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Surpassing the Limits to Human Cognition? On the Level of Detail in the Norwegian Building Design Guides

Erlend Andenæs[1], Berit Time[2], Tore Kvande[1] and Jardar Lohne[1]

1. Department of Civil and Environmental Engineering, Norwegian University of Science and Technology, Høgskoleringen 7A, Trondheim 7491, Norway

2. SINTEF Community, Høgskoleringen 7B, Trondheim 7465, Norway

Abstract: The SINTEF Building Research Design Guides are a series of Norwegian building technical recommendations. The design guides are highly reputed and widely used in the Norwegian construction sector, serving as a link between the technical regulations and the design process of the individual construction project. This paper examines the element of risk in the use of multiple design guides to extract information about a topic not explicitly covered by any single guide, using the example of blue-green roofs. The research has been conducted in the form of a document study. While the advice given in the design guides is both valid and coherent, the amount of information presented is likely to be overwhelming for industry professionals. There are great degrees of awareness of quality risk present in the individual design guides, but an overall risk picture is not presented. Input from the fields of project management and psychology can help develop risk awareness strategies. The design guides may benefit from an aggregate level of information, where main technical challenges are grouped into super-level categories.

Key words: Risk, quality risk, blue-green roofs, human cognition.

1. Introduction

In Norway, the requirements of the building code are given on a function-based level [1]. The technical regulations for buildings (TEK17 [2]) specify requirements of the Planning and Building Act of 2008. Any technical solution may be chosen as long as it complies with these requirements. The Norwegian Building Authority [3] expresses the structure of the legislation as follows:

"*The collected requirements of the government, defined in the Planning and Building Act and its associated regulations, set a minimum level of quality and safety to be fulfilled by the finished building. TEK10 [The Technical Regulations of 2010] specifies requirements on all essential topics pertaining to health, safety, environment, and usability. The requirements are stated in the form of overall, qualitative, functional requirements*" (our translation).

Note that the functional structure and role of the current regulations (TEK17) are identical to that of TEK10 [4]. This form of legislation gives architects and designers wide freedom, but there is also an inherent risk in that this large degree of freedom left to designers entails a potential high level of quality risk—preliminarily defined here as *the probability and consequences of technical building defects*. The core of the issue is to ensure that the chosen solution will remain functional throughout its intended life span.

Challenges of quality risk in the built environment today can be exemplified through the introduction of so-called blue-green roofs [5]. One challenge brought by climate change in the Nordic region is an increase of the number and intensity of precipitation events [6]. Heavy rainfall may exceed the capacity of urban stormwater drainage systems, necessitating local measurements to retain and detain stormwater. Blue-green roofs, wherein vegetated roof assemblies

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Corresponding author: Erlend Andenæs, Ph.D. candidate, M. Sc., research fields: Building materials, blue-green roofs, quality risk.

are used to store water on rooftops, constitute such a measure. While these roof structures intend to reduce the risk of flooding, they introduce a novel state of operation for the roof as part of a building envelope.

The main quality risk element induced by blue-green roofs is the risk of water intrusion into the building. This may occur due to design flaws, build flaws, material flaws, accidental damage or degradation over time [7]. One particular challenge within a Norwegian climate is the prevalence of freeze-thaw cycles. It is known from experience in the Norwegian building sector that roof damages are common, although comprehensive building statistics are not available [8]. Research on the limited datasets available shows that intrusion of precipitation water is the culprit in around 2/3 of all roof defect cases [9], and that moisture in some form is involved in ¾ of all building defect cases [10]. It has also been noted [11, 12] that vast resources are spent in the construction sector to repair defects, before and after handover. Defects constitute a recurring problem in the construction sector, which is likely never to be fully eliminated due to the inherent complexities of construction projects. Analyses of quality risk may serve a crucial role in *lowering* the number of defects, even if eliminating them is likely impossible.

In the Norwegian building sector, the main strategy for mastering quality risk is to follow the prescriptions of the SINTEF Building Research Design Guides, hereafter mainly referred to as “design guides”. The SINTEF Building Research Design Guides (Norwegian: Byggforskserien) are an authoritative series of multidisciplinary building technical recommendations published by SINTEF Community (formerly SINTEF Byggforsk) which is widely used in the Norwegian building sector. The principal objective of the design guides is to adapt experience and results from practice and research to be of practical benefit to the construction industry [13]. The design guides serve as a link between the technical regulations and the design process of the individual construction project, by presenting pre-accepted solutions that comply with regulations as well as best practice from a building physics standpoint. Through understanding the SINTEF Building Research Design Guides, one may understand, for instance, the risks of blue-green roofs in a Norwegian climate. The design guides provide a comprehensive list of individual risk elements. However, the practical application of the design guides involves an element of risk considering the total understanding of the subject by the user. The level of detail is, in fact, impressive, yet no immediate overall picture stands out.

To assess this general problem, the following research questions have been investigated:

- How does risk management factor in the structure of the SINTEF Building Research Design Guides?
- What challenges exist related to the structure of the design guides?
- How can the quality risk management in multidisciplinary design guides be improved?

The following limitations apply to the research: a limited selection of design guides, those relevant to blue-green roofs, is examined—a full list is provided in Table 1. The validity of the individual recommendations in the design guides is not evaluated. It has not been evaluated whether there are contradictions in the material, nor are overlaps accounted for (certain recommendations are repeated in several of the evaluated design guides). The recommendations are not weighted according to importance or relevance.

2. Theoretical Framework

2.1 Approaches to Quality Risk

While risk analysis literature is comprehensive with many well-established and refined methods of quantifying risk, the theory has seen little application on the risks of building defects. In a series of articles, Aljassmi et al. [14-16] apply risk analysis methods on building defects. The articles analyze the magnitude and pathogenicity (ability to trigger other risky conditions) of a set of identified defect causes. Similarly, Nieto-Morote and Ruz-Vila [17] analyzed construction defects using a fuzzy method approach. While there are some drawbacks for restricting calculations to known and specified defect causes, it would not be practically feasible to do calculations on unknown factors. In itself, this exposes an inherent challenge in risk management: there will, in general, be unknown factors that cannot be analyzed in advance, but which will influence the project outcome regardless. Building projects are inherently complex, and will involve complex causal relations that cannot be quantified in a practical fashion, such as human factors in design and assembly, post-construction modifications to the building, the impact of aging, adherence to use and maintenance plans, etc. As such, there are inevitable limits to quantify risk [17]. Understanding the full spectrum of risk encountered in building projects, broader perspectives need being taken into account.

