and these account for approximately 20% of the current preschool facilities, see Table 11.

Table 11: Number of preschools in each category and construction period.

| Type of pre-school | -1960 | 1960 - 1980 | 1980 -2000 | 2000- | Unknown | Total |
|---|---|---|---|---|---|---|
| Detached | 820 (8%) | 1 940 (18.9%) | 1 419 (13.8%) | 1 061(10.3% | 1 162 (11.3%) | 6 402 (62.3%) |
| In multi-family building | 444 (4.3%) | 630 (6.1%) | 512 (5.0%) | 185(1.8%) | 27 (0.3%) | 1 798 (17.5%) |
| In school | 361(3.5%) | 387 (3.8%) | 174 (1.7%) | 130(1.3%) | | 1 052 (10.2%) |
| Premises | 287(2.8) | 313 (3.0%) | 172 (1.7%) | 47(0.5%) | | 819 (8.0%) |
| Mismatched | 70(0.7) | 62 (0.6%) | 49 (0.5%) | 19(0.2%) | | 200 (1.9%) |
| **Total** | **1 982** | **3 332** | **2 326** | **1 442** | **1 189** | **10 271** |

Regional differences of preschool are showed in Table 12 where the different preschools are categorized by different counties pretty large regional differences can be seen, with Stockholm accommodating almost one third of the preschools in multifamily buildings and municipalities like Halland and Södermanland having more than 72% of detached preschools.

Table 12: Regional distribution of the percentage of preschools in each category.

| Region | Detached | In multi-family building | In school | In premises | Mismatched | Total |
|---|---|---|---|---|---|---|
| Stockholm | 54.8% | 31.0% | 7.4% | 5.3% | 1.5% | 100% |
| Uppsala | 58.4% | 17.9% | 13.0% | 8.8% | 1.9% | 100% |
| Södermanland | 72.3% | 9.9% | 4.8% | 6.9% | 6.1% | 100% |
| Östergötland | 65.6% | 17.1% | 8.2% | 7.8% | 1.2% | 100% |
| Jönköping | 58.7% | 14.1% | 15.0% | 9.7% | 2.4% | 100% |
| Kronoberg | 63.6% | 12.6% | 11.6% | 10.1% | 2.0% | 100% |
| Kalmar | 64.0% | 13.0% | 10.5% | 9.6% | 2.9% | 100% |
| Gotland | 66.1% | 13.6% | 8.5% | 10.2% | 1.7% | 100% |
| Blekinge | 51.5% | 20.1% | 17.2% | 9.7% | 1.5% | 100% |
| Skåne | 61.4% | 17.4% | 11.2% | 8.5% | 1.5% | 100% |
| Halland | 72.9% | 9.3% | 8.5% | 7.4% | 1.9% | 100% |
| Västra Götaland | 66.4% | 14.6% | 8.9% | 8.5% | 1.6% | 100% |
| Värmland | 67.5% | 9.2% | 10.3% | 9.6% | 3.4% | 100% |
| Örebro | 64.6% | 14.2% | 9.7% | 8.3% | 3.1% | 100% |
| Västmanland | 58.2% | 19.0% | 12.7% | 9.0% | 1.1% | 100% |
| Dalarna | 66.2% | 11.0% | 11.0% | 9.7% | 2.0% | 100% |
| Gävleborg | 65.5% | 9.5% | 13.5% | 8.7% | 2.9% | 100% |
| Västernorrland | 63.0% | 8.1% | 17.2% | 9.9% | 1.8% | 100% |
| Jämtland | 57.5% | 9.6% | 17.4% | 13.8% | 1.8% | 100% |
| Västerbotten | 68.8% | 7.2% | 13.3% | 9.0% | 1.7% | 100% |
| Norrbotten | 68.5% | 6.6% | 16.0% | 7.4% | 1.6% | 100% |
| **Sweden** | **62.3%** | **17.5%** | **10.2%** | **8.0%** | **1.9%** | **100%** |

Detached preschools are the most common type of preschool in all municipalities, as shown in Table 13. Preschools in multi-family buildings are more prevalent in Sweden's major cities compared to other categories. Preschools located within school buildings are more common in rural areas.

