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Flat Roofs Defects – Norwegian Building Sector Perspectives

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Abstract. Flat roof constructions covered with flexible roofing is a common feature on large buildings, as they are robust and require little maintenance. However, faults in flat roof design or their assembly could lead to costly building damages or defects. A preliminary mapping of main risk factors for flat roof defects has been carried out by studying design, assembly, and maintenance practices. This article is based on semi-structured interviews with actors in the Norwegian building sector between September 2017 and March 2018. The interviews did not target a specific subgroup; a broad and explorative approach was instead chosen in order to seek out opinions from all parts of the supply chain. The goal was to map knowledge and attitudes regarding flat roof faults. A point of particular interest concerned the perceived prevalence of substandard constructions due to counterfeit materials or shoddy building practices. It was found that most roof faults could be attributed to aging or design flaws. Counterfeit materials or shoddy workmanship was perceived to be uncommon among large and well-established companies. However, responders from several backgrounds – manufacturer, municipal and university building owners – suspected that such malpractices might be more common among smaller contractors geared towards the non-professional market. As a whole, the Norwegian roofing industry was perceived by respondents as generally trustworthy and compliant with regulations. However, interview responses suggest further research is required on the practices in the non-professional sector.

1. Introduction

Flat roofs or “compact roofs” are commonly found on large buildings with a flat roof structure. These roofs consist of a sandwich structure of vapour protection, insulation, and the roofing itself, built on top of a supporting structure. These types of roof require little maintenance once assembled, while not adding significantly to a building’s overall height, making them more favoured than slanted roofs on large buildings. They are also known as “warm roofs”, since the compact structure creates a continuous thermal connection between the interior and exterior surface.

The most crucial component of a flat roof is the outer layer, the roofing itself. Typically consisting of a bituminous membrane or asphalt membrane, sheets of flexible roofing protect the underlying structure from climatic and traffic loads, as well as the ever-present threat of water. It is crucial that its water-tightness is retained, as the nature of compact roofs make faults very difficult to discover before significant damage has occurred. Costly repairs and rebuilding work of flat roofs is a common occurrence. Gullbrekken et al. [1] report that 22 % of all building defects investigated by SINTEF Building and Infrastructure concerned roofs, of which compact roofs or terraces comprised almost half (47 %). An article written by a materials supplier [2] in a technical journal highlights quality problems with flat roofs in Norway in particular



However, little rigorous research seems to have been written about damages inflicted by material causes in a Nordic context. Due to the severity and apparent prevalence of flat roof defects, it was decided to interview experienced technical personnel in the Norwegian building sector to map knowledge and attitudes towards defects on flat roofs. Semi-structured interviews were carried out, with a focus on building damage mechanisms and strategies for preventing roof damage. We reached out to interviewees that represent the sector from several different perspectives; building owners, material producers, and controlling agencies.

The main research questions investigated are:

- What are the most common forms of roof defects, as seen from the industry perspective?
- What are the primary mechanisms causing these forms of defects?
- What can be done to prevent or mitigate these forms of defects?

The scope of the research is limited to a Norwegian context. A thorough investigation into statistics and cases would require more time and resources than were available. Hence the article is limited to reporting the impression of actors in the building sector.

2. Theory

The impact of the Architecture, Engineering and Construction (AEC) industry on society and the environment is profound. The AEC-industry employs 7% of the workforce and generates 10% of the GDP worldwide. In doing so, the AEC-industry consumes 17% of the freshwater [3], 30–40% of the energy [4], 50% of the materials and 60% of harvested land [5]. The AEC-industry is thus a key industry for moving society towards sustainability, with respect to all three pillars of sustainability; i.e. social, economic and environmental sustainability.

The AEC-industry is thus of vital importance in fighting the two fronts of climate change: climate mitigation and adaptation. The industry is also identified as the industry with the biggest overall potential for achieving reductions in greenhouse gas emissions, but also the industry with lowest costs associated with the reduction of greenhouse gas emissions [6].

In meeting these challenges, combating building defects will directly affect both the economic and environmental performance of the built environment, by reducing costs and embodied emissions [7] of repairs, but also in some cases in-use-energy consumption (i.e. air leakage in well insulated buildings).

2.1. Previous research on compact roof damages

Gullbrekken et al. [1] reviewed all Norwegian building defect cases reported to SINTEF building research between 1992 and 2003. 22 % of all defects concerned roofs, with compact roofs and terraces making up 47 % of those. 65 % of the roof defect cases were related to precipitation intrusion, with indoor moisture (condensation) accounting for another 15 %. However, the data is limited to reported cases to one specific agency and may not be representative for the building sector. Without comprehensive sets of quantitative data, a qualitative and explorative approach appears to be best suited to map the prevalence of roof defects in a Nordic context.

