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Sharing incident experiences: a roadmap towards collective safety information in the Norwegian construction industry

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ABSTRACT

This article presents a study on sharing practices after incidents across organizations in the Norwegian construction industry as a means towards improvement of occupational safety. Interviews were performed with safety personnel from different actors, including clients, contractors and designers. The findings show that several arenas for sharing of safety-related information across actors exist; however, the sharing is limited, not structured, and occurs occasionally. Furthermore, the information is not widely shared across all actors in the industry for whom the information could be valuable, e.g., early phase actors. As a willingness to share and an excitement for new technology are present, the work goes on to propose how and where the industry can improve on information sharing after incidents to move towards inter-organizational learning. A roadmap for the Norwegian construction industry is suggested for collective information sharing with a focus on technological and digital solutions.

KEYWORDS

occupational safety; accident prevention; inter-organizational learning; safety information sharing; digitalization

1. Introduction

The past 5–10 years have shown stable numbers of non-fatal incidents in the construction industry in Europe [1]. Statistics from the Norwegian construction industry also show that the numbers of fatalities and incidents have stabilized and the improvement rate has flattened out in the past years [2]. Furthermore, the same types of accidents reoccur [3–5], where the three topmost common types in the years 2015–2019 in the Norwegian construction industry were fall, struck by object and cut by sharp or pointed object [4]. This repeating nature of accidents and the stable numbers indicate that a deeper learning is missing [6], and that safety-related experiences can be utilized better.

Experience feedback is an essential principle for improvement and learning to support the prevention of severe incidents [7], i.e., to collect and analyse data of past and present safety performance to support decisions on mitigation actions and to improve safety management. Since the number of severe incidents is relatively low, most construction companies experience a limited number of incidents that in turn limits the amount of available information in a company and the possibility to use the experiences for improvement and learning.

The industry is characterized by temporary project organizations consisting of different actors and companies working together on tasks with a time and cost limit. Actors may be simultaneously involved in multiple projects. The nature of the industry contributes to complexity, interdependencies between actors, where one actor creates a foundation for the next actor and one vocation can influence the safety of another vocation, and by this challenge safety work [8]. Complexity and fragmentation lead to blurred and non-linear communication lines and information sharing [9]. Rather than keeping information in silos, which is often how teams in projects operate [10], the different actors can gain valuable information from other actors, enhancing the safety during construction. Although each project in the construction industry is unique, many processes are repeatable and can be learnt from for future projects [11].

Sharing and learning from incidents across organizations in the construction industry have large potential to help prevent future incidents [12]. The literature on learning from incidents is found to be fragmented, empirical and applied research is scarce and the step of sharing of safety information is underexposed [6]. Furthermore, the reviewed literature to a large degree focuses on information or knowledge sharing in an organization or within a project, and empirical studies on inter-organizational sharing and learning in the construction industry are limited.

This research addresses sharing of safety-related information across companies in the construction industry in Norway as one knowledge-enlarging way contributing to the reduction of unwanted incidents and accidents. The following research questions are framed: how is information after incidents currently shared across the construction industry; what gaps exist in the sharing processes between organizations; and how can collective safety information be obtained?

2. Exploring inter-organizational learning from incidents

Information can be described as a refined form of data which are relatively easy collected and transferred, whereas knowledge goes a step further, where the information is understood and applied by the holder. Nonaka and Takeuchi [13] distinguish knowledge from information by the first being about beliefs, commitment and action, and the latter to be necessary to create knowledge. The exact distinction between information and knowledge is often perceived as unclear [14]. In this article, the focus is on information sharing as an input towards learning and improvement.

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In the process of organizational learning, knowledge is created from experiences in the organization [15], and brings about change [16]. Learning from incidents is related to the organization's safety approach and can involve all levels as well as systems in the organization [17,18]. Experience feedback is an important process in safety management systems for prevention and improvement of safety activities, for safety performance [7] and for future safety planning [19,20]. Managing knowledge on safety is a key emergent issue for safety improvement, including continuous learning from past incidents [21], which require safety information as input.

Learning can also happen between organizations across the industry. The definitions of inter-organizational learning in the literature are related to creation of collective knowledge, e.g., knowledge acquisition and transfer (see Mariotti [22]). Inter-organizational learning has in recent years gained more attention in different fields to evolve companies in terms of innovation, effectivity and performance [23], but is limited for the construction industry and for safety.

Several models for learning from incidents in an organizational perspective are available (e.g., [18,24,25]). The steps in the models slightly vary, but mostly include steps related to collection and reporting, investigation and analysis, dissemination, and implementation and prevention (see Drupsteen and Guldenmund [6]). The steps are assumed to be similar in an inter-organizational learning perspective. These steps determine the effectiveness of learning after incidents [26,27]. Dissemination of investigation results is found to be a weak link with the potential to be improved [28]. Obtaining and use of safety knowledge in the construction industry is found to be more frequently discussed in the literature than sharing [29], but sharing of information and knowledge is a premise for learning. Drupsteen and Guldenmund [6] point to sharing and processing of information in learning from incidents as one of the main issues that need more attention, as applying lessons learned in new situations could make it possible to prevent other incident types. Also, storage and transfer systems for safety knowledge in organizations are found to be ineffective [30], while being a premise for experience feedback and to be able to serve as input to safety management in the next projects.

