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Barriers and Facilitators for Usage of Self-Compacting Concrete—An Interview Study

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Abstract: Workers in the construction industry must endure different weather conditions, long working hours, and engage in repetitive and strenuous jobs with unrealistic deadlines. Sick leaves, caused by accidents and by work-related diseases, are common in the construction industry. Hand–arm vibration from hand-held power tools is a cause of significant ill health (disorders of the blood vessels, nerves, and joints). Self-compacting concrete (SCC) is a fluid concrete and does not need to be vibrated. Despite the health advantages of SCC, its market share in Sweden is lower than in comparable countries. The aim of this article is to describe views, opinions, and knowledge concerning the work environment and health in concrete casting and to identify barriers and facilitators of SCC usage. Semi-structured interviews were conducted with 24 interviewees from the construction industry in Sweden. The answers were analysed from a human–technology–organisation (HTO) perspective in order to identify barriers and facilitators for a broader usage of SCC. The results indicate that knowledge about SCC is low within the Swedish construction industry, including educational institutions; when SCC is chosen, it is chosen exclusively due to its technical characteristics, and not because it eliminates vibrations. Barriers to a broader usage of SCC comprise an incomplete knowledge base, clients who never choose it, recipes that are said to be too demanding, and workplace traditions. Facilitators comprise large companies investing in knowledge development about SCC and engaged persons promoting it. This study used an HTO-based model (BTOH) to identify barriers and facilitators for a broader usage of SCC, thus contributing to a deeper understanding of reasons for the low usage of SCC and ways of increasing it.

Keywords: construction workers; hand–arm vibration; self-compacting concrete; qualitative

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1. Introduction

The construction industry is considered to be traditional and introduces new developments such as digitalization at a slower pace than other industry sectors. The total expenditure of research and development in the EU amounts to 2.4% of GDP [1], and the construction industry has one of the lowest spendings in this respect.

At the same time, this industry has some of the highest frequencies of sick leave caused both by accidents and by work-related diseases. The total cost of construction industry work-related diseases in the EU has been estimated at 0.5–2.0% of GNP [2]. In Sweden, sick leave in the construction industry caused by strain and vibration injuries costs society up to EUR 120 million per year [3]. During 2021, 29% of all reported work-related diseases in the Swedish construction industry were various strain injuries [4]. During the period of 2015–2020, 46% of all insurance-confirmed work-related diseases in the construction industry were vibration-related injuries [5].

One demanding task after casting with regular concrete is using vibration rods and manually vibrating the concrete to reduce the air content and fill the formwork properly.

This manual vibration is a laborious work activity. The vibration rods weigh about 10 kg and the work process requires that they are lifted repeatedly throughout a shift [6]. This can lead to wear and tear, also causing chronic back, shoulder, and arm pain [7]. Additionally, workers are exposed to loud noise during vibration. Loud noise, above 85 dB, over a long period of time can lead to hearing loss and increase the risk of accidents on the construction site [8,9]. A 2018 study encompassing over 1000 construction sites across 10 countries from 1980 to 2016 demonstrated that most sites exceeded the 85 dB noise safety limit for an 8 h workday [10]. Measurements at construction sites [11,12] have shown noise levels above 90 dB and up to 100 dB. In addition to repeated lifting and noise, workers are also exposed to hand–arm vibration. Extensive and prolonged exposure to hand–arm vibration can lead to a number of adverse health effects, primarily in the peripheral neurological, vascular, and musculoskeletal systems [13,14]. In order to counteract the health risks associated with work with vibrating machines, the Directive of the European Parliament (2002/44/EC) [15] suggests an exposure action value of 2.5 m/s^2 and an exposure limit value of 5.0 m/s^2 for the daily vibration dose. Despite the current exposure action level, research indicates that 10% of a population could still develop neurosensory injuries after 5 years of exposure at the action level [16].

However, there are types of concrete that do not require vibration after casting. Self-compacting concrete (SCC) is a fluid concrete and, as such, does not need vibrations to fill a formwork, even if the formwork is of considerable complexity. It is denser, has a higher compressive strength, and requires less post-production treatment [17]. As there is no need for vibrations when casting with SCC, this strenuous, noisy and potentially harmful task is eliminated. This may improve concrete workers' work environment, health, and safety [18]. In addition, one may expect economic benefits when using SCC. Despite SCC having a higher market price per m^3 compared to regular concrete, its reduced labour requirements result in a lower overall casting cost, according to estimations [18]. Yet, it must be mentioned that there are drawbacks to using self-compacting concrete as well. For example, the amount of cement in its composition exceeds the amount used in recipes for regular concrete [6]. As cement production is environmentally unfavourable, this indirectly increases the CO_2 footprint of SCC. On the other hand, a number of different techniques and solutions have contributed to the aforementioned positive developments. Today, there is already concrete on the market that has a 20 to 30 percent lower climate impact compared to conventional concrete. This has been achieved through the development and production of new concrete compositions with lower cement contents. Similarly, new types of cement have also been developed with lower clinker contents. Alternative binders that are more climate-friendly are also being used, and active work is being performed to climate-optimize designs to use the right concrete in the right place. Many of the techniques and methods mentioned below are already in use today, but there is still room for further improvement and development [19,20].