2.2. Design of flat roofs

Flat roofs are usually built from insulating and waterproofing layers on top of the roof's structural system. Construction details are outlined a design guide by Noreng [8]. A flat roof contains several layers that are functionally waterproof, which means that once water enters the assembly through a defect, it may not easily escape again, and it can run horizontally for great distances before finding a way to the layer below.

Contrary to their name, flat roofs are not completely flat. They need to have a slight slope to ensure proper drainage of water. Water must be led into a drain or otherwise off the roof. If allowed to form pools, water may find its way through defects in the roofing or possibly seep into the building construction, as the roofing is only folded a few centimetres up along adjoining roofs or parapets.

2.3. Flat roof degradation

Exposure to the elements will deteriorate roof materials over time. Haagenrud [9] sorts degradation agents into four categories: mechanical, electromagnetic, biological and chemical agents. For flat roofs, UV radiation and elevated temperatures from sun exposure are considered major degradation factors [10].

2.4. Water damage

One of the primary purposes of a roof, as well as other building facades, is to protect the underlying construction against water intrusion. The roof itself needs to be resistant to water and retain this resistance for the entirety of the building's life cycle. Moisture in a building construction leads to rot in organic materials such as wood, corrosion in metals, and its high thermal conductivity deprecates the insulating properties of insulation materials. Additionally, water in the outer layers of the construction may freeze and thaw repeatedly as outdoor temperature swings around 0°C, these freeze-thaw cycles impart mechanical damage to the materials.

2.5. Counterfeit materials

Norway, as a developed country, has a corruption statistic well below the world average [11]. Furthermore, the Norwegian society is characterised as very trustful. This, of course, affects how business is conducted. However, recent research has shown that the construction industry is vulnerable to both crime and corruption. This can be traced back to ethical challenges that scourge the industry [12]. One particular element relevant for flat-roofs is that of counterfeit materials. Counterfeit materials are defined as "unauthorized materials which special characteristics are protected as intellectual property rights, patents and copyrights" [13]. Counterfeit materials are not necessarily flawed by definition, but can generally not be trusted to perform as well as approved materials whose properties have been tested and documented. As for consequences, especially in regards of clients, it might be higher operational costs or – or in the worst case – structural collapse [14]. Thus, in order to mitigate the problem, both clients and contractors need Knowledge about the materials, as well as specific procedures and policies in order to manage the project supply-chain [15].

2.6. Material approval

The CE marking is required to be affixed to all products sold in the European Economic Area. The CE marking signals conformity with relevant product standards, but is in itself no mark of quality, nor does it mean that the product meets any performance requirements.

In a similar manner, national governing bodies may offer supplementary tests and documentations of conformity. In Norway, construction products may be certified by SINTEF Certification. Its mark of Technical Approval declares the product fit for use according to Norwegian technical regulations. However, SINTEF Technical approval does not automatically imply a product will meet project-specific requirements.

3. Method

The research methodology used in this research was qualitative in nature, gathering empirical evidence from the use of interviews. The qualitative approach chosen was grounded theory as described by Creswell [16]. Thus, the focus was to understand the process regarding flat-roof defects seen from the view of the representatives from the industry, and then seek to generate some shared knowledge about this particular process. A literature review was also conducted to gain insight into the physical processes by which common roofing materials are degraded over time. The literature study was conducted independently of the interviews, so results from each did not influence the methodology of the other.

For these interviews, large, established actors in the building sector were approached. It was assumed that those would have the best overview of the industry as a whole. In smaller companies, the employees may be responsible for a multitude of tasks and therefore unable to specialize in any single subject. Small companies may also have their experiences restricted to a small geographical area. In large companies, it is easier to find persons whose work is limited to a field of expertise. These persons may

have long experience with the subject, and a professional network of contacts, keeping them updated and giving them a good overview of the notions and beliefs held across the industry on a regional or national basis and over longer periods.

The primary method of data collection for this paper has been through semi-structured interviews, following an approach as outlined by [17] and [18]. Specific relevant companies or government organizations in the Norwegian building sectors were identified and approached with a call for interviews, outlining the basic purpose of the research. The actors then forwarded the request to the person perceived to be the most relevant within the organization. These were provided with the interview questions to prepare. The respondents were all found to have a background in construction or material science, with many years of experience in the field.