A model to describe inter-organizational learning in the construction industry is presented in Table 1, based on the orders of feedback and memory of control systems in complex systems by Hare [31] and the adaptation of it for safety by Kjellén and Albrechtsen [7]. Further, Jacobsson et al. [32] and Jacobsson et al. [18] have used a similar model for organizational learning. The model in Table 1 presents the different ways learning from incidents can take place across the construction industry and illustrates the importance of information sharing for inter-organizational learning.

On the lower level, experiences from an incident are shared within a project, e.g., from a contractor involved in the same project to a client. On the medium level, single or few experiences and incidents are shared across actors, either between a few actors (also across actor types) or several actors of the same type. A higher learning level indicates industry-wide experience-sharing across the industry. A fifth level could be added for learning across industries.

2.1. New technological solutions and integration of safety

Developments in information and communication technologies can integrate safety information better in existing tools and systems and make exchange of information across organizations become more feasible and useful. Many tools and technologies are available for safety, such as databases for collecting and extracting near misses [33], incident information for risk assessment [34] and tools for knowledge capturing, safety planning and training [35], but mainly within organizations. New technologies have the potential to be applied across the construction industry. Several technologies are suggested in the literature, such as artificial intelligence (AI), visual monitoring (VM), virtual reality (VR), simulations, augmented reality (AR) and building information modelling (BIM) [36–39], although not all for sharing incident information across actors. A literature review on construction hazard prevention through design shows broad possibilities for the use of BIM in safety, e.g., to link safety information with scheduling, product information and other technological solutions [40]. Although technology and solutions are developing, Hallowell et al. [39] found that the research is lacking a focus on how to access reliable safety information through more empirically driven feedback.

3. Method

This article is based on a qualitative research study, where interviews with actors in the Norwegian construction industry have been conducted.

3.1. Data collection and analysis

The interviews were undertaken with various actors from the construction industry concerning information flow after incidents and accident investigations. A semi-structured interview approach was chosen, where the interviewees were given the opportunity to comprehensively describe their views and new aspects which were not anticipated by the interviewer [41]. Tjora [41] points out that these types of interviews give the interviewees' subjective perspective; however, through many interviews it is possible to find phenomena within delimited areas.

An interview guide was created with the following topics: introduction, accident investigation procedures, results of accident investigations, information flow of the results, learning arenas, improvement potential and closing questions. The questions in the interview guide were adjusted to three different actor types.

In total, 13 interviews with 19 individuals working with safety at clients, contractors and designers (consulting engineers and one architect) were undertaken. Interviewees were recruited based on convenience selection, and through contact persons in the industry. Table 2 presents an overview of the interviewees. The interviewees represented 10 different companies. All of the interviewees were employed in large, professional organizations which are well established in the Norwegian construction industry (Table 2).

The interviewed safety personnel had a viewpoint from a company perspective, and not from specific projects. This gives more validity to the data as the responses are related to the routines in the company, rather than in a specific project.

Table 1. Levels of inter-organizational learning in the construction industry.

	Level		Learning potential	Information sharing
	0	Organizational learning (no learning between organizations)	n/a	n/a
Lower	1	Learning within a project	Typically involves learning from local incidents within the project. Information is shared between actor levels and actors in the project. Mainly short-term memory limited to the project duration.	Information is managed and communicated through deviation processes within a project. Limited documentation, e.g., incident reports or entry in deviation register.
Medium	2	Learning from another project	Involves an actor sharing experiences with another or more actors independently of a common project, processed and implemented into the overall organization. Medium-term memory limited in the organization to relevance of the incident for the organization.	Informal or semi-formal sharing of information through dialogue or discussion during planning activities or other meeting arenas.
	3	Learning across similar actor types	Involves experience sharing between similar actor types, e.g., clients, contactors, etc. Medium to long-term memory through common grounds and understanding.	Informal or unstructured, e.g., dialogue meetings. Formal or structured, e.g., actor networks or associations.
Higher	4	Learning across all actors (industry-wide)	Experience sharing on an industry level across several actor types. Long-term memory in a commonly accessible system.	Informal or unstructured, e.g., conferences. Formalized and structured information, e.g., industry networks and associations, common groundwork.

Note: n/a = not applicable.

Table 2. Overview of interviewees.

Actor	Interviews	Informants
Client	2	2
Contractor	8[a]	10
Designer	3[b]	7

[a]One group interview with three interviewees.
[b]One group interview with representatives from five companies.

This also shows the variety across projects. Additionally, relevant documents on investigation practices and examples of information sharing were divulged by the interviewees. The data, especially sharing practices with other actors, were triangulated through interviews with different actor types.

