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Process induced building defects in Norway – development and climate risks

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Process induced building defects in Norway – development and climate risks

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Abstract. The SINTEF building defects archive is an important source to knowledge on building defects in Norway. This study presents a review of defects investigated by SINTEF in the period 2017–2020, including 175 defect cases registered in 125 reports. The main goal is to understand the primary causes of process induced building defects today and which building elements may be considered as risk spots. The review shows that almost 3 of 4 defects is related to moisture, caused by sources as precipitation, condensation of humid indoor air or built-in moisture. Defects associated with the building envelope make up more than 70% of the cases, of which most defects are linked to exterior wall or roof constructions. The results from the present study have been compared to a review of defects reported in the archive during the period 1993–2002. The comparison reveals that the share of damages caused by precipitation is almost doubled, while the share of damages caused by humid air from the interior is approximately halved. The results imply that climate adaptation of buildings is important. As climate change causes more precipitation with higher intensities, the load on buildings increases and a larger focus on risk reduction and protection towards penetration of water from the outside is required.

1. Introduction

An increasing number of observations provide an overall representation of global warming and other changes to climate systems. Adapting to the effects of climate change therefore represents a significant challenge for the society in the coming years [1]. According to different scenarios of climate development in Norway, increased temperature, precipitation and changes in precipitation patterns should be expected [2]. The Norwegian climate already puts a great demand on planning, design and maintenance of buildings. However, a changing climate will require increased attention to better climate adaptation of buildings to reduce the risk of damages. Even with satisfactory climate adaptation, damages in buildings may occur, caused by construction that deviates from basic principles [3] or unfortunate use of materials. Building materials have to fulfil several requirements throughout the lifetime of building components. Hence, it is important to choose materials and solutions that are durable and suitable to avoid defects.

Process induced building defects may be defined as absence or reduction of a presupposed capacity that is discovered after a building project or operation has been completed [4]. Hence, process induced building defects are defects that results in costs that should not have occurred, or additional costs related to a more frequent maintenance than predicted. The defects occur because involved actors have not succeeded in fulfilling requirements in standardized or recognized methods or specifications, during planning, production, or material manufacturing. Defects caused by normal wear are not defined as process induced building defects.

Process induced building defects in Norway have been studied through comprehensive analyses of building defects reported in the building defects archive of SINTEF in Norway in the period 1993–2002 [3, 5]. To increase the knowledge on defects concerning roofs, [6] performed a thorough study focusing on pitched wooden roof defects, based on the research presented by [3, 5]. In addition, [7] performed a study of defects involving ETICS reported by SINTEF in the period 1993–2017. However, the conclusions in the cited research are based on building defect assignments, of which a large share is carried out more than 20 years ago. In order to increase the knowledge on building defects in Norway today, the present paper presents a review of building defect assignments carried out by SINTEF in the period 2017–2020. The main goal is to understand the primary causes of process induced building defects today and which building elements may be considered as risk spots. In addition, the analysis of defect cases from 2017–2020 has been compared to the earlier analysis [3] of defects in the archive, in order to investigate possible changes in building defect sources and distribution throughout the years.

2. Method

SINTEF has analysed building defects in Norway for more than 60 years, both on behalf of the construction industry and through comprehensive field investigations. The analyses are filed in assignment reports in a database which make up the SINTEF building defects archive. The archive is an important source to knowledge on types and causes of process induced building defects in Norway.

The present study was carried out as a qualitative investigation of building defect assignment reports in the SINTEF building defects archive. Assignments carried out in the period 2017–2020 were analysed. The material includes 175 defect cases described in 125 reports. The analysis was carried out by retrieving the following information from the assignment reports:

- Type of client
- Year of construction of the building or the building element (or, in the case of renovations, the year of renovation)
- Year of assignment
- Type of building
- Localization of damage (primary building element)
- Type of construction
- Source of defect and cause of defect

The retrieved information was sorted and analysed. In addition, the analysis of defect cases from 2017–2020 was compared with the earlier analysis of defects reported in the archive in the period 1993–2002. The analysis from 1993–2002 included 2423 defect cases described in 2003 assignments and is reported in [3].