The market share of SCC in concrete casting varies considerably among different countries. Denmark uses SCC in about 30% of its total casting, Norway use about 5%, and Israel about 10% [21]. In Sweden, SCC is still considered to be innovative; despite its advantages, the market share of self-compacting concrete (SCC) in Sweden is about 5–10% of the total Swedish precast concrete production [6,18]. However, there have been changes in the industry over the past 10 years. In some parts of Sweden, individual concrete companies have managed to locally increase the share up to 30%, while in others it is still almost 0% [6,22].

The gap between work environmental advantages of SCC and its low usage in Sweden has not been studied enough. In particular, studies concerning barriers and facilitators of SCC adoption in Sweden are lacking. In order to fill this knowledge gap, this article presents the opinions of university teachers, construction engineers, design engineers, clients, consultants, and contractors concerning the work environment during concrete casting, the existence of SCC and its usage, and the associated influence of SCC on different aspects of the construction process. The aim of this study is to describe views, opinions, and knowledge concerning the work environment and health in concrete casting, and to identify barriers and facilitators of SCC usage. By examining Sweden's experience, this study offers insights into SCC adoption. These findings can support other countries in developing their own implementation strategies.

2. Literature Overview—Background and Framework

This section gives an overview of subjects related to innovations in the construction industry. In order to structure and analyse the articles found, an HTO model was used, namely the BTOH model [23]. The model describes the components of a company and their interactions: B—Business development; T—Technology; O—Organisation; and H—Humans (Figure 1). According to Lindqvist et al. [23], all four components need to be present and in balance for a company to be successful or for a work process to be efficient. They argued that component B (business) is the main one in the model and therefore occupies the first letter in the model's acronym. Every company starts with a business idea and is held afloat by it. The other components are subordinate and need to comply with the business idea [23]. By analysing each of these components, it is possible to identify inefficiencies and potential improvements in the different work processes, including the adoption of innovation. The applicability of the model to our case is granted by the presence of a business component which includes business ideas, everyday business processes, and business development. Specifics particular to SCC are discussed later in Section 6.

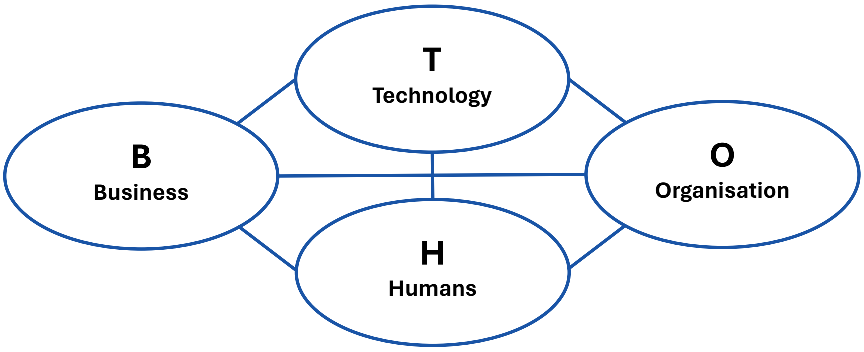

Figure 1. The BTOH model by Lundqvist et al. [23] (with terminology translated).

2.1. Innovations in the Construction Industry, Types, and Areas

Innovation can be viewed as an intervention process, which strives for an invention's commercial success [24–26]. Seaden and André [27] related "innovation" with actualizing new processes, product use, or management setups in order to improve the efficiency of an organisation. Dulaimi et al. [28] have suggested a different formulation: innovation is the generation, development, and implementation of new ideas that lead to practical or commercial benefit. According to Bygballe and Ingemansson [29], innovation is all about the usage of a new product or material, implementing a new process, and setting up a new organisation or business relations and contacts.

Innovation areas and types tend to differ across time periods and countries. Bygballe and Ingemansson [29] have, in their studies of innovations in leading construction companies in Sweden and Norway, shown the presence of a strong focus towards organisational and activity-related innovations such as management development, planning the level of production, partnering with other actors and sellers, and customer relations. Other areas of innovation were mentioned, for example, innovation activities around standardization. Material and technical developments appeared harder to enforce and less central. Ozorhorn and Oral [30] and Liu et al. [31] have found that the main innovation types were modern methods of construction (prefabrication). Bamigboye et al. [32] have highlighted construction materials; Timchuk et al. [33] identified innovative technologies as the main area of innovation; and Samarasinghe and Wood [34] specified digital technologies separately.