Interviews were arranged in person or via phone. The interviews were loosely structured around the interview questions, but respondents were allowed, and encouraged, to bring up other matters they felt appropriate, as according to the principles of semi-structured interviews. Notes were not taken during the interviews; instead, the conversations were recorded and later transcribed. This was done to reduce distraction, and to allow the conversation to flow freely and uninterrupted, a concern noted by Novick [19].

The interviews were carried out in late 2017 and early 2018. Actors from all sides of the building sector were approached, to gain a perspective as broad as possible. Respondents include representatives from two different property developers, materials suppliers, an insurance company and a government agency. A total of 7 people were interviewed, in 5 separate interviews.

The interview material was later analysed with the purpose to map the various fault mechanisms of flat roofs mentioned by respondents. It was decided to present the highlighted faults in chronological order throughout a construction process, from the design phase until the use phase. As for the analysis of the data, a grounded theory approach was chosen. Specifically, the incidents and experiences collected from the interviews were analysed using a bottom-up approach [20]. Furthermore, the data was coded thematically as described by Strauss and Corbin [21] and Cresswell [16]. Answers were sorted into different categories relevant to the research questions. Thus, the transcripts were examined for developing categories, then meaning was put into the categories and finally, the meaning was synthesized, building a connection between the categories which results in the proposition stated as the conclusion in this study.

4. Results

Select quotes have been compiled in Figures 1-3. Figure 1 shows quotes related to the construction process, while Figures 2 and 3 present more general findings. A common theme among respondents was that problems tend to arise in transitions, both on a literal and processual level. Joining a new roof to an existing construction may create design challenges, and it is difficult to verify the integrity of the “seam”. Additionally, some issues appeared in the transition between construction phases, for instance with contractors having to rely on poorly detailed design drawings, or technicians leaving debris on the roof that may be trod into the roofing by traffic later. Several respondents also stressed the importance of adequately inspecting the roof after the handover, and the importance of maintenance throughout the building’s life cycle. Some cases of counterfeit materials were mentioned, but all respondents considered it to be a rare occurrence.