While the SINTEF Building Research Design Guides are primarily relevant for the Norwegian building sector, similar guidelines exist in different countries worldwide. They are not however, to the knowledge of the authors, made to the level of detail found in Norway. In Denmark, the independent organization BYG-ERFA develops and publishes design guides with a similar scope and purpose to those in Norway [18]. In Sweden, the Moisture Research Centre (FuktCentrum) at Lund University and The Research Institute of Sweden (RI.SE) perform research and publish guidelines for moisture safety in building projects [19]. The Finnish Rakennustieto (RTS, Building Information Foundation) conducts research and publishes guidelines for the construction industry in Finland, with offices in Russia and Estonia [20]. In other countries, national building authorities may in some cases also issue guidelines (e.g. Ref. [21]). Some examples have been collected by Asphaug et al. [22] who mentions Canada and the US in addition to the aforementioned countries.

2.2 Quality Risk Perspectives

Little research seems to have been carried out on the level of risk of defects of building envelopes. In project management literature, the term "uncertainty" is usually favoured over "risk" as it covers both positive and negative outcomes. The term is defined as "An event that, if it occurs, has a positive or negative effect on a project's objectives" [23, 24]. Strategies to manage risk (negative outcomes of uncertainty) include avoiding, reducing, sharing or accepting the risk [25]. Note that the perspective of risk depends on one's involvement and role in the project, this would also affect the approach used towards risk management [26].

Risk, or uncertainty, is actively evaluated and managed in many aspects of the construction sector. However, most risk management literature appears to focus on process risks, related to the effectiveness and efficiency of the construction process itself, or on the economy of the individual parties [27]. The quality of the building is seldom focused on in a risk perspective, but rather treated as a separate field of study [28].

The term "quality risk" is not well defined in literature. Other terms found to describe the same subject include "defect risk" [29, 30], "quality management" [28], "quality deviations" [31] or "defect management" [16]. In the following, we use "quality risk" to include all of these terms. Identified defect categories include design flaws, build flaws, material flaws, accidental damage, gradual degradation, and use flaws. The latter two categories of defects occur during the use phase of the building (barring exceptionally long construction periods) and are excluded from the scope of this article.

It should be noted that while "quality risks" and "building defects" may appear to be synonymous terms, this is not the case. Building defects are an outcome of quality risks. The term “quality risk” expresses a potentiality, while “building defects” expresses an actuality.

Experiences from the Norwegian construction sector suggest that the current practice of quality risk management in the design process does not work satisfactory. Even though correct design and construction of roofs is fundamentally known information, defects still occur [9].

Quality risks can be encountered in many stages of the building process [32]. It is found necessary to limit the scope of this article to only include parts of the process, namely the design stage. This article will aim to investigate how the SINTEF Building Research Design Guides determine risk management using the case of blue-green roofs. Blue-green roofs are a novel building element that is not explicitly covered by a dedicated design guide, but whose principles of construction can be extracted from a handful of existing design guides. Seen in isolation, the design guides serve as a measure to reduce quality risk. However, it is conjectured that aspects of their implementation might carry an inherent risk that hitherto has received little attention. The challenges to their use are varied, and exist on at least three levels:

(1) The process of extracting relevant knowledge from the sum of several design guides is complex, and there is no super-level guidance to aid it.

(2) The challenges involved in blue-green roofs as described in the design guides exist over the full timeline of the building’s life span, from conception to the use phase.

(3) Blue-green roofs are erected in the concurrence between several crafts and disciplines, involving challenges related to water management, structural mechanics, thermal insulation, landscape architecture, waterproofing, and several others.

2.3 Building Defects

Limited research has been identified concerning the extent of building defects in Norway. A study by Ingvaldsen [33] in the early 1990s estimated that approximately 10% of the entire production of the Norwegian building sector concerned the repair of defects, either before or after the moment of handover. In total 60% of the defects were found to originate in choices made before the construction. Further research in 2006 estimated that the repair of process-related defects constituted 2-6% of the annual net production value of the building sector [12]. Newer, comprehensive data are not available. Organizations such as SINTEF or certain insurance companies register and keep track of defects on building projects they have been directly involved with, and studies have been conducted on these limited data sets [9, 10, 34, 35], but no shared platform exists to create a comprehensive set of data on a national level. A project started in 1998 aimed to create a national database of building defects [8], but such a database has yet to materialise.

Qualitative interviews in recent years indicate that defects on roofs are still a challenge in the Norwegian building sector [7]. Comprehensive numbers are not available, but there is little reason to believe the situation has improved since the 1990s. A white paper from 2012 concludes a general lack of information on the quality of the building stock in Norway [36]. Given the changing climate with an increasing amount of precipitation [6], the risk of building defects is increasing.

2.4 Norwegian Legislation

The general structure of the Norwegian building regulations is described by Skatland et al. [1], Lisø et al. [13] and Stenstad [37]. It is illustrated in Fig. 1. The legislation is structured hierarchically with the Norwegian Planning and Building Act at the base, specifying overall objectives of the building code. Functional requirements are quantified in the technical regulations, TEK17. The text of TEK17 is also accompanied by a guideline addendum (VTEK) for every paragraph, which serves to contextualize the requirements of the regulations and present pre-accepted solutions. VTEK frequently refers to the SINTEF Building Research Design Guides for practical examples, documented solutions, and further information about the subject of the regulations. Operative requirements are given in Norwegian and European standards. The SINTEF Building Research Design Guides are found at the bottom of the hierarchy, describing documented solutions based on all the above requirements. Note that independent evaluation and verification of the chosen solutions are required alongside the Building Design Guides. Third-party control might also be required to validate designs in certain fields such as structural engineering, fire safety, and building physics, depending on the type of building.

Several illustrations of the formal framework governing Norwegian building regulations exist. Given the complexity of the system, these different representations differ according to the perspectives they want to accentuate. Probably the best is found in Ref. [13], since it places the guidelines clearly in relation to the SINTEF Building Research Design Guides. Among other representations, see also Ref. [1].