3. Results

The results presented in this section mainly discuss the analysis of defect cases reported in the 2017–2020 period. The analysis from 1993–2002 is thoroughly presented in [3], but some of the results are included in Figure 1–Figure 5.

Figure 1 presents registered building defects distributed by type of clients. The bulk of the clients are building owners, mostly professional, but also private. Figure 2 presents building defects distributed by building type. The sub-category "domestic buildings" includes detached houses, semi-detached houses (duplexes or similar), row houses and chain houses. Apartment buildings are blocks of flats with multiple stories. Culture and research buildings is a broad category including buildings for education or research, e.g. kindergartens, schools or laboratories, cultural buildings such as museums or libraries, buildings used for sports, as well as religious buildings. Office and enterprise buildings includes, in addition to offices and similar, also hotels, shopping centres and military buildings. The analysis of building type shows that 63% of the defect cases reported in 2017–2020 are found in residential buildings. In comparison, only 37% of the total number of buildings in Norway in 2020 were residential buildings. Table 1 shows the development in number and type of residential buildings in the Norwegian building stock the last 20 years.

Distribution of building defects by localization of defects is shown in Figure 3. Defects related to the building envelope, including roofs, exterior walls, and slab-on-ground floors, make up 70% of the investigated defect cases in the 2017–2020 period. The category "other building components" includes all elements that are not part of the building envelope, for example intermediate floors, internal walls, stairs, bathrooms and similar. The present study has not focused on discussing these types of damages. This is also the case for the category technical installations (including e.g. heating, cooling or ventilation installations, electric installations or sanitary installations).

Figure 4 details the distribution of defect localization, presenting the distribution of defects concerning roofs by type of roof construction. Unventilated (compact) roofs are roofs where the material layers are placed as close to each other as possible. Type 1 insulated pitched wooden roofs are pitched wooden roofs with separate exterior air barrier (wind barrier) and underlayer roof (waterproof layer), i.e. roofs with ventilation in an air cavity between the air barrier and the underlayer roof. Type 2 insulated pitched wooden roofs are pitched wooden roofs with combined exterior air barrier and underlayer roof (watertight breather membrane). The sub-category terraces on concrete floors includes slab structures on ground level, such as slabs above underground parking garages.

An overview of different sources of defects is presented in Figure 5. The present study concentrates on defects related to moisture, which make up 71% of all the defect cases reported in 2017–2020. As given in Figure 5, the defect sources are divided into different moisture sources. Indoor moisture is moisture load produced by humans, animals, or plants. Defects related to built-in moisture is caused by moisture found in materials or constructions. The category "water in soil" includes defects caused by insufficient drainage or run-off conditions on the outside terrain. As show in Figure 5, 9% of the defects are related to moisture in combination with other sources. In many cases, this type of defects are sulphate attacks or reinforcement corrosion. 24% of the defects are not caused by moisture, but by sources as temperatures, insufficient workmanship, or material malfunctions.

The distribution of building defects based on the number of years from the completion of the building or building element until the defects were reported is presented in Figure 6. In the case of renovations, the number of years from renovation until the defect is reported is used. Approximately 13% of the building defects are reported within the first year, and about 50% of the defects are reported 5 years after completion of the building.

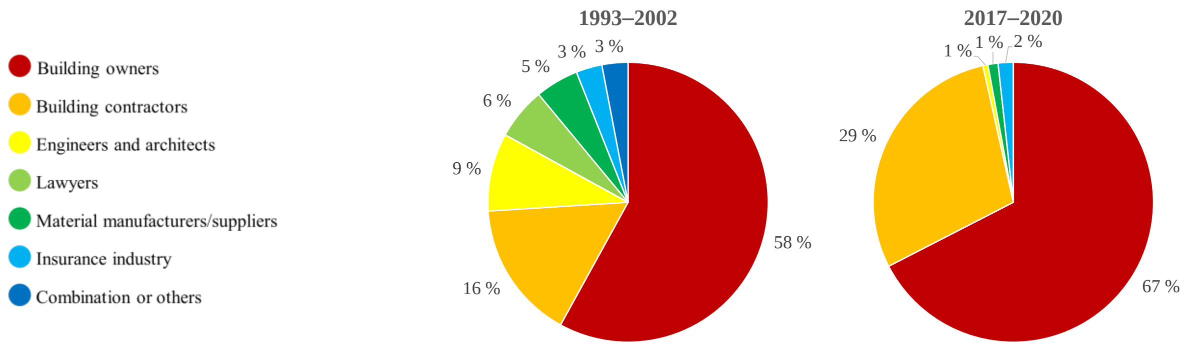

Figure 1. Building defects distributed by type of clients.