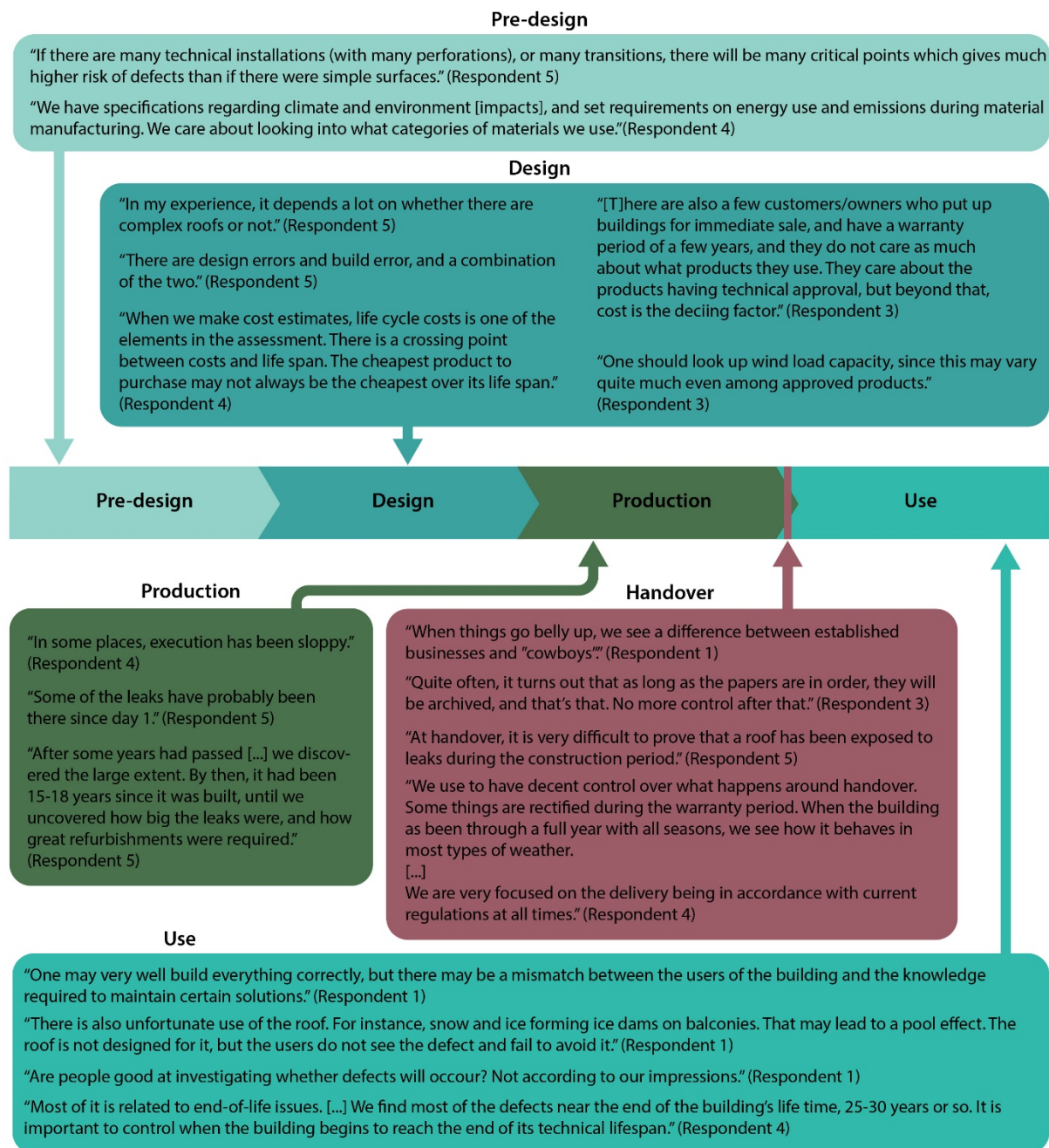


Figure 1. Selected respondent quotes on the origins and nature of roof defects, sorted according to the relevant phase in a construction project.

Causes	Physical phenomena	
	Design	Materials
	"There are problems in transitions. Few problems related to materials." (Respondent 2)	"[I have not experienced [CFSS]. It may be that we just have not exposed it, but we have not focused on it in particular." (Respondent 1)
	"Reinforcing in corners. There should be some reinforcing layers under the roofing (or above) in case of movements in the building. Sometimes, this is not applied, and then the roof may be vulnerable to defects." (Respondent 3)	"Here in Norway, we have such strict requirements for approval, that when something is approved, the customer considers it sufficient." (Respondent 1)
	"Sometimes, there are solutions that look good on the drawing board, but which present some practical challenges." (Respondent 4)	"Improper use of the proper materials has occurred." (Respondent 2)
	"There were chosen some solutions that were known, even at the time, to be problematic." (Respondent 5)	"[EPDs] become a mark of quality in their own. It is not mandatory to make EPDs for products, so it is mostly serious actors who bother to make them." (Respondent 4)
		"[We] hear about projects that suffer because of poor material choices, but little of that involves the large actors." (Respondent 4)
	Cases/examples	
	<p>"We have some notifications of deviations from the roof contractor on [case building], where the consequences of addressing the deviation would be to build new houses for the technical installations and removing what stands there now. They currently cannot guarantee the integrity of the transitions." (Respondent 5)</p> <p>"In [case building] we discovered that some water was leaking down in certain points. That raised suspicion." (Respondent 5)</p> <p>"There was a producer outside of the EU which did not have CE marking, but who ostensibly had technical approval from SINTEF." (Respondent 3)</p> <p>"In a work capacity, I will say that the [roofing industry] is pretty clean and tidy. But in a private capacity, well ... I will not mention names, but the contractor had to do all the work over again on 12 dwellings. That cost a lot of money. When flat roofs are laid without any sloping, a few bells ought to have been ringing with the company. The industry has a lot of room to improve in terms of seriousness." (Respondent 5)</p>	
	Production	
	Faults	Weather
	"Building errors - the craftsman has been unlucky and made a few mistakes. Bad welds and such." (Respondent 3)	"If you have a warehouse of 30,000 square meters and are under time pressure, insulation will probably be laid down in all types of weather." (Respondent 5)
	"We rarely see poor execution. In those cases, it is mostly in attachments to small buildings." (Respondent 4)	"One has to manage to anchor the roof against the strongest storms. Even if the product is approved, it isn't always enough. That failure mode sticks out a little; and every year some roofs are torn off by wind." (Respondent 3)
	"Fraudulent workmanship may happen as often as fraudulent materials. It is probably a larger problem." (Respondent 4)	
	"We have some experience regarding work on flat roofs: People are not good enough at securing the roof against damages." (Respondent 5)	
	People	
	<p>"It is not unheard of that the owner wants to have it as inexpensive as possible. If a 3 mm roofing is recommended, but a 1.6 mm roofing may be allowed at half the cost, many contractors may be pressed to use the cheap solution." (Respondent 1)</p> <p>"Our impression is that most actors are serious and do a good job. It is like elsewhere: A few spoil things for many, and much depends on the knowledge of the end user." (Respondent 1)</p> <p>"If you want to do a poor job, you could probably do so." (Respondent 2)</p> <p>"Some owners are very conscious of their material choices; those are usually professional property managers with large building portfolios." (Respondent 3)</p> <p>"Private actors that build dwellings as quickly and cheaply as possible may be tempted to go for cheap solutions, but we cannot do that." (Respondent 4)</p> <p>"My impression is that the large, established actors are professional when it comes to roofs. The contractors care about using proper products. They are afraid of cheap products and contractors that enter the market with cheap products, concerning both the competitive situation and their reputation. There have been many outcries against non-serious actors showing up with cheap products." (Respondent 4)</p>	