2.2. B—Business

A company's business characteristics, such as its size, revenue, market success, and the way the business is conducted, all play an important role in the successful implementation of innovations. Xue et al. [35] have found that collaboration is a critical factor for construction innovation. The negative features of supply chains and poor inter-organisational cooperation with partners hinder innovation. At the same time, collaboration with investors and academia promotes innovations within new technology and materials [35].

Meng and Brown [36] studied how firm size affects innovation in construction in the UK and the Republic of Ireland. It was observed during the analysis that larger firms implement innovations concerning education, employee competence, new technologies, and materials more frequently than smaller ones. Noktehdan et al. [37], and Miozzo and Devick [38], have stated that larger firms are the main drivers for innovations. Opstadt and Valenta [39] ranked the largest companies highest on stability and profit. Meng and Brown [36], and Chundakkadan and Sasidharan [40], emphasized that not only the size but also the economic prosperity of a company influence the number and character of innovations. They mean that large and successful companies attempt innovations more readily, that the attempted innovations are of a long-term variety, and that they can be implemented in pursuit of best practice as well as work and safety improvements [36]. Small companies prefer short-term innovations for resolving daily obstacles in their projects. Small and economically weak companies usually implement innovations to save money and/or to please clients [36].

In the construction industry (and in business in general), the actors assume that it should be possible to calculate the benefits of innovations [41]. Cost-saving increases in productivity and efficiency may serve as good outcomes and goals of innovations [41]. Decreasing the overall cost of a project could also be a driver of innovation [36]. However, excessive economic concerns could also hinder innovations [42].

Clients are frequently labelled as drivers of innovation. At times, a client's wishes and a company's ambition to please their clients force the company to attempt and implement innovations [43,44]. A client may, however, impede innovations. In the work of Bygballe and Ingemansson [29], it was pointed out that clients need to be willing to take risks, maybe increase costs, and try something new. If they are more focused on price and control, it hinders the innovation process. Lindblad and Karrbom Gustavsson [45] have carried out a longitudinal case study on the implementation of building information modelling (BIM) at the Swedish Traffic Agency (STA). They concluded that clients (especially public clients) may be "agents of change" if they have the ability to drive industry changes in their own organization and if they are open to accept changes and able to absorb new knowledge.

2.3. T—Technology

Technology may act either as an innovation input or as an innovation output [30]. Technology has a dual role, acting as both an input and output within the cycle of innovation. For example, 3D printing technology is an output of advances in electronics and material science, but it can also be considered an input for innovative ways of building houses. This "construction by printing" reduces CO_2 emissions by 40% compared to traditional methods [46,47]. Lai et al. [48] viewed technology as a driver for innovation, while Ercan [49] considered it as a resource of innovation, and Gok and Peker [50] treated it as an intermediary between innovation and financial gain. Xue et al. [35] have specified that technology is the key source of innovation in construction. As an example of when such a source is missing or lacking, Lindblad and Carrbom Gustavsson [45], in examining the implementation of BIM at the STA, named a low or inadequate technical base as one of the reasons for the incomplete implementation. The STA had challenges with interoperability and a lack of well-established and accepted standards.

2.4. O—Organisation

An organisation's structure, culture, and the information exchange within it are identified by several authors as elements that can either impede or promote the generation and implementation of innovations [51,52]. It is frequently mentioned in the literature that many innovations happen not on a high organisational level but in smaller construction projects. If specific routines to identify and analyse these innovations exist in the company, there is a chance that they will be adopted throughout the organisation and become part of its repertoire. Information and knowledge exchange pathways between projects (horizontally) and between management and workers (vertically) as well as between the company itself and external actors (laterally) were named as the most influential promoters of innovation adoption [29,30,35]. Coming back to the partially unsuccessful implementation of BIM, one of the reasons for failure was the low information and knowledge sharing and also the low ability of the STA to incorporate and assimilate new knowledge [45].

Xue et al. [35], Vnoučková and Urbancová [53], and Lijauco et al. [54] have enhanced the importance of organisational culture in stimulating innovative behaviour, which motivates organisational members to come up with and practice new ideas. Teräväinen and Junnonen [41] studied the desired cultural change in a Finnish construction company. Bad communication of ideas from management to workers and a lack of dialogue with workers were named as barriers to cultural change, for example, the inability to explain the core meaning to the recipients of the new recommendations, requirements, and expectations. Other barriers include the perceived homogeneity of the company's work force; since everybody is like everybody else, they all think alike, and new ideas are never generated [41].