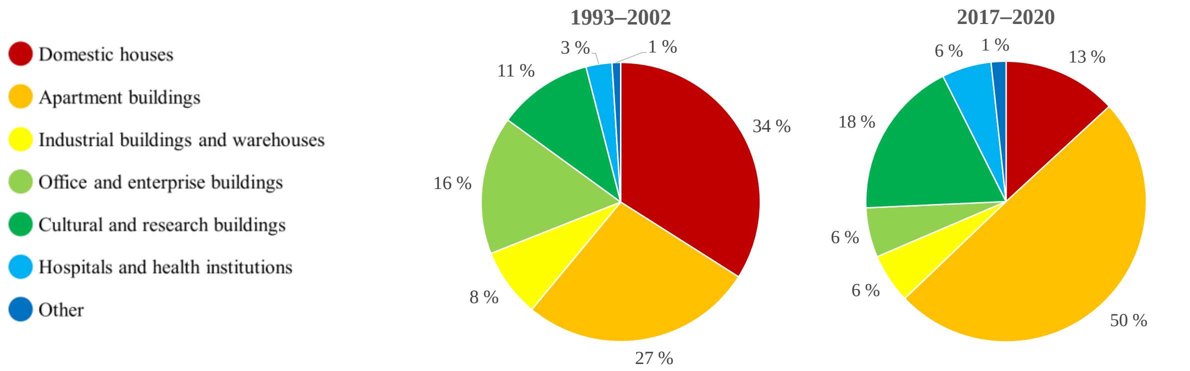

Figure 2. Building defects distributed by type of building.

Table 1. Development in number and type of residential buildings in the Norwegian building stock [8]. Numbers in parentheses indicate the share of the given building type of the total number of residential buildings.

	2001		2020	
Residential buildings (total)	1 352 872		1 564 662	
Detached house	1 102 553	(81.5%)	1 174 481	(75.1%)
Semi-detached house (duplex)	108 971	(8.1%)	171 080	(10.9%)
Row house, chain house, triplex or similar	116 832	(8.6%)	172 198	(11.0%)
Multi-storey/apartment building	22 368	(1.7%)	41 578	(2.7%)
Residence for communities	2148	(0.2%)	5325	(0.3%)

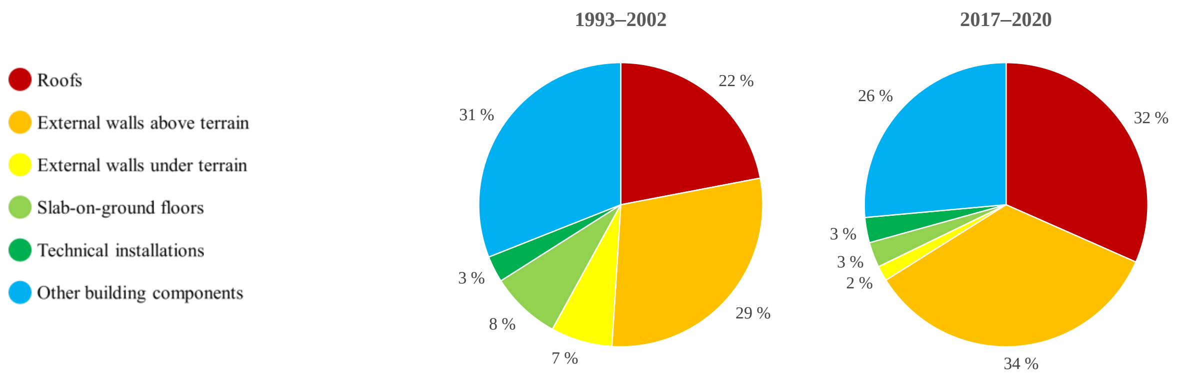

Figure 3. Building defects distributed by localization of damage.