Table 13: Number of preschools aggregated by municipality type.

| Municipality type | Detached | In multi-family building | In schools | In premises | Mismatched |
|---|---|---|---|---|---|
| Major cities | 48.4% | 38.3% | 6.3% | 6.4% | 0.6% |
| Commuter municipality near a major city | 66.9% | 15.7% | 9.3% | 6.1% | 2.0% |
| Larger city | 64.3% | 16.7% | 10.2% | 7.3% | 1.5% |
| Low-commuting municipality near a larger city | 65.9% | 10.3% | 11.1% | 9.8% | 3.0% |
| Commuting municipality near a larger city | 65.9% | 8.3% | 12.2% | 10.7% | 2.9% |
| Smaller city/town | 66.5% | 10.3% | 11.0% | 9.8% | 2.4% |
| Commuting municipality near a smaller city/town | 70.2% | 6.0% | 12.5% | 6.6% | 4.7% |
| Rural municipality | 59.4% | 9.3% | 17.2% | 12.5% | 1.6% |
| Rural municipality with tourism | 64.1% | 10.6% | 15.3% | 9.4% | 0.6% |
| Sweden | 62.3% | 17.5% | 10.2% | 8.0% | 1.9% |

In Table 14, we have included municipalities for which we have inventory data, in order to study how representative the data is for Sweden as a whole. There is an overrepresentation of multi-family buildings and an underrepresentation of detached preschools, schools, and local facilities compared to the rest of Sweden. However, there are also quite significant differences between the municipalities in all categories. Notably, there is also a large difference between Gothenburg and Stockholm, both major cities, in how they have located preschools.

Table 14: Distribution of preschool categories across the municipalities for which data were obtained, and a comparison with the total figures for Sweden as a whole.

| Municipality | Detached | % | In multi-family building | % | In school | % | In premises | % | Mis-matched | % | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Stockholm | 459 | 42.2 | 510 | 46.9 | 50 | 4.6 | 63 | 5.8 | 5 | 0.5 | 1087 |
| Göteborg | 325 | 57.9 | 141 | 25.1 | 51 | 9.1 | 40 | 7.1 | 4 | 0.7 | 561 |
| Kungsbacka | 66 | 78.6 | 9 | 10.7 | 4 | 4.8 | 4 | 4.8 | 1 | 1.2 | 84 |
| **Total** | **850** | **49.1** | **660** | **38.1** | **105** | **6.1** | **107** | **6.2** | **10** | **0.6** | **1732** |
| Sweden | 6 402 | 62.3 | 1 798 | 17.5 | 1 052 | 10.2 | 819 | 8.0 | 200 | 1.9 | 10 271 |

## 3.1.2 Urban locations of preschools

The dataset with different school types were exported to Google Earth and visually inspected in order to analyse the spatial configuration of preschools distributed on the map, see Figure 2, for Sweden, Figure 3 for Gothenburg, Figure 4 for Stockholm and Figure 5 for Kungsbacka.