The interviews were conducted between October 2017 and January 2018. Each interview lasted between 30 and 80 min. Most of the interviews took around an hour. Eight of the interviews were conducted in person, and five by phone. All of the interviews except one were recorded and transcribed. Detailed notes were taken for the interview that was not recorded. The interviews were transcribed and analysed with NVivo version 12. Preliminary analysis categories were taken from the interview guide, and later, while transcribing, new categories and sub-categories were added. In the next step, all of the interviews were gone through over again, using all of the established categories. This resulted in the addition of paragraphs to new categories, as well as restructuring. Thereafter, an analysis based on the final categories was performed. All of the data within each category were systematically analysed, which resulted in the findings.

All interviews were conducted in Norwegian except one which was in English. The citations from the interviews were translated into English by the author as close to verbatim as possible, albeit with a focus on not losing the meaning. Therefore, when necessary, to keep the meaning, some rephrasing was performed.

4. Empirical results

The focus of the empirical results is on information sharing after incidents across the Norwegian construction industry. The results are presented as three main topics: information sharing practices; potential of information sharing across the industry; and hindrances and promotors for information sharing.

4.1. Practices of information sharing across the construction industry

The interviews indicate that the arenas used for sharing of safety information in the construction industry include written information, seminars and conferences, groups and, to some extent, training. A large part of information sharing which occurs outside an organization is not formalized, and often takes place based on acquaintanceships. Moreover, it was found that information shared externally generally takes place on a management level (including safety personnel). Most of the information channels available are concentrated around clients and contractors (including sub-contractors). Table 3 presents an overview of the information sharing channels and recipients, as well as the potential inter-organizational learning level based on Table 1.

Information shared externally in written form included accident investigation reports and learning sheets, but no set routines for sharing between companies were found. When accident investigation reports are shared between actors, this often takes place within the project where the incident occurred, if the incident was relevant for more actors. In some cases, it was mentioned in the contracts from the client that the contractor needs to share incident data. Accident investigation reports were reported to be shared with the Norwegian Labour Inspection Authority (NLIA) and the police if requested. Otherwise, the authorities only receive limited information, which is mainly used for statistics.

Learning sheets, also called 'one-pagers', have become popular, and more and more companies are using these as a means for information transfer. The criteria for creating learning sheets are not standardized; however, they are usually created if an incident has learning potential, e.g., a near miss with high injury potential or a serious accident. The format is usually one A4 page, where the most important aspects of an incident with causes are summarized. Sharing within the organization

Table 3. Information sharing channels, recipients and inter-organizational learning potential.

		Actor				Learning potential
Type	Means of information transfer	R	CE	C	CO	Level
Written	Learning sheets	–	–	x	x	1/2
	Accident reports	x	–	–	–	1/2
Seminars and conferences	Yearly industry conferences, other conferences, e.g., the HMS conference	x	x	x	x	4
	Seminar/morning meeting after an accident organized by a company	–	–	x	x	2
	Seminars by the NLIA	x	x	x	x	4
Groups	'HMS Charter'/SfS BA	–	–	x	x	4
	Expert groups (consulting engineers etc.)	–	x	x	x	3
	Regional network	–	–	–	x	3

Note: C = clients; CE = consulting engineers; CO = contractors/sub-contractors; HMS = health, safety, and environment; NLIA = Norwegian Labour Inspection Authority; R = regulators; SfS BA = 'Working Together for Safety in the Construction Industry'.

where the incident occurred, or at the best across actors within the project, was found to be most common, but also examples of sharing across companies at projects were also found, e.g., through morning meetings among workers and supervisors.

Dissemination arenas outside companies included seminars, conferences and different groups, e.g., expert groups. Examples of conferences are those held by associations, such as the national conference 'HMS-konferansen' (health, safety and environment [HSE] conference) and other smaller seminars and conferences on specific topics. Some are only for members, while others are also open to all interested parties. Some companies have started to organize seminars or so-called breakfast meetings after specific accidents where they invite parties from the industry and use a learning sheet as the meeting topic. The NLIA also periodically holds seminars or workshops on chosen topics where the sector is invited:

> I think that the idea of learning sheets is very good. […] I was at a workshop at a client where they presented learning sheets after two blast accidents, it was great. (Safety manager, contractor)

It was also mentioned that regional networks exist, where safety managers from more than 20 companies (contractors) are present and meet several times a year. One of these networks has on a regional basis agreed to have the same requirements for sub-contractors on safety and a common standard for internal control.