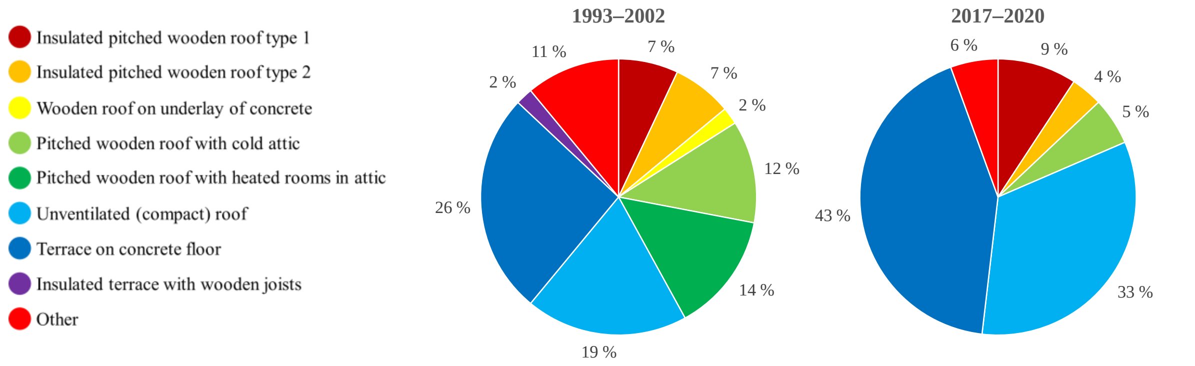

Figure 4. Building defects in roof constructions, distributed by type of roof construction.

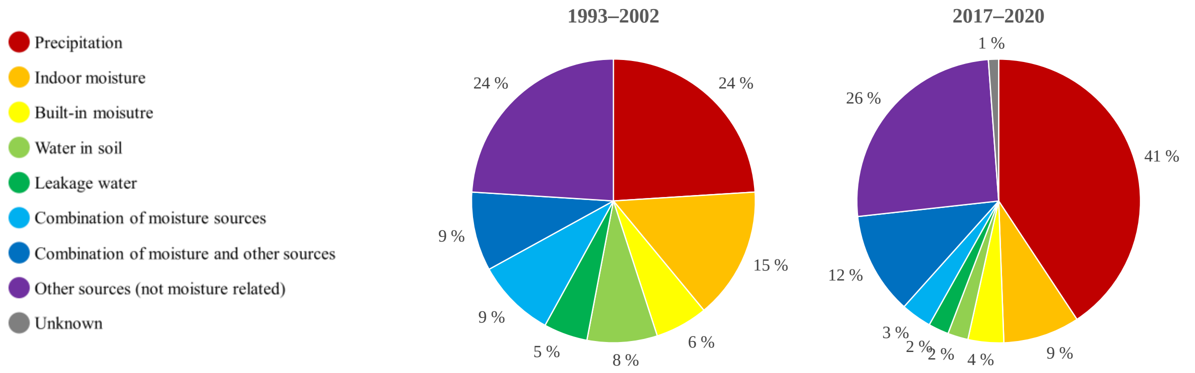

Figure 5. Building defects distributed by type of damage source.