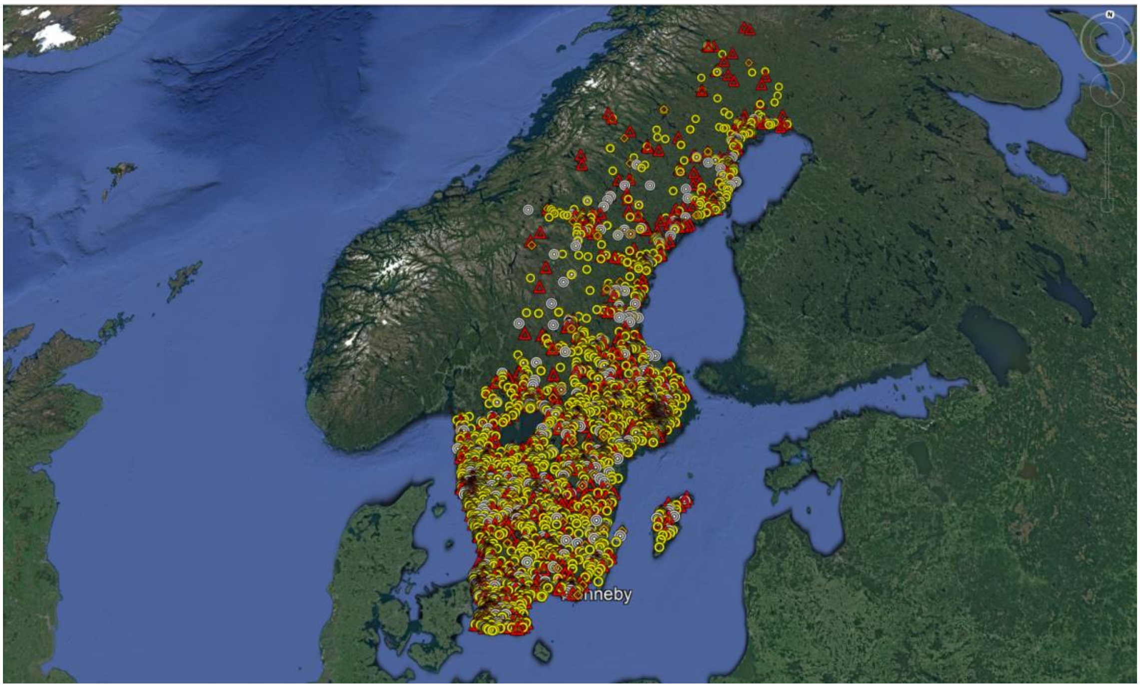

Figure 2: Location of all preschools in Sweden, yellow represents detached preschools, orange indicates preschools in multi-family buildings, red signifies preschools located within schools, and finally, white denotes preschools situated in local facilities.

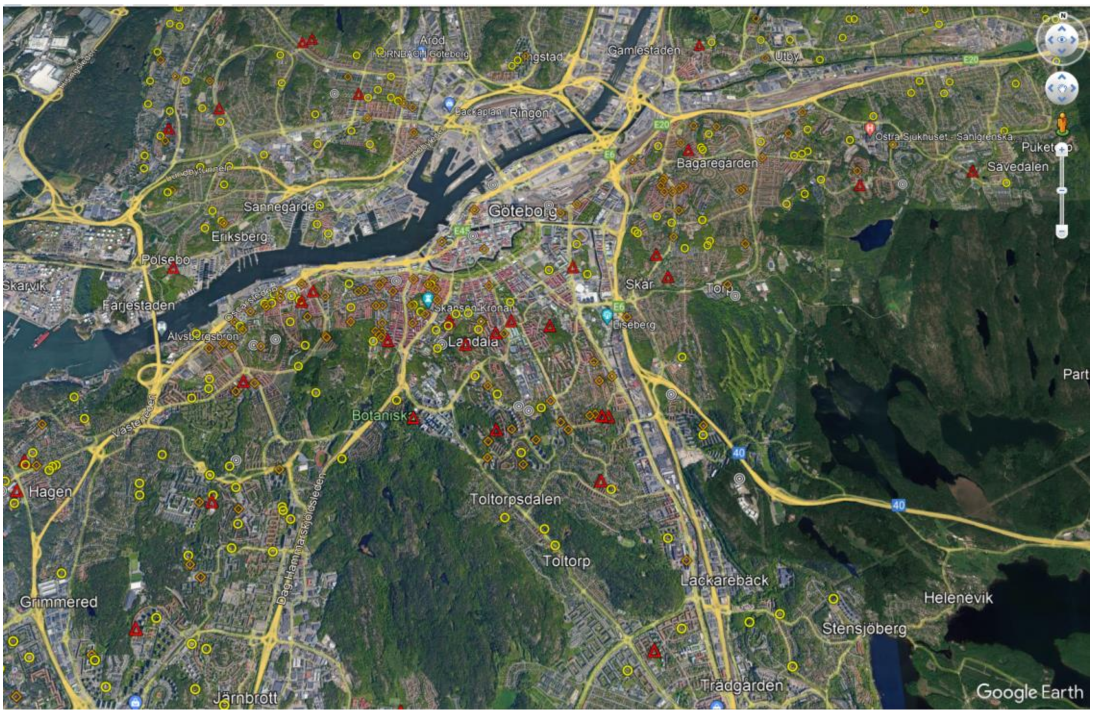


Figure 3: Location of preschools in Gothenburg. Yellow represents detached preschools, orange indicates preschools in multi-family buildings, red signifies preschools located within schools, and finally, white denotes preschools situated in local facilities.