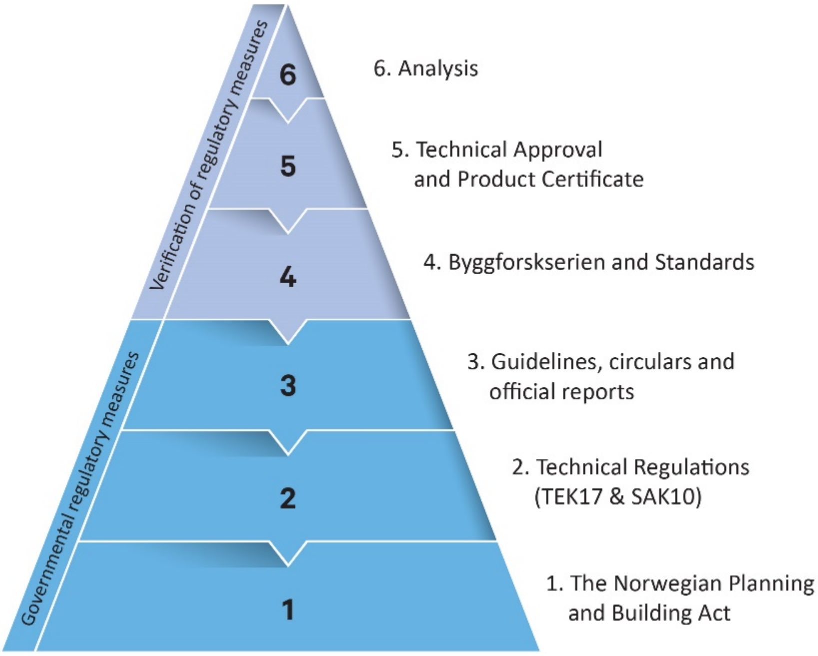

Fig. 1 The hierarchical structure of the Norwegian building regulations.
Source: adapted from Ref. [13]. Used with permission.

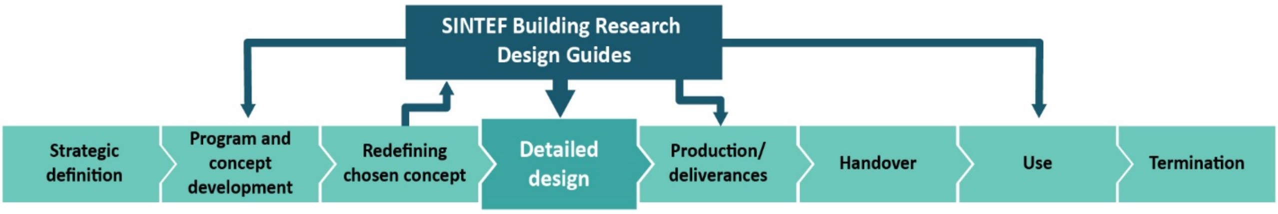

Fig. 2 The role of the SINTEF Building Research Design Guides in the construction process. The design guides aid planning, design details and facility management. Solutions chosen in the concept phase affect which design guides are consulted in the design, construction, and use phases.
Source: phase model adapted from Ref. [38].

2.5 The Role of SINTEF Building Research Design Guides

The Norwegian Building Research Institute (NBI) was founded in 1953, after a recommendation from a committee appointed by the Norwegian Association of Science and Technology (NTNF). Prior to this, some building research had been conducted at the Norwegian Technical College (NTH) since the early 1920s, but early building research in Norway was scattered and poorly organized [39]. The main goals of NBI were to conduct and coordinate building research and translate its results into useful practical solutions.

The first building design guides were published in 1958, in the form of "guide sheets". Handbooks in building design were published prior to this, but in practical use they were replaced by the design guides. Each building design guide covers an aspect of a building construction; examples include "walls against terrain", "additives to concrete mixes", "safety windows" or "securing water pipes against frost". SINTEF also issues Building Research Guides not directly related to building design, with a series for construction planning and one for building management. These series are outside the scope of this article.

The design guides supplement the construction process as shown in Fig. 2. They are most commonly used as a tool for detail design of individual building elements, but also advise on the concept development, construction process as well as the maintenance, operation and management (MOM) phase.

The guide text (VTEK) to the Norwegian technical regulations for buildings (TEK17) frequently refers to the SINTEF Building Research Design Guides for solutions that meet the requirements or to give more information on relevant topics. In perhaps the most explicit example, the introductory paragraphs to TEK17 state:

Norwegian Standards and design guides from SINTEF's Building Research Design Guides are useful tools to create good buildings. Therefore, we have added links to certain standards and design guides below the individual paragraphs, even though these tools are not available for free (in Norwegian).

Additionally, the guide text to paragraph 2-3 explicitly references the SINTEF Building Research Design Guides:

It shall be documented that the designed solutions and product specifications comply with the specified performance (in Norwegian).

Pre-approved solutions include solutions that are certified or otherwise approved, solutions specified in the SINTEF Building Research Design Guides, or other reputable sources (in Norwegian).

2.6 The "Chain of Recommendations"—What Are Designs Based on?

When creating detail plans for buildings, designers rely on external documentation to determine which solutions to recommend to the architect. It is the responsibility of the designer to ensure that the recommended solutions are sound and meet the technical requirements. This is ensured by grounding the recommendations in documented solutions and declarations of performance, i.e. technical reports, product datasheets, and officially issued recommendations. The SINTEF Building Research Design Guides present an example of the latter; containing pre-accepted solutions that meet the requirements of the technical guidelines. The design guides are not legally binding, but they are considered a useful tool and reference source for designers. A technical verification from the individual designer is still necessary to determine the suitability of the solutions presented in the design guides for the project in question [1, 37].

2.7 Cognitive Perspective of Apprehension—Mastering Complexity

Information overload is a recurring problem whenever humans need to process large amounts of information [40]. The problem has been recognised and examined in fields such as, among others, social studies [41], public relations [42], business and marketing [43], and the offshore industry [44]. In a complex task such as designing a building, being overwhelmed by information and requirements may increase the difficulty of the task and increase the risk of error.

An issue highlighted by Tang et al. [45] is that of data, information, and knowledge. In their article, the nature of data is "a statement taken at face value", information is "interpreted data that informs", and knowledge is "facts, feelings and truths hat make up what is known". Knowledge can both be explicit (recorded), implicit (gleaned from recorded information) or tacit (existing only in the mind). The process of gaining knowledge from data, or even from information, is not automatic or necessarily easy. When the volume of information becomes too big, the process of making proper use of it itself becomes a daunting task. A form of structuring or visual presentation of the information volume could be a helpful tool to sort through large amounts of information [40].

While no figure could be found for the mental capacity of the human brain, for the experimental test used in the research by Falschlunger et al. [40], 180 data points were considered a "high" amount of information for a person to process. The "medium" level is set at 120 data points, which is approximately the average amount of information contained in each of the examined Building Design Guides.