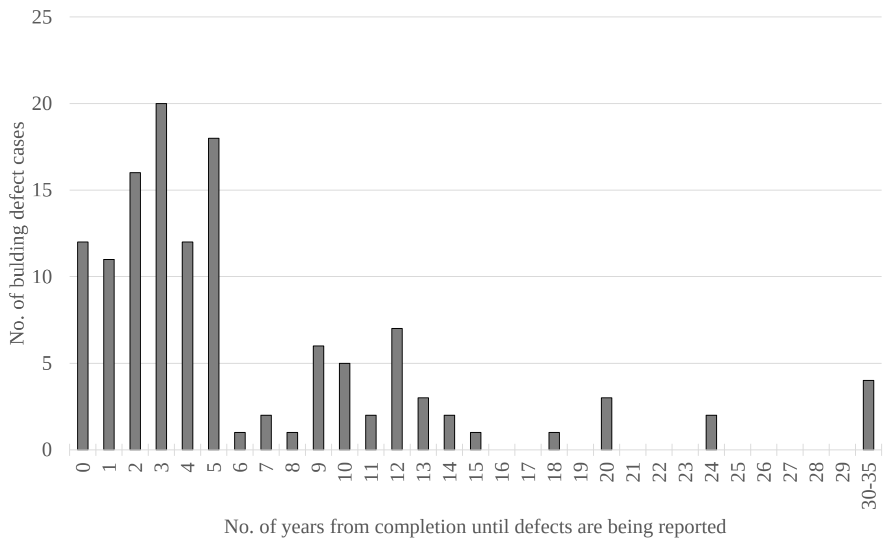

Figure 6. Distribution of building defects based on number of years from completion of the building until the defects are reported by SINTEF.

4. Discussion

4.1. Representativeness of the study

The analysis presented in this paper is based on the building defect assignment reports in the building defects archive of SINTEF. The reports are based on consultancy assignments from various actors in the building industry, as shown in Figure 1. The selection of building defects is consequently a result of the accessible reports in the archive and does not necessarily represent the actual distribution of building defects in the Norwegian building stock. It must be underlined that only a small part of the total amount of process induced building defects in Norway is included in the archive, and often it is types of defects that are not easy to analyse or judge. Hence, the study has a disadvantage in terms of general validity. However, the statistics from the archive is still a source to valuable knowledge on building defects, including information about typical risk spots and vulnerable building elements. One major advantage of the building defects archive is the number of reports collected over a long period of time, and the possibility of investigating development in type of defects. In addition, all the defect cases investigated by SINTEF have been thoroughly analysed, including evaluation of the causes of defects.

It should be added to this discussion that several different factors will affect the selection of defects assignments involving SINTEF. Costs related to the assignments will most likely affect the type of clients (actors) involved, making professional clients more dominant than private clients. Changes in costs could therefore result in changes in both the amount and type of defects registered in the archive. The policy of SINTEF the later years has been to work mostly for professional customers from the building industry, which also affect the character of the assignment reports. It is also reasonable to assume that the type of defects assigned to SINTEF is related to SINTEF's expertise. This will affect the number of defects registered in each category in the results. This is clearly shown in the share of defects on technical installations presented in Figure 3: defects related to technical installations do not reflect the actual share of defects in these installations, but rather expresses that this is not the area of expertise of SINTEF.

4.2. Sources of defects

Buildings in Norway are subjected to severe weather exposure and large moisture loads. Almost 3 out 4 defect cases assessed by SINTEF during 2017–2020 are caused by moisture, from sources like precipitation, condensation due to humid indoor air or from built-in moisture in materials and constructions. The overview of damage sources given in Figure 5 shows that penetration of water is a recurring cause of defects in building constructions. More than 40% of the reported defects may be linked to precipitation. In comparison, only 9% of the defects are caused by humid indoor air, for example due to leakages into the construction from the interior air. The comparison with the analysis from 1993–2002 shows that the share of moisture damages is relatively stable (71% in 2017–2020 and 76% in 1993–2002), while the allocation to different moisture sources has changed. Figure 5 shows that the fraction of defects caused by precipitation is almost doubled. Changes in precipitation patterns may be one reason to the observed increase in defect cases reported in which precipitation is involved. The results imply that increased focus on climate adaptation of buildings is important. As climate change causes more precipitation with higher intensities, the load on buildings increases. Consequently, a larger focus on risk reduction and protection towards penetration of water from the outside is required. This involves measures like watertight membranes, good solutions for run-off and drainage, as well as coordinated building processes. Details and penetrations though external walls are equally important to obtain a well-thought design to protect from water penetration.