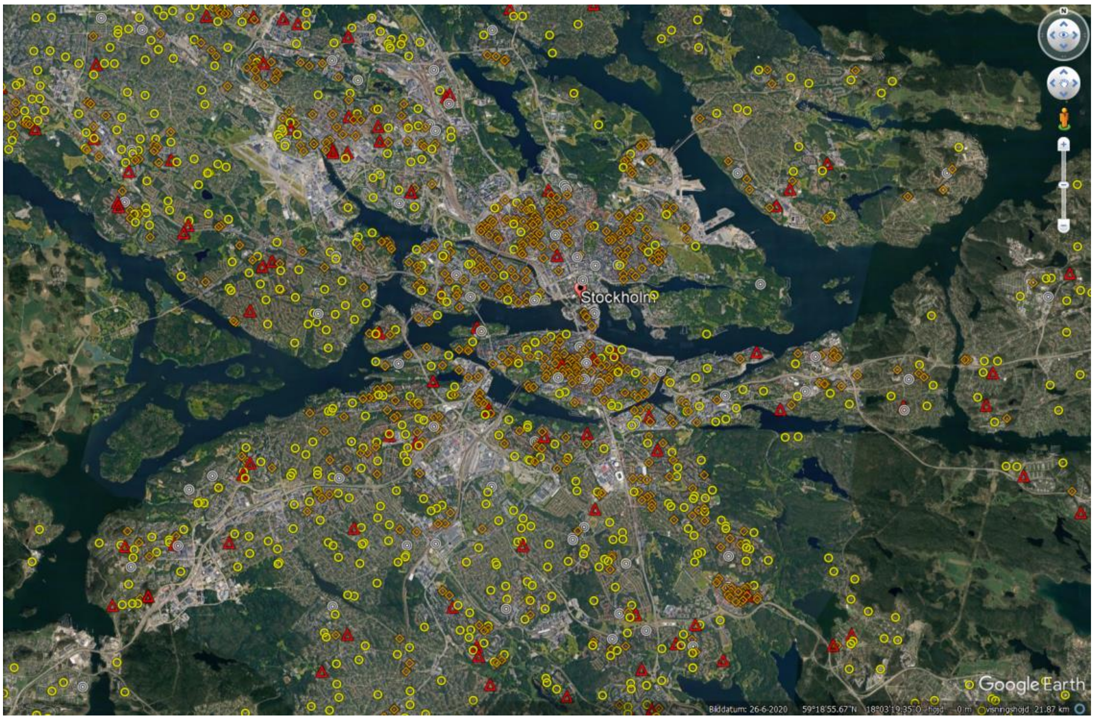


Figure 4: Location of preschools in Stockholm. Yellow represents detached preschools, orange indicates preschools in multi-family buildings, red signifies preschools located within schools, and finally, white denotes preschools situated in local facilities.


Figure 5: Location of all preschools in Kungsbacka. yellow represents detached preschools, orange indicates preschools in multi-family buildings, red signifies preschools located within schools, and finally, white denotes preschools situated in local facilities.

## 3.1.3 Total Floor Area

This section presents an estimation of the total area of PVC flooring in Swedish detached preschools. This estimation is derived using an average proportion of PVC flooring per heated area, based on data from municipal preschools in Stockholm, Gothenburg, and Kungsbacka. This approach assumes that these municipalities provide a representative sample of preschools for the entire country. The estimation accounts for the proportion of PVC flooring specific to each construction period. Table 15 displays the various types of PVC materials used across different construction years. It includes a detailed breakdown of the proportions for each of the three municipalities, alongside an estimated Swedish average (indicated in grey), which forms the basis of the national estimation.

Table 15: Estimated share of PVC flooring area in preschools from different construction periods in three municipalities, compared to the rest of Sweden.

| Municipality | Year of construction | Area PVC flooring | Total heated area | Share |
|---|---|---|---|---|
| Göteborg | -1960 | 1 700 | 13 191 | 12.89 |
| Göteborg | 1960-1980 | 26 666 | 64 988 | 41.03 |
| Göteborg | 1980-2000 | 10 823 | 31 386 | 34.48 |
| Göteborg | 2000- | 14 982 | 63 496 | 23.60 |
| Kungsbacka | -1960 | - | - | - |
| Kungsbacka | 1960-1980 | 986 | 5 170 | 19.07 |
| Kungsbacka | 1980-2000 | 2 466 | 13 187 | 18.70 |
| Kungsbacka | 2000- | 2 924 | 12 048 | 24.27 |
| Stockholm | -1960 | 4 070 | 18 442 | 22.07 |
| Stockholm | 1960-1980 | 31 412 | 90 361 | 34.76 |
| Stockholm | 1980-2000 | 10 148 | 44 401 | 22.86 |
| Stockholm | 2000- | 4 910 | 46 541 | 10.55 |
| Sweden | -1960 | 64 723 | 354 833 | 18.24 |
| Sweden | 1960-1980 | 492 242 | 1 337 772 | 36.80 |
| Sweden | 1980-2000 | 192 846 | 732 101 | 26.34 |
| Sweden | 2000- | 136 935 | 732 718 | 18.69 |
| Total | - | 886 745 | 3 157 424 | 28.08 |