2.8 Case: Blue-Green Roofs

The importance of solid recommendations can be highlighted through an example of a novel building element being introduced to the industry. A changing climate bringing increased precipitation in Norway causes a need for local stormwater management, of which blue-green roofs constitute a popular solution. However, there is a dearth of recommendations for and experience with blue-green roofs in the Norwegian building industry. Some guidance can be found in the existing design guides for compact roofs. Using multiple design guides to find information about a novel building element accentuates the challenges inherent in the structure of the design guides.

Blue-green roofs are roof assemblies wherein a mat of vegetation and its substrate layers are used to store precipitation water, making the roof part of a stormwater management strategy. Any green roof built for this purpose can be considered a blue-green roof [46]. Another definition separates green roofs, which only provide detention (temporary storage) of water and blue-green roofs, which provide retention (water loss through evaporation) as well [5]. In Norway, climate change is expected to cause an increasing frequency of extreme precipitation events [6], which may lead to flooding in urban areas. Using roofs to manage stormwater is an important part of the strategy to combat urban flooding [47]. Different types of blue-green roofs are illustrated in Fig. 3. All the types shown here are built as flat roofs with a compact structure.

However, the addition of vegetation to a conventional compact roof will impact its operating conditions, most notably by covering the waterproofing layer. This decreases the likelihood of leaks being detected before they have had significant time to damage the building. Additionally, repairing a blue-green roof is more expensive than a conventional roof as the vegetation and substrate must be removed from the roof during the repair process. However, as the roofing membrane is buried under the blue-green layers, it gets a significant degree of protection from the elements and traffic on the roof [48].

It follows that it is imperative to manage risk elements that could impact the building's quality in the design and construction phase. Such risk elements include design flaws, build flaws, use of inadequate

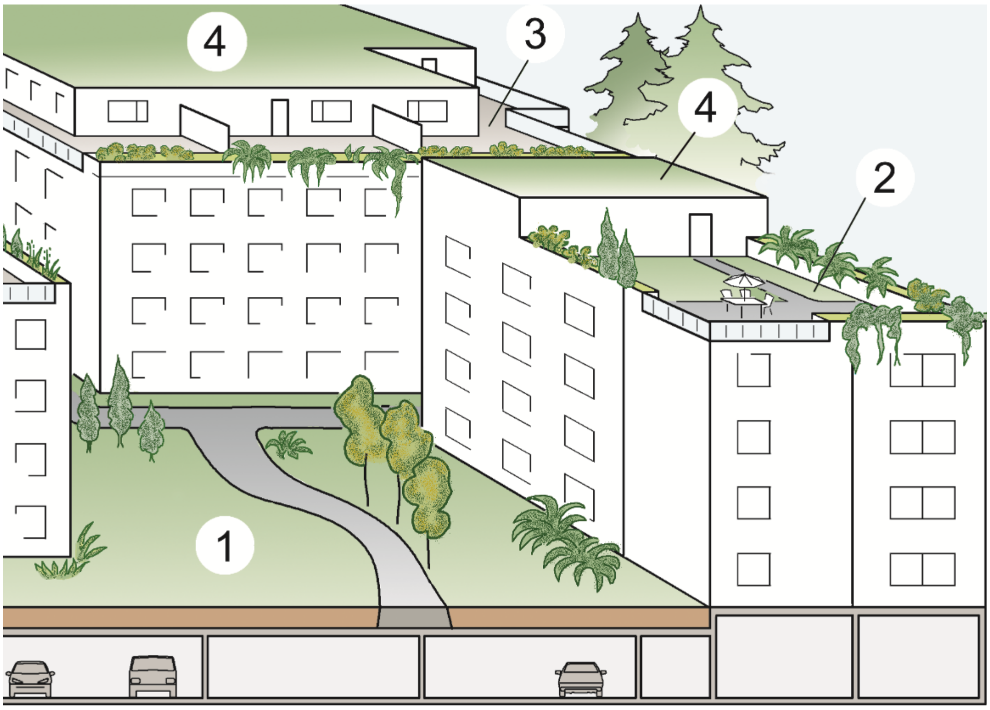

Fig. 3 Green and blue-green roofs in a typical residential construction project: (1) intensive green roof, park, built for vehicle access; (2) roof terrace with lawns and flowerbeds; (3) roof terrace with permeable paving, a "blue-grey roof"; (4) lightweight, extensive Sedum roof.

Illustration: SINTEF/Klima 2050.

materials, or accidental damage. Quality risk should be approached with the same rigidity as other forms of risk in the building sector, i.e. the risks of delays, cost overruns or personal injury, which have traditionally received the greatest focus in risk management literature [27].

The Norwegian climate poses specific challenges to the construction of flat roofs in general, and blue-green roofs in particular. The most important of these is frequent freeze-thaw cycles, changing climate conditions over the year, strong winds, and heavy precipitation [46]. The challenging climate has heavily focused the development of climate robust solutions within the SINTEF Building Research Design Guides. In addition, previsible climate changes will pose new and hitherto hardly known challenges to the built environment in general and the roofs of buildings in particular. The most important of these seems to be a dramatic increase in heavy precipitation and temperature increases [6].

2.9 Knowledge Gap

Taking all the above into account, a knowledge gap becomes apparent. Designers use the building design guides as a tool to anchor their design recommendations, but how can the guides be applied to reduce risk for a novel building element not directly addressed by any individual guide? It therefore is necessary to examine the application of multiple design guides with regards to quality risk, in the case of this article by using blue-green roofs as a case study.

3. Method

3.1 Desktop Study

A desktop study was conducted, with a twofold purpose: firstly, to assess the amount of information a user of the SINTEF Building Research Design Guides would need to process; secondly, to map the level of risk management made explicitly and implicitly in the design guides. A selection of design guides was chosen and analysed paragraph by paragraph. All individual recommendations in the body text of the assessed design guides were counted and sorted. Mentions of the concepts of risk in the text were also counted.

3.2 Selection Process

Design guides directly pertaining to compact roofs and green roofs were examined. This includes design guides from Sections 525.2, 525.3 and 544; a full list is given in Table 1. These guidelines were chosen to match a hypothetical roof construction project like that shown in Fig. 3, where a designer would use a variety of design guides as a reference to design the various roofs of a building. The focus on roofs in this article was chosen to make use of previous research on compact roofs, a so-called "convenience selection" according to Krippendorff [58]. Hereafter, the individual examined design guides will only be referred to by number.

3.3 Content Analysis

The text of the selected design guides was analysed paragraph by paragraph. Examined paragraphs include

Table 1 List of examined design guides.