In 2014, the 'HSE Charter for an injury-free construction industry' was established involving actors from clients, contractors, trade organizations, labour unions, authorities and academia. The Charter was working on initiatives and projects to improve safety. There were expert groups (e.g., for consulting engineers and clients) where, among other aspects, they created guidelines and checklists related to safety work. During 2018 and 2019 the Charter was developed into a network, 'Working Together for Safety in the Construction Industry' (SfS BA), which many of the interviewees believed in and had high expectations for. The goal of the network is to share experiences and work for a safer construction industry. SfS BA was established with inspiration from a similar network in the Norwegian petroleum industry (Working Together for Safety [SfS]):

> Eventually, we hope that the Working Together for Safety cooperation will become an arena where we actually share lessons learned. (Safety manager, contractor)

A challenge with information sharing across the industry mentioned was that the different actors in the industry have poor interaction and that meeting arenas are lacking:

> The contact between the consultants, the developer, and the contractor is poor. You know too little about each other, about each other's challenges. Then there are crashes where you deeply disagree, and you may end up in court. So, the construction industry lacks some meeting places where one can sit to discuss things before they happen, and preferably also after, such as the oil and gas industry has. (Safety advisor, consulting engineer)

On the question of whether some incidents were more suitable for sharing, many interviewees mentioned near misses. One reason is that in near misses there are aspects that can be learnt from without having negative consequences. Moreover, unwanted events often only focus on what went wrong, while for near misses it is easier to also look at what was done right and what should be continued. Incidents related to equipment were another example of incident type useful to share with other companies and suppliers, especially to modify or redesign equipment resulting in the whole industry becoming safer:

> Some incidents are suitable for workshops because the target group is relatively limited. If you take the incidents where there is a very large audience, then I think it can be good to establish collaboration for safety through a web page, where the information is available. (Safety manager, contractor)

4.2. Potential of information sharing across the construction industry

4.2.1. Inclusion of early phase actors

The consulting engineers themselves thought it would be beneficial for them to be involved in other project stages in relation to safety, e.g., in safety meetings and in accident investigation. They said that they were seldom included in accident investigations, seldom received results of investigations that they could learn from or seldom were otherwise included in information sharing that could improve safety, unless there were some calculation errors behind the incident. Also, contractors found information sharing to be lacking to earlier project actors. It was suggested that more attention could be given if an incident was related to the design by asking during investigations or in reports of unwanted events 'Did this have anything to do with design?':

> They have created some learning sheets for learning after the events, where they will try to look back. In the presentations that I have been to, they have not really managed to get back to the designers. They haven't figured out what more we could have done. (Safety advisor, consulting engineer)

One of the consulting engineers pointed out that information transfer is important to them to make better decisions in early phases and plan and design better for safety, as they are not able to understand risks in the execution phase as well as the executing actors. A specific example of an incident which was related to design was when choosing railing solutions. This decision needs to be taken prior to ordering the structural floors, as attachments are prepared and made ready to use in these floors. Another issue is that, in many cases, when the designers could have a bigger role in safety, they were not aware of it, as adaptations were done at the site to avoid hazardous situations, but never reported back to them:

> If we are to be able to see risks for the executors, the executors need to bring their knowledge into design. Otherwise, we will never be able to see such risks. (Safety advisor, architect)

4.2.2. Technology development as an enabler for information sharing

Several interviewees pointed out improvement areas for information sharing in the construction industry including new technology and the inclusion of more actors. It was mentioned that using new technology, i.e., three-dimensional (3D) models, can be beneficial for designers to communicate and receive feedback from later project phases:

> It has not come that far with safety in 3D yet, but it may be that it could be something if the models became interconnected. Then maybe we could get some feedback though that. (Safety advisor, consulting engineer)

Related to the phenomena of learning sheets it was suggested to have a common database for sharing of experiences between companies. A few interviewees suggested that the new safety forum in the construction industry, SfS BA, could be the place to organize such an initiative. At the same time, there was warning of an inflation of learning sheets, where learning sheets are created and disseminated but not used actively:

> I miss that we had experiences in a pot, by gathering the experiences in a common database. For example, to be able to see if there is anything we could have done differently in the design to avoid this incident. (Safety manager, client)

A possibility for safety was seen in BIM according to some interviewees; however, this is not prevailing in the industry. One interviewee stated that they were using BIM in the company, and that they had also tried to use it in one project for safety, going through safety aspects. The interviewee had a vision for the future where all projects use BIM, and rules for safety are available in BIM, so that already during design one can mark and eliminate hazards. Others mentioned the opportunities of AI and information sharing not only within the Norwegian construction sector, but also abroad:

> What I really believe in is when we start to get algorithms, or when we start to put AI on top of this, and that we can start to draw experience from thousands of construction projects, maybe not just in Norway, but also in all of Europe. Then it starts to get good. And it's coming. (Safety manager, contractor)

4.3. Obstructions for information sharing

4.3.1. Challenging frame conditions

Framework conditions of the industry were mentioned as a challenge for safety work. The rapid and constant changes were one of the challenges mentioned, especially compared to other more static industries, such as manufacturing. Moreover, aspects such as time pressure and progress were mentioned as hindering information sharing and learning combined with an underestimation of the potentials of incidents. Costs were also brought out as possible obstacles, e.g., how the sharing arenas will be financed, and who should bear the costs for participating. Another concern was related to how the industry is organized, with many companies in the project value chain, and thus whether it would work to create a forum similar to what is found in the Norwegian oil and gas industry:

> In the construction industry we now want to make something like the oil and gas industry, which is called Working Together for Safety. The disadvantage in the construction industry is that the clients do not have their own organisation. In oil and gas, you have the Norwegian Oil and Gas Association, which organises all the oil companies. They distribute a lot of information. (Safety advisor, consulting engineer)

4.3.2. Lack of standardization in taxonomy and reporting

Where systems for information management exist, they were often based on an internal system at one specific company. These systems often also seem to be used separately on different projects, meaning that there is often little or no connection between the information within the same company on different projects. Furthermore, definitions and categorizations regarding safety vocabulary flourish, whether in contracts, related to accident categorizations, when and what to investigate or indicators. Some companies use similar ones that they have agreed upon between the companies, others use definitions from associations, while others again have their own. To utilize available information and be able to share it across the industry, standardization and categorizations were mentioned as key elements. It was also perceived that the NLIA is not sufficiently precise in their categorizations and reports, e.g., what is meant by lack of planning as a contributing factor - if it is in an early project stage by consulting engineers or during construction by contractors.

Competence of safety personnel was found to be important for systematizing events, choosing events for investigations, during accident investigations, in analysis of events and for working with measures and proactive safety management. In the interviews, the quality of accident investigations was reported as a limitation for sharing and learning. Furthermore, it was pointed out that there is also a need for requirements for filling out documentation, so it is actually performed and information becomes available. It was suggested that a common template for the industry could be established:

> Often, we have forms to use, but then one skips to fill in some field, which could have been useful. So, it is about requirements and documentation. Filling in forms is probably not the most fun thing people know and it takes time. But you can see in hindsight, what the benefit of it is, because the human brain it doesn't remember very well. (Safety manager, contractor)

4.3.3. Willingness to share

The opinion as to whether the industry is open to sharing information, experiences and practices somewhat varied between the different interviewees. Many pointed out that the industry

is very open for this, and that safety is not what they compete on:

> I have attended the HSE conference for many years, and I think that it is sort of a characteristic for the largest [companies], that they are very good and generous when it comes to sharing. That is not point we compete on. (Safety manager, contractor)

Some, however, had the opposite viewpoint, where safety was looked at as a competitive advantage and also related to reputation. A client gave an example where after an accident, information about a contractor was put into a supplier database, which resulted in the company not getting a tender another time and therefore having to do improvements before they were qualified again. It was mentioned during the interviews that some interviewees had experienced legal charges based on the accident investigation reports. This was said to affect what is included in the reports:

> When we investigate, we have burned our fingers a couple of times, because the investigation report has been used as a basis for a prosecution. All injuries in the workplace are punishable under the Working Environment Act, and if you then have some available work capacity with a police lawyer, then our investigation report is the whole basis for the prosecution. So, we have managed to incur a couple of fines due to investigation reports. (Safety manager, contractor)

The results point to some regular weaknesses with regards to information sharing, but they also highlight opportunities for collective safety information for the construction industry which will be discussed in the next section.

5. Discussion

Experience feedback is important for the learning process and accident prevention [7,24], but sharing of information after incidents across actors is persistently weak. The study shows the following:

- several arenas for sharing safety information in the industry exist (Table 3), but they are predominantly unstructured, approaches are unformal and sharing is limited to few actors;
- characteristics of the industry contribute to fragmented information sharing and are one of the main roadblocks foreseen for collective safety information;
- taxonomies and reporting processes after incidents are not standardized, challenging information sharing and inter-organizational learning after incidents;
- a willingness to share safety information amongst many actors in the industry exists and achieving collective safety information is seen as an advantage for the whole industry;
- there is excitement in the industry for new technology and how technology can help to facilitate structured and effective information sharing.

These aspects are further discussed across this section and finally a roadmap to achieve collective safety information in the construction industry is proposed.

5.1. Collective safety information for the construction industry

Although accumulated experiences of the actors are far more comprehensive than within a project or a company, there is still a deficit to transfer information across actors other than to those directly involved in the incident. As inter-organizational learning is based on the experience of one organization [15], the limited sharing is preventing learning and safety improvement across the industry.

The results from this study show that majority of the shared safety information is shared through arenas that contribute to inter-organizational learning at lower and medium levels (see Tables 1 and 3). This means that the majority of information sharing happens within projects or mainly between similar types of actors, and the information sharing is not contributing largely to the industry-wide learning potential and safety improvement. Some arenas for information sharing on a higher level exist; however, such sharing is rather unstructured and non-systematized, and the numbers of actors receiving such information is small, as these channels are not frequently used. To facilitate inter-organizational learning, safety information after incidents as input to the medium and especially higher levels is needed. Earlier studies from other countries have found similar weaknesses with external information sharing in the construction industry. A study from the USA found sharing to be limited to written materials from regulatory agencies, and oral material through meetings organized by associations [30]. In the UK construction industry, a lack of systems to transfer experiences across projects to clients and their supply chains was found [21]. It is also reported that available collective safety information from authorities, agencies and other existing records is unstructured and fragmented, and the content is limited in its thoroughness [34,36,42].