In Sweden, the heated floor area for detached preschools is approximately 3.2 million square meters according to heated area taken from energy performance certificate register. This can be compared to the total area of the school category, which encompasses around 38 million square meters.

## 3.1.4 Estimation of PVC flooring after 2011

The potential for recycling PVC flooring is greatest if they were purchased and installed after 2011. Table 16 shows the total estimated amount of PVC flooring for each municipality on the left, along with an estimation of total quantities in buildings constructed after 2011. This does not take into account that buildings may have been renovated and thus may also have newer PVC flooring. At a national level, it is not possible to determine whether a building has been renovated, nor to identify the specific renovations undertaken.

Table 16: Left: Total estimation of PVC flooring. Right total estimation of PVC flooring in building constructed after 2011.

| Total Municipality | Estimated area PVC flooring(m2) | 2011- Municipality | Estimated area PVC flooring(m2) |
|---|---|---|---|
| Stockholm | 58 413 | Stockholm | 6 385 |
| Göteborg | 42 515 | Göteborg | 5 881 |
| Malmö | 22 956 | Malmö | 4 455 |
| Uppsala | 13 508 | Linköping | 2 842 |
| Sundsvall | 13 280 | Borås | 2 183 |
| Norrköping | 12 878 | Varberg | 2 062 |
| Linköping | 12 856 | Örebro | 1 518 |
| Helsingborg | 12 165 | Norrköping | 1 407 |
| Gävle | 11 561 | Jönköping | 1 309 |
| Huddinge | 11 395 | Skellefteå | 1 234 |
| Botkyrka | 11 236 | Lund | 1 106 |
| Västerås | 10 797 | Helsingborg | 1 082 |
| Borås | 10 786 | Enköping | 1 082 |
| Luleå | 10 290 | Kungsbacka | 1 035 |
| Lund | 10 129 | Gävle | 1 029 |