Number	Year of publication	Norwegian title	Translation of title	Length [words]	Reference
525.207	2018	Kompakte tak	Compact roofs	4,900	Ref. [49]
525.304	2007	Terrasse på etasjeskiller av betong for lett eller moderat trafikk	Terrace on concrete floorplates for light or moderate traffic	3,900	Ref. [50]
525.306	2009	Terrasser med beplantning på bærende betongdekker	Terraces with vegetation on load-bearing floorplates	3,600	Ref. [51]
525.307	1999	Tak for biltrafikk og parkering	Roofs for car traffic and parking	4,350	Ref. [52]
544.202	2011	Takfolie – egenskaper og tekking	Roofing membranes—properties and installation	5,100	Ref. [53]
544.203	2011	Asfalttakbelegg - egenskaper og tekking	Asphalt sheet roofing—properties and installation	5,300	Ref. [54]
544.204	2008	Tekking med asfalttakbelegg eller takfolie – Detaljløsninger	Roof installation with asphalt sheet roofing or roofing membranes—detail solutions	2,750	Ref. [55]
544.206	2016	Mekanisk innfesting av asfalttakbelegg og takfolie på skrå og flate tak	Attachment of asphalt roofing and roofing membranes on sloped and flat roofs	5,150	Ref. [56]
544.823	2013	Sedumtak	Sedum roofs	4,450	Ref. [57]

Note that a newer version of guide 525.307 was published while this article was in writing.

Table 2 Modality level of recommendations in the SINTEF Building Research Design Guides.

Modality level	1	2	3	4
Example wordings (Norwegian)	• Can • May • (Kan)	• Should • "SINTEF recommends…" • "It is recommended that…" • Statements in imperative • (Bør)	• Must • "It is important that…" • "… is necessary" • (Må)	• Required • References to legislation • (Skal)
Meaning	An option	Recommendation	Strong recommendation	Required by legislation

Table 3 Use of concepts concerning risk and the definitions used to categorize these.

None	Implicit	Explicit	Formalized
Paragraph does not concern moments of risk.	Paragraph concerns moments of risk but does not specify how they may occur, or their consequences.	Paragraph mentions concrete consequences that are to be avoided.	Measures to mitigate risk are directly specified or quantified.

only the main body of the design guide, and not the sections at the beginning and end, which concern the scope of the design guide, references to legislation, product standards, and further reading. Text in figures was also excluded from the analysis.

The validity or technical accuracy of the recommendations in the text was not assessed, but the modality of individual recommendations was counted by the criteria presented in Table 2. The four levels of modality were defined according to SINTEF's writing guidelines for the Building Research Design Guides [59]. Each paragraph of text could include several individual recommendations.

Table 3 shows the criteria for determining the overall risk modality of each individual paragraph. Not every recommendation given in the text contained a mention of risk, and not every mention of risk could be tied to a specific recommendation, hence it was decided to count the risk modality according to the paragraph and not according to the individual recommendation.

4. Results

4.1 Extent of the Content

The nine examined design guides contained 337 paragraphs of recommendations that were examined in depth. This number excludes, for instance, paragraphs explaining the scope of the design guides, background information, figures, information about the authors, and references to further reading. The examined paragraphs contained 977 specific recommendations in total. Thus, each design guide contains a little more than 100 specific recommendations on average.

The examined design guides also contained references to other design guides for supplementary information. The references are listed in Table 4. It follows that an engineer seeking a broad overview of the supplementary information would have to read through 22 additional design guides, containing an estimated 2,200 individual recommendations to keep track of. Also note that cross-references within the examined design guides do not cover all the nine guides, as two of them were created after the latest revisions to any of the other relevant guides. While the remaining two guides could easily be found using SINTEF's Building Research Design Guide website, their existence cannot be surmised from the text of the remaining design guides.

4.2 Modality

The modality of the recommendations in the nine examined Building Design Guides is distributed as shown in Fig. 4. It is shown that modality level 3 (strong recommendation) is the most commonly given, followed closely by level 2 (recommendation). Regulations (modality level 4) are listed comparatively rarely in the main text of the design guides. Given the role of the design guides as a tool for interpreting the regulations and suggesting a best practice based within their framework, this distribution is not surprising.

Table 4 SINTEF Building Research Design Guides examined in this document (left) and other guides referenced in their text (right). Guides in brackets in the right column are references between the examined guides. Note that none of the other guides reference guides 525.306 or 544.823, as these were written after the latest revision of the other guides.

Examined design guides	Referenced design guides		
• 525.207	• 470.103	• 525.101	• (544.202)
• 525.304	• 470.112	• (525.207)	• (544.203)
• 525.306	• 471.043	• (525.304)	• (544.204)
• 525.307	• 471.044	• (525.307)	• (544.206)
• 544.202	• 514.114	• 525.861	• 544.803
• 544.203	• 520.339	• 525.886	• 571.803
• 544.204	• 520.415	• 525.931	• 573.121
• 544.206	• 523.621	• 525.933	• 700.802
• 544.823	• 523.731	• 527.245	• 725.118
	• 525.002	• 541.421	• 744.201

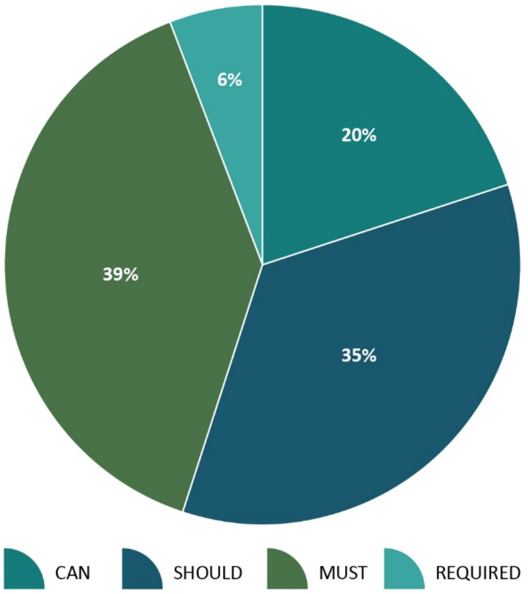

Fig. 4 Distribution of modality levels of the 977 individual recommendations given in the examined material.