Furthermore, the comparison shows that defects caused by humid indoor air is approximately halved. Stricter air tightness requirements in Norwegian building regulations have resulted in larger focus on correct installation of exterior air barriers and interior air and vapour barriers. An important regulatory measure to guarantee compliance with building codes in Norway is the Technical Regulations (Regulations on technical requirements for construction works) under the Norwegian Planning and

Building Act (pba). The current requirement of air tightness of buildings is an air change (at 50 Pa pressure difference) of ≤ 0.6 h^{-1} in general for residential buildings, and a minimum requirement of ≤ 1.5 h^{-1} for all buildings. The current requirements have been in force since 2017, but the airtightness requirements have been unchanged since 2007. In addition, more buildings than before are constructed as passive houses, where the requirement is an air change ≤ 0.6 h^{-1} for all types of buildings according to NS 3700 [9]. In comparison, the requirement in the Technical Regulations from 1997 (until 2007) was an air change ≤ 2.5 h^{-1} for detached houses and a minimum requirement of ≤ 3 h^{-1} for all buildings. As about 50% of the buildings investigated in each of the two studied periods were less than 5 years old (see Figure 6 and [3]), it is likely that many of them were completed under different requirements of airtightness. In addition, according to the Norwegian building regulations heat recovery of ventilation air has been mandatory since 2007, which makes mechanical ventilation of indoor air necessary. Hence, newer buildings are constructed more airtight and is better ventilated, which may explain the reduction in the share of damages caused by air leakages and subsequent condensation or relative humidity above the critical level for moisture problems to occur.

4.3. Localization of defects

The analysis shows that defects associated with the building envelope make up more than 70% of the reported defects in 2017–2020. Many defects are linked to roof constructions. The analysis from 1993–2002 revealed that 40% of defects in roofs were found in ventilated pitched wooden roofs, while only 20% of the defects were linked to unventilated (compact) roofs, as shown in Figure 4 and in [3, 6]. The assignments from 2017–2020 shows, however, that the fraction of defects linked to unventilated roofs has increased to 30%. In addition, more than 40% of the roof defects are found in unventilated terraces (this category also includes slabs above e.g. parking garages below ground level). In total, defects in unventilated roof constructions make up almost 3/4 of all reported roof defects in the period.

The results may reflect a general increase in the use of unventilated roof constructions, but the numbers also indicate that these types of constructions may be difficult to build correctly to avoid water leakages from the outside. As an example, about 80% of the defects on unventilated terraces are linked to penetration of precipitation, in which leakages in the roof membrane and insufficient connections to terrace doors are recurring reasons to defects. The latter may partly be explained by a change in the Norwegian regulations, which incorporated requirements to universal design in buildings in 2010. This has affected the accepted height of door sills, which may be challenging to combine with sufficient moisture safety. In addition, roofs are to a larger extent built with supplementary installations, such as photovoltaic panels, ventilation equipment, rooftop gardens and similar, which may increase the risk of penetrations in the roof membrane and subsequent water leakages. The use of roofs as part of the storm water management is also growing, introducing a more complex variety of perspectives regarding handling of quality risk [10]. When analysing the fraction of defect cases, it is of great importance to keep in mind that the distribution will be affected by the type of buildings the damages occur in. Figure 2 shows that a larger fraction of assessed defects is linked to apartment buildings, which may also be one reason for the increase in defects in unventilated roof constructions. This may partly be described by a general increase in the number of apartment buildings in Norway, which is approximately doubled the last 20 years, as shown in Table 1.

5. Conclusion

SINTEF has analysed building defects in Norway for more than 60 years, both on behalf of the construction industry and through comprehensive field investigations. A review of the building defect assignments carried out in the period 2017–2020 compared to assignments carried out in 1993–2002 indicates that stricter air tightness requirements has resulted in fewer defects related to air leakages and subsequent condensation. The share of defects linked to precipitation has increased, especially in unventilated roofs and terraces. The results imply that increased focus on climate adaptation of buildings is important. As climate change causes more precipitation with higher intensities, the load on buildings increases. Consequently, a larger focus on risk reduction and protection towards penetration of water from the outside is required. This involves measures like watertight membranes, good solutions for run-off and drainage, as well as coordinated building processes.

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