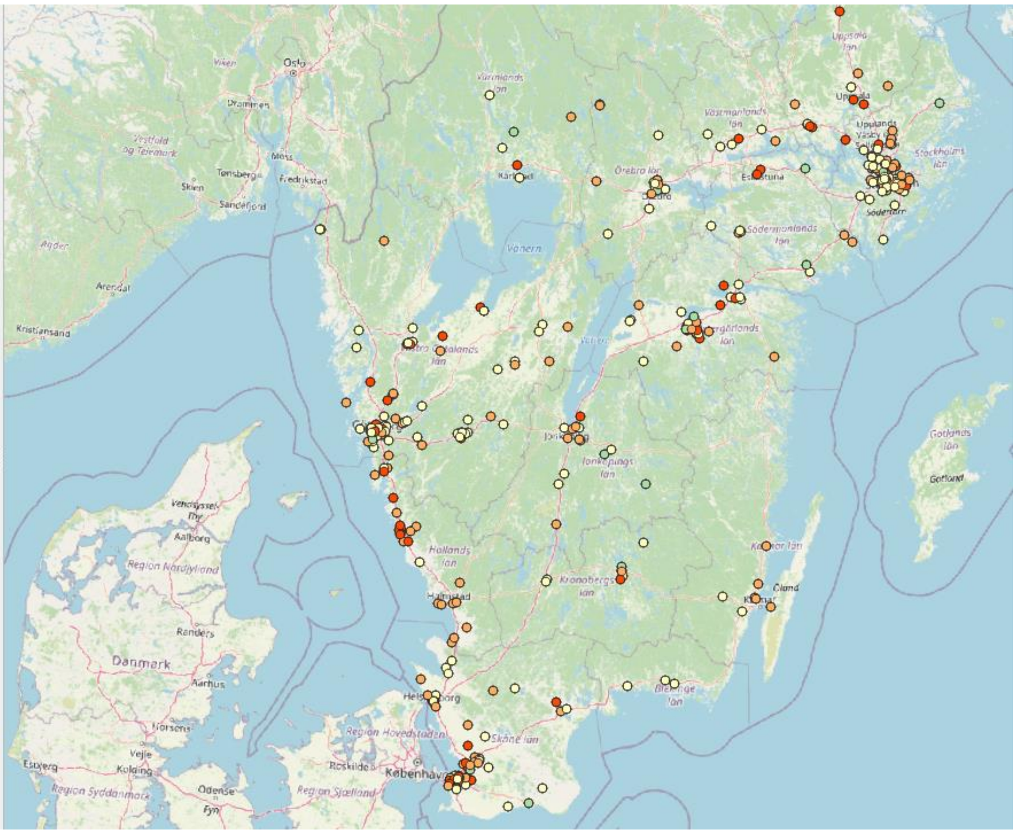


Figure 6: Shows preschools built after 2011 coloured by their heated area group size. Red 1500-4000 m2, Orange, 1000-1500, Yellow 500-1000 and Green 0-500.

### 3.1.5 Building specific estimations

A predictive analysis was conducted to determine whether preschools are equipped with PVC flooring. A well-balanced selection group consisting of a total of 310 preschools was chosen for the study, with an even distribution of preschools that either reported having PVC flooring or not. The goal of the analysis was to create a reliable predictive model that, by analyzing various characteristics and attributes of the preschools, can predict the presence of PVC flooring on a national level. The 14 building parameters used were as follows:

- Construction year
- Heated area
- Number of floors
- Building footprint area
- Building footprint width
- Building footprint length
- Main heating system
- Specific energy uses for the newest EPC.
- Specific energy uses previous EPC.
- Building category
- Basement
- Number of stairwells
- Percentage of full-time positions with a preschool teacher degree.
- Square meters per child

The model was trained using 80% of the data, with the remaining 20% used for testing purposes. Table 17 presents the results of the prediction, with AdaBoost and Random Forest being the highest-performing models among the evaluated algorithms. Random Forest achieved the highest AUC value at 0.749, and AdaBoost had the highest accuracy (CA) at 0.734, both significantly surpassing random guesses and indicating a reasonable ability to correctly classify preschools based on the presence of PVC flooring. These two models also demonstrated acceptable performance across F1-score, precision, and recall, confirming their efficacy in the classification task.

Table 17: Predictions results for preschool with or without PVC flooring.

| **Modell** | **AUC** | **CA** | **F1** | **Precision** | **Recall** | **MCC** |
|---|---|---|---|---|---|---|
| AdaBoost | 0.734 | 0.734 | 0.732 | 0.739 | 0.734 | 0.473 |
| Random Forest | 0.749 | 0.702 | 0.701 | 0.702 | 0.702 | 0.404 |
| Neural Network | 0.661 | 0.685 | 0.685 | 0.687 | 0.685 | 0.372 |
| Tree | 0.68 | 0.669 | 0.66 | 0.691 | 0.669 | 0.36 |
| kNN | 0.705 | 0.661 | 0.66 | 0.664 | 0.661 | 0.325 |
| SVM | 0.701 | 0.645 | 0.643 | 0.649 | 0.645 | 0.294 |
| Logistic Regression | 0.669 | 0.645 | 0.645 | 0.645 | 0.645 | 0.29 |
| Naive Bayes | 0.696 | 0.605 | 0.604 | 0.606 | 0.605 | 0.21 |

In the second attempt, the goal was to predict which preschools have large and small amounts of PVC floorings. The data, comprising a total of 452 observations, was evenly split into two balanced categories: over 150m2 and less PVC flooring. The results of the classification are less compared to the first attempt, with only 65% correctly classified, see table Table 18. This suggests that the model is better at classifying buildings with and without PVC floorings, rather than estimating the amount of PVC flooring in a specific building.