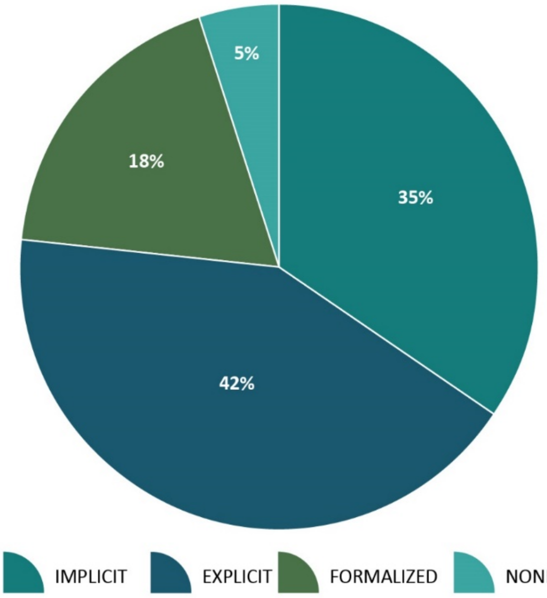

Fig. 5 Distribution of risk explicitivity levels among the 322 examined paragraphs, according to the definitions in Table 3.

4.3 Use of the Concepts of Risk

The distribution of risk awareness in the 322 examined paragraphs is shown in Fig. 5. It shows than almost two thirds of the paragraphs contained specific references to risks, with the majority of the rest implying a risk scenario without specifying it. Only less than 5% of the paragraphs had no references to risk at all.

5. Discussion

This paper aimed to answer the following three research questions: How risk management factors in the structure of the SINTEF Building Research Design Guides, what challenges exist related to that structure, and how risk management in multidisciplinary design guides can be improved.

5.1 How Does Risk Management Factor in the Structure of the SINTEF Building Research Design Guides?

The SINTEF Building Research Design Guides work as a measure to reduce quality risk on a detail level, by presenting documented solutions for a large variety of aspects of construction. However, according to Ingvaldsen [12], 60% of all building defects originate in choices made before the start of construction. This primarily includes the design phase, which is the phase receiving the most practical input from the design guides. A need for risk management through design guidelines is clear and evident. On a paragraph-by-paragraph level, the design guides display a high level of risk awareness. There appears to be a lack of focus on the overall risk picture. While each recommendation in itself might be a solid piece of advice with a clear risk perspective, assembling a greater understanding of risk in the overall building design is difficult. Research from the field of psychology suggests that the amount of information provided in the examined design guides may be too high for the human brain to process effectively, leading to a risk of recommendations not being followed. This is especially the case if multiple design guides are used concurrently.

5.2 What Challenges Exist Related to the Structure of the Design Guides?

It is shown that the amount of information conveyed to the reader within the selection of relevant design guides may be greater than what is humanly possible to process. Even though all the information required for a given design project may be contained within the Building Design Guides, they do not present a procedure by which the information can be used to reduce risk. While a skilled and experienced engineer can possibly manage this process, it is dependent on the experience of the individual designers and as such vulnerable to human error.

The hierarchical structure of the Norwegian building guides presupposes that an independent evaluation and verification is performed even if the Building Design Guides are used as a basis for the design process. No mechanism has been found that ensures the accuracy of this verification, although the adoption of third-party control at least intends to help reduce the risk appreciably.

5.3 How Can Risk Management in Multidisciplinary Design Guides Be Improved?

The fields of project management and finance have long since developed tools to manage risk and a culture for identifying and avoiding it. While some of the methods cannot readily be adopted for quality risk management, there still is much to learn from conventional risk management. In terms of suggestions for the building design guides, the authors have identified the following general principles that would aid risk management in their application:

- Stratification—presenting guidelines for how guidelines are used. For instance, a super-level tool or guide to aid the extraction of information from multiple design guides. Some risks are greater or more commonly encountered than others, and a solidly defined hierarchy can help determine which risks to give particular focus in the design process.
- Simplification and consolidation—creating a hierarchy of the main technical challenges related to the building part in question, by outlining the greater principles to be followed in addition to specific details. An example of such consolidation of information is seen by Asphaug et al. [22], who assessed the various SINTEF Building Research Design Guides relevant to habitable basements and identified 10 main challenges for moisture safety. Likewise, Sivertsen et al. [60] present a 21-point, multidisciplinary “check list” for procurement in climate adapted buildings. By this way, a large amount of detail information can be sorted and allocated into a manageable number of overarching concerns, which makes it easier to assess risk in a systematic fashion.
- Cooperation—using a cooperative project delivery model to take full advantage of the knowledge and experience of all participants in the project. As mentioned above, blue-green roofs are an example of a building part involving several disciplines and risk perspectives in concurrence, where no single actor has a complete overview of all risk elements. However, the required expertise is more likely to be found within the project organization. A delivery model that encourages cooperation makes it easier to identify, communicate, and manage these risks, particularly those that occur in the interface between disciplines.

6. Conclusion

Building design guides are a tool used in several countries to identify and assess building technical challenges. The study shows that the SINTEF Building Research Design Guides serve as a risk reduction measure on a detail level, a purpose they are widely used for in the Norwegian building sector. The majority of paragraphs in the examined material showed a high level of risk awareness. However, being written as a large number of narrow recommendations, a wider perspective tends to be missing from these design guides. The amount of information presented may also be greater than what a single person or project organization can process, increasing the risk of advice not being followed due to a slip of perception or of communication. The high number of continuously updated design guides also makes it difficult to stay up to date on the latest recommendations. While using the Building Design

Guides effectively to reduce risk may not be an insurmountable task, it depends largely on the abilities and experience of the individual designer. This implies there is a significant and largely unaddressed human factor in play when using the design guides as a tool for reducing quality risk.

While this research is limited to the Norwegian design guides, the same fundamental challenges are likely to be faced by multidisciplinary design guideline tools used in different countries. Future research should investigate and compare guidelines in multiple countries to assess how—and how successfully—these challenges are addressed internationally.

Data Availability Statement

Some or all data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request. This includes the spreadsheets used to count the recommendations in the design guides, but not the text of the design guides themselves.

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References

[1] Skatland, J., Møystad, O., and Lohne, J. 2018. “Society’s Blueprints—A Study of the Norwegian Building Code’s Modal Descriptions of a Building.” *Nordic Journal of Architectural Research* 30.

[2] DiBK. 2017. *Byggteknisk forskrift (TEK17)*. Direktoratet for Byggkvalitet. Accessed Nov. 5, 2020. https://dibk.no/regelverk/byggteknisk-forskrift-tek17/.

[3] Norwegian Building Authority. 2012. *Veiledningen til Tilsyn, Section 3.2.3.2*. Direktoratet for Byggkvalitet. Accessed Oct. 6, 2020. https://dibk.no/saksbehandling/kommunalt-tilsyn/temaveiledninger/tilsyn/del-3--vedlegg/vedlegg-3.2/3.2.3.-funksjonsbasert/.