Early phase actors such as designers and consulting engineers in this study expressed a need for more safety information back from the building phase, indicating a need for broader information sharing also across project phases. Earlier research show that designers can influence safety early in a project through the decisions they make [43–47], and lack of information sharing across projects is a barrier for hazard identification as information is not available [34,39]. Some attempts at practical information and decision support for designers exist (see Cooke et al. [48]); however, in practice in the Norwegian industry, few feedback mechanisms were found. The lack of information sharing back to early-phase actors (e.g., consulting engineers and architects) is thus hindering inclusion of solutions in early project phases, which could improve safety during construction.

Stagnating accident numbers [1,2], interrelations between companies in projects [8], new developments and evolving risks require advancements in safety work. Achieving systematic inter-organizational learning through collective safety information is one possible solution. Collective safety information may be seen as a shared register of incidents. Increased sharing of safety information across the industry gives a broader experience base through the greater collection of data, which can be fed back to various actors. This can improve and help decision-making and increase learning opportunities for different actors and companies, and serve as an input to proactive safety management throughout project phases.

The objective is that collective safety information should be available to all relevant actors. There are, however, several potential challenges to collective safety information, many related to the characteristics of the construction industry, including the actor types, number of actors of different size, several phases influencing risks, various risk types between vocations, projects with constant changes, time pressure and costs. Information needs to be understood, accessible and

relevant for the receiver, whether a small or large company. Having basic knowledge and similar problems and structure to another organization are beneficial with regards to learning between organizations [49]. For learning from past safety incidents, it follows that a common safety understanding, having a similar structure and sharing information are important.

5.2. Willingness to share

A premise for safety information sharing, and thus collective safety information, is the willingness to share information by actors. The empirical data point to an opportunity for cooperation and sharing experiences across the industry, and importantly a quite large willingness to improve on safety through sharing experiences. Even though some possible inconveniences were pointed out in the interviews, such as prosecution, many of the larger companies, both clients and contractors, have realized that they are dependent on the safety performance of their sub-contractors, and thus need to contribute to pulling the smaller companies up. It was also highlighted by most of the interviewees that safety is not what the companies compete on, and that everyone is served with good safety in the industry as one actor can influence the risks of another actor.

Positive steps are taken through knowledge areas, showing that there is a demand for safety developments in the industry, as well as a willingness to learn. One example of the willingness to share experiences is proven by the establishment of the SfS BA collaboration, inspired by the Norwegian oil and gas industry, where actors across the industry work with specific problems to improve safety in the whole of the Norwegian construction industry. The collaboration has established project and working groups across actors in the industry, trade unions and academia on specific topics [50].

Although there is positivity towards sharing safety information, protection of information could be a concern with regards to sharing, as found in other fields [51]. Factors such as blame, shame and prosecution can limit the willingness of information sharing by individuals [52]. These factors are also relevant for sharing across organizations, e.g., incidents can affect a company's reputation and competitiveness. A company which had experienced that the sharing of accident investigation reports resulted in some negative consequences such as fines was more aware of what they included in the next accident investigation reports and more reluctant to share reports. On the contrary, trust has been found to be an important factor to enhance sharing [53,54]. Also, the interviews implicitly show that trust is an important factor for willingness to share.

5.3. Roadmap towards implementation of collective safety information

Information sharing across actors is a premise to facilitate the higher levels of inter-organizational learning with regards to safety, and to contribute to proactive and predictive functions for safety. The complexity of the construction industry requires a more holistic course of action for safety management including interactions between systems, people in the organization, procedures and sub-cultures existing [21]. Collective safety information can be a means for this. The potential for sharing experiences across the industry is increasing with digital and technological developments, which can also allow for a better integration between other managerial systems and safety. To move towards collective safety information, a roadmap for the Norwegian construction industry is proposed based on the results, summed up in Figure 1.

The figure illustrates the path towards collective safety information and the means to reach it at each step in an iterative process regularly being updated with new data, as well as a periodic validation of the taxonomy.

5.3.1. Identify user groups

Relevant user groups need to be identified and recruited for development and small-scale testing towards collective safety information through, e.g., available networks. The process is iterative, where more actors and companies can be incorporated as the system develops. The start should include actors from the execution phase, such as contractors and clients, where data can be collected. In the final stage, actors across project phases should be included, especially for dissemination of information, such as designers in early phases as well as other actors in the executing phase. It is also relevant to involve trade unions and labour inspection authorities in the dissemination process. Including a wide range of actors will directly respond back to the empirical findings and the need for better involvement of actors across project phases, who expressed a need for more safety information back from the execution phase.

The challenge is to ensure that the results and means of dissemination are relevant and accessible for companies in the whole industry. Not all accident types are relevant for all vocations or activities, and a sorting possibility differentiating the needs and to access relevant information is required. With digital solutions, sharp-end workers can also access relevant information, through tools such as smart phones and apps [55].