Table 18: Prediction results for preschool with larger than 150m2 PVC floor area.

| Modell | AUC | CA | F1 | Prec | Recall | MCC |
|---|---|---|---|---|---|---|
| Logistic Regression | 0.661 | 0.654 | 0.654 | 0.654 | 0.654 | 0.308 |
| kNN | 0.671 | 0.632 | 0.632 | 0.632 | 0.632 | 0.264 |
| Neural Network | 0.635 | 0.621 | 0.62 | 0.622 | 0.621 | 0.242 |
| Random Forest | 0.671 | 0.61 | 0.61 | 0.61 | 0.61 | 0.22 |
| AdaBoost | 0.604 | 0.604 | 0.604 | 0.605 | 0.604 | 0.209 |
| Naive Bayes | 0.65 | 0.566 | 0.563 | 0.568 | 0.566 | 0.134 |
| SVM | 0.578 | 0.549 | 0.549 | 0.55 | 0.549 | 0.099 |
| Tree | 0.496 | 0.516 | 0.516 | 0.517 | 0.516 | 0.033 |

The relatively low classification accuracy for the most accurate models, ranging between 65% and 73%, was somewhat expected due to the challenges in obtaining data that could effectively explain the replacement of PVC flooring at the national level. Key indicators of renovation needs, such as valuation year or tax values, are not available for detached preschools as they are not taxed like commercial properties. Reporting of PVC flooring replacements is often insufficient in public records such as procurement databases, as these are less costly than other building renovations. Exchanges of PVC floorings are often managed through framework agreements (Swedish: Ramavtal), complicating the specific tracking to individual buildings. Nevertheless, the collected data contains valuable information that enables reliable estimations at a municipal level, which is more trustworthy than building-specific comparisons. A consistent pattern emerged where buildings built in 1960-1980 often had a larger proportion of PVC flooring.

Further analyses indicate that companies like Tarkett and Ragn-Sells can identify larger buildings with extensive heated floor areas likely containing significant amounts of PVC flooring, although it is not possible to precisely specify individual buildings. Identifying preschools with a large amount of PVC flooring is feasible through the project.

# 4 Discussion and conclusions

This section contains discussion and main conclusions of results with possibilities and implications for the material producers and building and real estate sector.

## 4.1 Discussion

In the construction and real estate sector, the goal is to become increasingly circular, but the material quantities required to achieve circular flows on a large scale are rarely discussed. The problem is that the materials to be circulated are scattered and that we do not have control over what they contain and what quality they have. Today's waste management routines and legislation do not always reward sorting waste from renovation and demolition projects. To facilitate circular flows, the material should be kept clean and preferably analyzed before it is dismantled and becomes waste. This should be done in conjunction with an environmental inventory. This is a challenge when Tarkett only wants to recycle PVC flooring of a certain quality and manufacturing period. A solution to this is to be able to predict volumes of a certain material and year of manufacture in advance.

In the current project, preschools have been used as a type building category and a method for predicting PVC floorings manufactured after 2011 has been developed. This methodology can be applied to other types of materials and manufacturing periods or other criteria provided that data is available for training the machine learning models.

This study has been developing a data-driven method of tracing and assessing the recycling potential for PVC flooring in the preschool stock, based on data from building maintenance plans received from the building management organisations in three municipalities, combined with data from the Swedish building registers. If the results from the three municipalities are scaled up to national level, the estimated amount of PVC flooring is almost 900 000 m2 in the Swedish preschool stock.

Assuming an even distribution of construction of new preschools from 2000 to 2023, PVC flooring laid after 2011 should make up about 9%, which corresponds to about 80,000 m2.

Based on the assumption that PVC flooring contributes to an effect of 38 kg $CO_2$ e/m2, 3040 tonnes $CO_2$ can be saved by recycling PVC floorings from detached preschools (62% of all preschools).

If we assume that the remaining preschools (38%) have the same amount of PVC flooring, this sum would be 4900 tons, which correspond to more than 1000 people's annual $CO_2$ emissions.

Assuming that all PVC flooring in preschools produced before 2010, containing DEHP and DINP as plasticizers, are replaced by new PVC floorings, it would cost half a billion to a billion, assuming that it costs about 1000 SEK to lay a new PVC flooring with DINCH as plasticizer.

The key is to be well informed when and where the PVC flooring will be dismantled in the near future in order to prepare for necessary field testing and/or laboratory analyses to verify type and quality of material, proper planning of collection, sorting and transportation of material for recycling.

First of all, the property owners themselves also need systems to keep track of where they have different types of PVC flooring and when they need to be replaced. In this study, documentation was received from three municipalities, who have carried out inventories of PVC flooring in existing preschools and have documented this as a complement to their maintenance plans.

The next step is for the manufacturer and supplier of PVC flooring to establish contact with the main end-users of PVC flooring, such as preschools, schools, hospitals, warehouses to get informed well in advance when sufficient amounts of PVC flooring are going to be changed.