[4] DiBK. 2010. *Byggteknisk forskrift (TEK10)*. Direktoratet for Byggkvalitet. Accessed Nov. 5, 2020. https://dibk.no/globalassets/byggteknisk-forskrift-tek102/byggteknisk-forskrift-tek10-med-veiledning.pdf.

[5] Shafique, M., Kim, R., and Lee, D. 2016. “The Potential of Green-Blue Roof to Manage Storm Water in Urban Areas.” *NEPT* 15: 715. https://doi.org/http//dx.doi.org/10.14257/ijca.2016.9.8.07.

[6] Hanssen-Bauer, I., Førland, E. J., Haddeland, I., Hisdal, H., Mayer, S., Nesje, A., Nilsen, J., Sandven, S., Sandø, A. B., and Sorteberg, A. 2015. *Klima i Norge 2100 Kunnskapsgrunnlag for klimatilpasning oppdatert i 2015*.

[7] Andenæs, E., Engebø, A., Kvande, T., Bohne, R. A., and Lohne, J. 2019. “Flat Roofs Defects-Norwegian Building Sector Perspectives.” In *IOP Conference Series: Earth and Environmental Science*, p. 012069.

[8] Lisø, K. R., and Rolstad, A. N. 2009. *Nasjonal database for byggkvalitet (No. 34-2999)*. SINTEF Building and Infrastructure.

[9] Gullbrekken, L., Kvande, T., Jelle, B. P., and Time, B. 2016. “Norwegian Pitched Roof Defects.” *Buildings* 6: 24. https://doi.org/10.3390/buildings6020024.

[10] Lisø, K. R., Kvande, T., and Thue, J. V. 2006. “Learning from Experience—An Analysis of Process Induced Building Defects in Norway.” In *Proceedings of the 3rd International Building Physics Conference—Research in Building Physics and Building Engineering*, 425-32.

[11] Egan, J. 1998. *Rethinking Construction—The Report of the Construction Task Force*. Department of Trade and Industry, London, UK.

[12] Ingvaldsen, T. 2008. *Byggskadeomfanget i Norge (2006) (No. 17-2008)*. SINTEF Building and Infrastructure, Oslo, Norway.

[13] Lisø, K. R., Kvande, T., and Time, B. 2017. “Climate Adaptation Framework for Moisture-Resilient Buildings in Norway.” *Energy Procedia* 132: 628-33. https://doi.org/10.1016/j.egypro.2017.09.698.

[14] Aljassmi, H., Han, S., and Davis, S. 2016. “Analysis of the Complex Mechanisms of Defect Generation in Construction Projects.” *Journal of Construction Engineering and Management* 142: 04015063. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001042.

[15] Aljassmi, H., Han, S., and Davis, S. 2014. “Project Pathogens Network: New Approach to Analyzing Construction-Defects-Generation Mechanisms.” *Journal of Construction Engineering and Management* 140: 04013028. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000774.

[16] Aljassmi, H., and Han, S. 2013. “Analysis of Causes of Construction Defects Using Fault Trees and Risk

Importance Measures." *Journal of Construction Engineering and Management* 139: 870-80. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000653.

[17] Nieto-Morote, A., and Ruz-Vila, F. 2011. "A Fuzzy Approach to Construction Project Risk Assessment." *International Journal of Project Management* 29: 220-31. https://doi.org/10.1016/j.ijproman.2010.02.002.

[18] BYG-ERFA. 2020. *Om BYG-ERFA*. Accessed Nov. 5, 2020. https://byg-erfa.dk/bygerfa.

[19] FuktCentrum. 2015. *Fuktcentrum*. Accessed Nov. 5, 2020. http://www.fuktcentrum.lth.se/english/about-us/.

[20] Rakennustieto. n.d. *Mission, Values and Vision*. Accessed Nov. 5, 2020. https://www.rakennustieto.fi/index/english/missionvaluesandvision.html.

[21] EPA. 2013. *Moisture Control Guidance for Building Design, Construction and Maintenance*. US Environmental Protection Agency. Accessed Nov. 5, 2020. https://www.epa.gov/sites/production/files/2014-08/documents/moisture-control.pdf.

[22] Asphaug, S. K., Kvande, T., Time, B., Peuhkuri, R. H., Kalamees, T., Johansson, P., Berardi, U., and Lohne, J. 2020. "Moisture Control Strategies of Habitable Basements in Cold Climates." *Building and Environment* 169: 106572. https://doi.org/10.1016/j.buildenv.2019.106572.

[23] Johansen, A. 2015. "Project Uncertainty Management: A New Approach—The 'Lost Opportunities' Practical Uncertainty Management Seen from a Project Joint Perspective." Doctoral thesis, Norwegian University of Science and Technology.

[24] Torp, O., Bølviken, T., Aslesen, S., and Lombardo, S. 2018. "Is Integration of Uncertainty Management and the Last Planner System a Good Idea?" In *Proceedings of the 26th Annual Conference of the International Group for Lean Construction*.

[25] Hillson, D. 2003. *Effective Opportunity Management for Projects*. New York: Marcel Dekker.

[26] Andenæs, E., Engebø, A., Time, B., Lohne, J., Torp, O., and Kvande, T. 2020. "Perspectives on Quality Risk in the Building Process of Blue-Green Roofs in Norway." *Buildings* 10: 189. https://doi.org/10.3390/buildings10100189.

[27] Taroun, A. 2014. "Towards a Better Modelling and Assessment of Construction Risk: Insights from a Literature Review." *International Journal of Project Management* 32: 101-15. https://doi.org/10.1016/j.ijproman.2013.03.004.

[28] Arditi, D., and Gunaydin, H. M. 1997. "Total Quality Management in the Construction Process." *International Journal of Project Management* 15: 235-43. https://doi.org/10.1016/S0263-7863(96)00076-2.

[29] Fan, C.-L. 2020. "Defect Risk Assessment Using a Hybrid Machine Learning Method." *Journal of Construction Engineering and Management* 146: 04020102. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001897.

[30] Lee, J., Ahn, Y., and Lee, S. 2020. "Post-Handover Defect Risk Profile of Residential Buildings Using Loss Distribution Approach." *Journal of Management in Engineering* 36: 04020021. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000785.

[31] Burati, J. L., Farrington, J. J., and Ledbetter, W. B. 1992. "Causes of Quality Deviations in Design and Construction." *Journal of Construction Engineering and Management* 118: 34–49. https://doi.org/10.1061/(ASCE)0733-9364(1992)118:1(34).