5.3.2. Standardized entity typing

Standardization was mentioned by many of the interviewees as being important for information sharing and the further utilization of it. The taxonomy regarding safety in the Norwegian construction industry and use of the definitions needs to be structured and standardized for collective safety information. Technical vocabulary requires language models to describe work tasks and tools [56]. Type classifications for activities, incidents, causes, contributing factors, damages and application areas need to be agreed upon centrally in the system to categorize and systematize the ingoing information. This can further enhance the value of the output data returning to the industry and serve as an input in safety management across project phases and companies in the industry. Existing work related to machine learning models for safety performance can be used including factors for input and sub-factors, e.g., categorizing risk management during execution, work systems in the projects, project management, external conditions, etc. [57]. Furthermore, use of the same incident causation models can also uplift the feedback process and make the information transfer smoother [20]. Similarly, the lack of standard processes between the different organizations involved in projects can challenge learning from incidents [11]. This does not mean that all actors need to use the same systems or categorizations internally; however, to analyse the information collectively, it should be classified in the same manner. Also, Le et al. [58] highlight the need for an ontology to classify and structure the safety information. Such taxonomy can be built upon already established classifications used by, e.g., the NLIA or other actors in the industry. Through a common

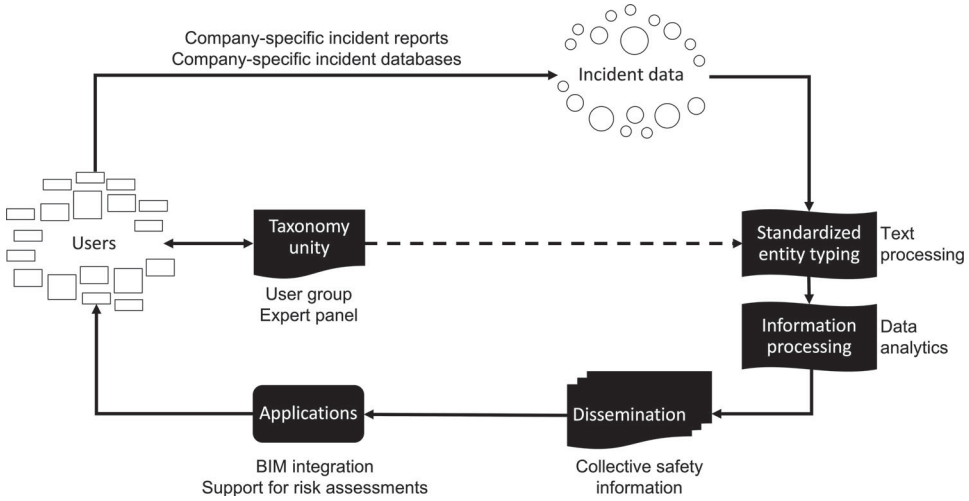

Figure 1. Roadmap towards collective safety information in the construction industry. Note: BIM = building information modelling.

initiative, a taxonomy for collective safety information should be established.

Systematization and standardization are also premising the use of new technology and digitalization. Ouyang et al. [59] point out the lack of standardization as a challenge to obtain useful information, and low integration between data stored different places as a challenge with big data in use for safety. Almklov and Antonsen [60] argue that there is an increased tendency towards detailed standardization in safety science, where digitalization is a catalyst for this. Although standardization might not necessarily be beneficial for sharing of information in all situations [61], in an inter-organizational perspective, more standardized definitions, categorizations and practices within the industry could enhance sharing and cooperation on safety aspects.

5.3.3. Technological solutions for information processing

The benefit of ensuring a wider and structured experience collection is that the experience base becomes larger with more possible hazards and the information becomes less biased. In the past, storing safety information in databases has been common, although mostly internally, and the use of the databases for safety prevention has been seen to be limited [24]. New technological applications provide the opportunity to ease collection and make information widely accessible, which can be beneficial for safety management across actors and phases in the industry. The results show that few new technologies and solutions are commonly in use for safety management throughout construction projects in Norway, and lesser for experience sharing from incidents and to feed information back to safety management.

The collected information needs to be structured and analysed to later serve as an input for other tools. Technology can be used to extract data from written injury and investigation reports [62,63]. One example is applying machine learning, making such extraction processes and labelling of incidents easier and less time consuming [64]. Recently, scientific literature on machine learning and safety has grown also for the construction industry. A review by Sarkar and Maiti [65] shows that the scientific papers among others analyse patterns of accidents, predict accident outcomes and severity, and predict injury risk. Examples from other industries show how use of natural language processing can be used in operation planning to consider safety-relevant aspects based on multiple data sources and reducing the dependence on individual experience [56]. Brundage et al. [66] promote technical language processing as an evolvement of natural language processing to serve for technical descriptions in industry with domain-specific adaptations, where the human is a part of the processing loop, to reduce errors in the text analysis. Similarly, errors can occur in pre-processing and analysis of incident information, and the suggested human-in-the-loop approach can ensure validated information to be shared and as an input to, e.g., risks assessments in early phases or safety management during construction. Also, other text classification models have been developed for classification of near-misses from safety reports [67]. As technology and models are being continuously developed, improved and validated, the way towards collective safety information for the industry is shortened.