In the future this information will most probably be accessible though building information management models and digital twins of the buildings containing product specific information, location, installation year and amounts of all materials and products in the building.

How does this fit with the material manufacturers' strategy for the future? The flooring manufacturer Tarkett has the aim to increase material recycling, and believes that the developed method can form the basis for a form of exploration to estimate the quantities and types of materials and products available in the building stock, but also which ones are to be dismantled and replaced in the near future, which makes it possible to prepare for reuse or recycling. This means that the actors who are looking for materials or products to reuse or recycle can identify where they are and when they may become available and prepare their business to receive the materials or products, thereby contributing to more circular flows. This method enables forecasts on stock level to quickly get an idea of available materials and products.

The results from the project are an example of how limited building-specific information can be used to predict the presence of the material or product in the entire stock. In the report, we have used the example of PVC floorings in preschools, but this method can be used for all types of materials and products, provided that there is access to information on occurrence in a representative proportion of the stock.

In contrast to previous research that has shown that it is possible to predict the presence of asbestos, PCBs, radioactive concrete, and radon indoors with a high degree of accuracy using similar methods on the building level. In this project the estimation of high and low amount of PVC flooring were around 65-70% which is rather low.

There are international proposals that specific information on specific materials and products (comparably to content declaration in food or clothes) in new buildings should be logged in digital logbooks, but it is still unclear who should be responsible for ensuring that this information is synchronized with the national property registers, and there are no proposals on how presence of materials and products in existing buildings should be reported. There will still be a lack of information on this for many years.

Currently, the knowledge of the types of in situ PVC flooring and its use in various building types are limited, making material recovery and quality assurance difficult. Characterizing the presence of PVC flooring and recycling potential in buildings can encourage property owners' and demolition contractors' actions that will increase recycling of old PVC flooring from demolished and renovated buildings. In fact, the entire flooring production value chain can benefit from more available and cost-efficient reclaimed material for PVC products, meanwhile, less non-recyclable wastes from renovation, deconstruction, and demolition for incineration.

The results from this project showed that, even though we only have limited material data available, a fairly good estimate of the presence of materials can be made.

If the data mining of PVC flooring and the subsequent descriptive analysis prove beneficial to the C&D industry, then a similar method can be applied extensively to assess other in situ materials in the Swedish building stock for prospective material recovery.

# 4.2 Conclusions

This research project has focused on analysing and quantifying the presence of PVC flooring in Swedish building stock using Swedish preschools as a case building category. The study has developed several methods that have been used to estimate the total quantities of PVC flooring in pre-schools by integrating data from several registers. Below are the key findings of this project:

1. A method for classifying preschools into sub-building categories has been developed through the integration of data from the preschool unit registry, property registry, and energy performance certificates. The method is highly accurate and can be used in future studies to understand the specific characteristics of preschool buildings.
2. A calculation method has been developed to estimate the total amount of PVC flooring in Swedish preschools, based on the created subcategories of preschools and their years of construction. This method enables the calculation of the proportion of PVC flooring in the various categories of preschools and has the potential to be applied to other types of buildings, such as hospitals and schools, but requires further verification. The estimation appears possible at a municipal level, as the three municipalities have shown similar proportions of PVC flooring, yet it is more challenging to make accurate estimates for individual buildings.
3. Efforts have been made to predict the amount of PVC flooring in individual preschool buildings, which has proven difficult due to the limited parameters that explain PVC flooring replacements in the existing registries. The lack of available property taxation information has been a complicating factor, and preschools with similar characteristics, size, and year of construction there may have been completely different decisions regarding PVC flooring.
4. Based on data from inventories of PVC flooring in preschools conducted by three municipalities, the total amount of PVC flooring in the entire preschool inventory has been estimated to be approximately 1,236,000 square meters, of which about 86,500 square meters were installed after 2011. The results of the study can be used to make a rough estimate of the amount of PVC flooring in the entire preschool stock in Sweden.
5. Energy performance certificates have provided significant opportunities for analysing energy performance in large building stocks. Unfortunately, the energy performance certificates contain very little information regarding the materials and products in buildings, which complicates analyses related to identification of content and amounts of certain substances. A national transparent register for products in buildings would contribute to significant gains in decontamination of hazardous substances, enhancing circularity and reducing climate impact.

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