[32] Johansen, A., Olsson, N. O., Jergeas, G., and Rolstadaas, A. 2019. *Project Risk and Opportunity Management: The Owner's Perspective*. Routledge.

[33] Ingvaldsen, T. 1994. *Byggskadeomfanget i Norge—Utbedringskostnader i norsk bygge-/eiendomsbransje—og erfaringer fra andre land (No. 163-1994)*. Norges byggforskningsinstitutt, Oslo, Norway.

[34] Kvande, T., Bakken, N., Bergheim, E., and Thue, J. V. 2018. "Durability of ETICS with Rendering in Norway—Experimental and Field Investigations." *Buildings* 8: 93. https://doi.org/10.3390/buildings8070093.

[35] Lisø, K. R., Kvande, T., and Thue, J. V. 2005. "High-Performance Weather-Protective Flashings." *Building Research and Information* 33: 41-54. https://doi.org/10.1080/0961321042000323798.

[36] KMD, R.N.M. of L.G. and R.D. 2012. *Meld. St. 28 (2011-2012) (Stortingsmelding No. 28-2012)*.

[37] Stenstad, V. 2014. *Krav til byggverk og kommunens rolle*. DiBK.no. Accessed Aug. 26, 2019. https://dibk.no/om-oss/Nyhetsarkiv/Fagartikkel-om-krav-til-byggverk-og-kommunens-rolle/.

[38] Tiltnes, S. 2015. *Veileder for fasenormen "Neste Steg"—et felles rammeverk for norske byggeprosesser*. Bygg21 Report.

[39] NBI, Norges byggforskningsinstitutt. 2003. *Byggforsk gjennom 50 år*. NBI.

[40] Falschlunger, L., Lehner, O., and Treiblmaier, H. 2016. "InfoVis: The Impact of Information Overload on Decision Making Outcome in High Complexity Settings." In *Special Interest Group on Human-Computer Interaction*, p. 6.

[41] Bawden, D., and Robinson, L. 2009. "The Dark Side of Information: Overload, Anxiety and Other Paradoxes and Pathologies." *Journal of Information Science* 35: 180-91. https://doi.org/10.1177/0165551508095781.

[42] Tortosa-Edo, V., López-Navarro, M. A., Llorens-Monzonís, J., and Rodríguez-Artola, R. M. 2014.

"The Antecedent Role of Personal Environmental Values in the Relationships among Trust in Companies, Information Processing and Risk Perception." *Journal of Risk Research* 17: 1019-35. https://doi.org/10.1080/13669877.2013.841726.

[43] Lurie, N. H., and Mason, C. H. 2007. "Visual Representation: Implications for Decision Making." *Journal of Marketing* 71: 160-77. https://doi.org/10.1509/jmkg.71.1.160.

[44] Wulff, I. A., Rasmussen, B., and Westgaard, R. H. 2000. "Documentation in Large-Scale Engineering Design: Information Processing and Defensive Mechanisms to Generate Information Overload." *International Journal of Industrial Ergonomics* 25: 295-310. https://doi.org/10.1016/S0169-8141(99) 00020-7.

[45] Tang, L. C. M., Zhao, Y., Austin, S., Darlington, M., and Culley, S. 2008. "Overload of Information or Lack of High Value Information: Lessons Learnt from Construction." Presented at the ECKM 2008 9th European Conference on Knowledge Management and Evaluation, Southampton, UK.

[46] Andenæs, E., Kvande, T., Muthanna, T., and Lohne, J. 2018. "Performance of Blue-Green Roofs in Cold Climates: A Scoping Review." *Buildings* 8: 55. http://dx.doi.org/10.3390/buildings8040055.

[47] Stovin, V. 2010. "The Potential of Green Roofs to Manage Urban Stormwater." *Water and Environment Journal* 24: 192-9. https://doi.org/10.1111/j.1747-6593. 2009.00174.x.

[48] Teemusk, A., and Mander, Ü. 2009. "Greenroof Potential to Reduce Temperature Fluctuations of a Roof Membrane: A Case Study from Estonia." *Build Environ* 44: 643-50.

[49] Noreng, K. 2018. "Compact Roofs." In *SINTEF Building Research Design Guide*, 525.207, SINTEF Community, Oslo, Norway.

[50] Noreng, K., and Krohn, J. Chr. 2007. "Terrace on Concrete Floorplates for Light or Moderate Traffic." In *SINTEF Building Research Design Guide*, 525.304, SINTEF Community, Oslo, Norway.

[51] Krohn, J. Chr., and Noreng, K. 2009. "Terraces with Vegetation on Load-Bearing Floorplates." In *SINTEF Building Research Design Guide*, 525.306, SINTEF Community, Oslo, Norway.

[52] Noreng, K. 1999. "Roofs for Car Traffic and Parking." In *SINTEF Building Research Design Guide*, 525.307, SINTEF Community, Oslo, Norway.

[53] Noreng, K. 2011a. "Roofing Membranes—Properties and Installation." In *SINTEF Building Research Design Guide*, 544.202, SINTEF Community, Oslo, Norway.

[54] Noreng, K. 2011b. "Asphalt Sheet Roofing—Properties and Installation." In *SINTEF Building Research Design Guide*, 544.203, SINTEF Community, Oslo, Norway.

[55] Noreng, K. 2008. "Roof Installation with Asphalt Sheet Roofing or Roofing Membranes—Detail Solutions." In *SINTEF Building Research Design Guide*, 544.204, SINTEF Community, Oslo, Norway.

[56] Noreng, K. 2016. "Attachment of Asphalt Roofing and Roofing Membranes on Sloped and Flat Roofs." In *SINTEF Building Research Design Guide.* 544.206, SINTEF Community, Oslo, Norway.

[57] Noreng, K. 2013. "Sedum Roofs." In *SINTEF Building Research Design Guide*, 544.823, SINTEF Community, Oslo, Norway.

[58] Krippendorff, K. 2013. *Content Analysis*, 3rd ed.

[59] SINTEF. 2015. "Writing Rules—Building Research Design Guides and Wet Room Norms for the Norwegian Construction Industry." *Not issued for publication*.

[60] Sivertsen, E., Elvebakk, K., Kvande, T., and Time, B. 2019. *Klimatilpasset bygning—anvisning for anskaffelse i plan—og byggeprosessen (No. 12-2019), Klima 2050 Report*. SINTEF Building and Infrastructure, Trondheim, Norway.