Figure 2. Selected quotes on the nature of flat roof defects and their causes, sorted according to topic category (Continued in Figure 3).

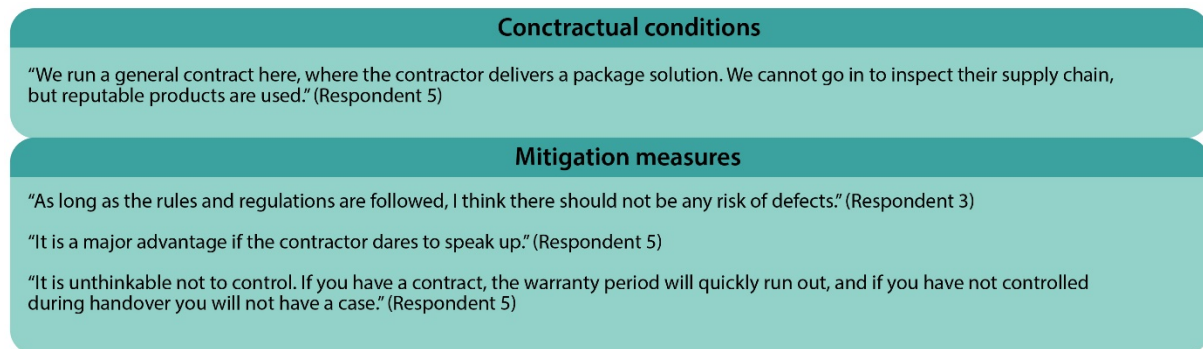


Figure 3. Continuation of Figure 2.

5. Discussion

In this article, we set out to answer the following: The most common forms of roof damage, as seen from the industry perspective, the primary mechanisms by which they are caused, and what can be done to prevent or mitigate them.

Most defects can be put into either of two categories: early in the life cycle, and late in the life cycle. The former category usually comprises damages caused by faulty design or workmanship, and they become apparent early on. However, they seem to be the most common in transitions between new and old constructions. The latter types of defects appear due to aging, usually in the form of material failure. A third category is damages incurred at any random point in the life cycle. This may come in the form of damage from extreme weather events or accidents related to work on the roof and happen independently of the age of the roof. The interviews did not provide enough data to determine which category is the most commonly seen one.

Neither of the interviewees could point to any single form of defect standing out in terms of frequency. Various forms of defects that led to pooling and insufficient drainage were mentioned relatively often. It was also pointed out that problems may arise where the roof ends in a higher wall or other building construction, particularly when this is an older construction, as it is challenging to integrate the roof design with an existing structure.

Several mechanisms exist to define the responsibility for a roof's integrity at handover and in the next few years. Inspections by qualified personnel for the building owner during the construction process also helps to ensure a product of the right quality.

6. Conclusion

On the overall topic of roof defects, respondents agreed that there was general room for improvement from every part of the building sector. However, none of the respondents would unequivocally support the notion that the business sector of flat roofs, in general, was significantly more problematic than that of other building parts. While the supplier article that initiated the research (2) showed cases of fraudulent/counterfeit material usage on flat roofs, it was not believed by any interviewees that such cases were indicative of a more significant trend. It was stated that while cases of counterfeit materials did exist, exaggerations in the media gave the impression of a bigger problem than what is the case. Counterfeit materials were therefore not considered a topic of major concern. Flaws originating in the production phase were considered just as common as material flaws. The importance of using reputable actors throughout the entire supply chain was a common theme among all the interview answers.

Some of the mentioned defects also originate during the design and use phases. Both the designer and the end user of the roof need to be aware of the importance of proper drainage. Transitions between roofs and other building components were considered problematic from both a design and maintenance perspective, notably if the transition also divided new and old building parts.

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