5.3.4. Dissemination of the processed information

The fast developments in technology also bring about smoother opportunities for information sharing. In the literature, different tools have been suggested to centralize safety information for risk assessments, safety planning and training [34,35,58,68]. Le et al. [58] proposed a social network platform using a wiki-web solution for sharing health and safety information. Hegde et al. [68] proposed the use of blockchain technology as a solution for operational follow-up of safety instrumented systems to enable the exchange of failure information. Through blockchain technology, information can be anonymously and securely exchanged. This decentralized platform between multiple actors also makes it possible to restrict access to selected information, e.g., sensitive information [68]. For the construction industry, such application could gather safety information towards collective safety information, as well as feed safety systems with reliable experience data back from the collective safety information. Relevant information can in this way be shared across project phases and actor types without overloading other actors with irrelevant information. Such information can further be used as an input in other digital solutions, such as BIM. Potential challenges with the aforementioned options need to be considered and solved, such as the possibly vast amounts of data, which require a great deal of storage space [68].

Greater use of BIM for safety was a future hope from some interviewees, although it is evident from the data collection that use of BIM for occupational safety is not yet common in the Norwegian construction industry. In Norway, more clients are starting to use BIM throughout the lifecycle of their projects, but far from all. One example of connecting BIM and risk management in practice is through the RiskBIM project in the Norwegian railway, aiming at supporting, among others, safety, health and working environment processes in BIM [69]. Hallowell et al. [39] highlight the possibilities of integrating incident information processes through machine learning algorithms into BIM and forecast safety-related outcomes. This can be used to communicate safety concerns from designers or planners downwards to the sharp end (construction managers and work crews). Although research describes possibilities using new technology, the examples from Norway show that in practice it is not much in use.

Similar tools to the outlined exist within companies or corporations, compiling information from different databases and different projects [57]; however, in practice they only contribute to internal information sharing. An example from the petroleum industry shows the potential of compiling information across several data sources into one interface, making the information more accessible and visualizing it for the operation planners [56]. Possibilities include barometers for the industry or for trades indicating the safety level. In an inter-organizational perspective, such information can be useful also across actors, including authorities, clients and contractors.

The described outline gives an opportunity for expansion of tools and possibilities towards inter-organizational learning, and to share experiences also with smaller actors with less accumulated experiences to improve safety for the whole industry.

5.3.5. Establish use cases

The progress towards collective safety information should start with involving selected users in the processes in Figure 1. The starting point is to agree upon an industry taxonomy and classification which are understandable in the industry. This step is highly important at the beginning of the work towards collective safety information, but it should also be updated and verified with time. A group of users should be involved in the steps of collection, processing and dissemination of safety information to develop a model. The same users or additional users then apply the available information through application pilots. Once the developments progress and the content of the collective safety information expands, the number of involved users can be expanded. The aim must be to have relevant and available information for all potential users, to contribute to proactive safety management. It is important that user needs and the collected data are verified and updated to remain relevant, through the taxonomy and application processes as a sub-process parallel to the main collective safety information process.

Furthermore, based on the collected information, further potential applications can be developed, e.g., proactive safety indicators or safety level barometers overall for the industry, which can further service as input to processes such as industry initiatives on specific topics.

6. Conclusions and further research

The construction industry as a whole experiences a large variety of incidents. However, the experiences within a project or a company are far smaller than the accumulated experiences across projects and actors. Comprehensive data provide an opportunity to better understand the possible scenarios and factors affecting safety, and the potential to improve safety during construction through capturing the broadness of the different types of incidents that can occur. This study has looked closer at one activity of the learning process: sharing of information from past experiences, as a means towards safety improvement. Dissemination of experiences has received less attention in the scientific literature compared to other activities of the learning process [6,30].

The literature on learning from incidents is to a large degree dominated by traditional organizational learning, not largely considering learning between projects and organizations. Le Coze [70] suggests more cross-disciplinary research on learning from accidents. This study adds to this through information sharing in an inter-organizational learning perspective.

To move towards collective information sharing, and thus better utilize the available safety information and through it improve safety at construction sites given the framework conditions of the industry, present obstacles related to information sharing need to be investigated further and resolved. These include limited availability of good data to share, lack of standardization, need for interdisciplinary competence in safety and technology, blame and trust issues, and the ability to customize information to users' needs. Several possible technologies and solutions are described in the literature, but there is a gap between research and practice for such sharing on Norwegian construction sites. Finally, this study proposes a roadmap towards collective safety information.

More studies on practical applications for sharing within the industry and evaluations on how these applications affect inter-organizational learning are needed to further improve safety of the construction industry. Based on the roadmap, a pilot for collective safety information can be established.

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Data availability statement

Data supporting the findings are available within the article. Additional data are not publicly available due to the nature of this research.

Informed consent statement

The Norwegian Centre for Research Data (NSD) was notified about the project, and informed consent was obtained from all interviewees.

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