2.5. H—Humans

This component of the BTOH model is indispensable. There are no companies without people. People operate machinery, make organisational and business decisions, and generate and implement ideas.

Xue et al. [35] emphasized that people in key positions who are not interested in changes hamper innovation. The same can be said about personnel if they lack the knowledge, skill, and personal qualities necessary for changes [41]. Lindblad and Karrbom Gustavsson [45] have mentioned low qualification and low maturity for BIM as yet more reasons for its unsuccessful implementation. At the same time, Xue et al. [35] and Chai et al. [55] have pointed out that leaders and active staff in general contribute to cultural change towards the facilitation of innovations. Key individuals, for instance the champions, are important in determining innovation and creativity in organisations [35].

A synthesis diagram of previous research on innovations in the construction industry is given in Figure 2.

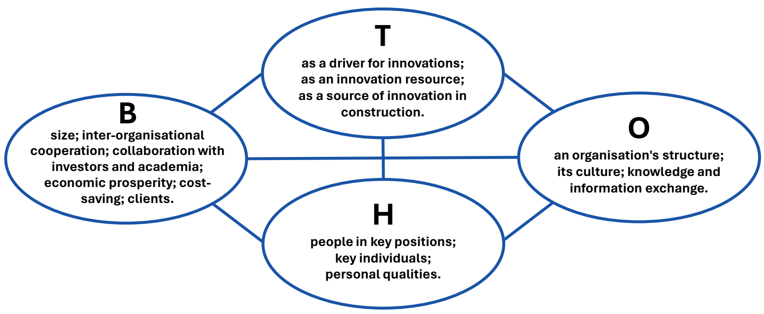

Figure 2. A synthesis of previous research on innovations in the construction industry applied to the BTOH model.

3. Method

This is an interview-based qualitative study. It uses interviews in order to identify the views, knowledge, opinions, and attitudes of 24 persons from the construction industry.

This study covers perspectives and methods through the field of interpretive and qualitative research. The purpose of qualitative research focuses on understanding problems or specific situations by investigating people's views and behaviours within their contexts and environments [56]. Semi-structured interviews were chosen as the data collection method in this study in order to obtain rich descriptions of SCC usage and related issues. Such interviews utilize an interview guide with open-ended questions, the question order is flexible, and follow-up questions are posed as needed to gather in-depth information [57]. The chosen method thus becomes suitable for this study because it summarizes subjective points of view, and the attitudes and knowledge of different representatives of the construction sector in Sweden, which aligns with this study's aim. The interviews were recorded and transcribed.

The semi-structured interviews were conducted with 8 groups of people (3 in each group) from various parts of the construction industry. These participants were selected to cover the entire range of competence, experience, and work activity (from purely theoretical to hands-on in the field) in the construction industry. The interviewees' profiles are presented in Table 1. There was 1 woman among the participants and the rest were men. The prospective participants were contacted by using already existing communication channels between the researchers and a large number of construction firms, and governmental and educational institutions.

Table 1. Profiles and numbers of interviewees.

Group Number	Profiles of the Interviewees	Number of Interviewees
1	University teachers of construction engineers	3
2	Construction engineers with less than 1 year of experience	3
3	Construction engineers with more than 1 year of experience	3
4	Contractors who often use SCC in their work	3
5	Contractors who seldom use SCC in their work	3
6	Design engineers working on the client's side	3
7	Consulting design engineers	3
8	Work environment managers	3
Total		24

The interview time was 60–90 min, and the interview language was Swedish. The interview guide included the following question areas:

- The interviewee's work experience;
- The work culture and organisation at the interviewee's workplace;
- The interviewee's reflections on the health and safety of construction workers;
- The interviewee's reflections about working methods of different types of concrete that would make improvements at a construction site;
- Reflections on experiences of different types of reinforcement concrete and their properties;
- Working priorities, both private and at the workplace;
- Decision making concerning usage of SCC and regular concrete;
- Changes made at the interviewee's company prior to SCC adoption.

A qualitative manifest content analysis (QMCA) [58] was used to analyse the interviews. A QMCA was selected due to the open-ended nature of the interview questions, which yielded responses with latent content. QMCAs are well-suited for identifying and interpreting latent content within qualitative data [58]. The analysis was conducted in five steps:

- Reading the transcribed interviews several times.
    - This step ensured deep familiarization with the data and allowed for the identification of preliminary patterns.
- Highlighting meaningful units which were related to the research aim.

- ◦ Key phrases or segments of the transcripts that directly connect to the research question were marked for further analysis.
- Condensing and coding the meaningful units.
  - ◦ Highlighted units were summarized and assigned descriptive labels (codes) to capture their thematic essence.
- Clustering of codes into sub-categories.
  - ◦ Codes with similar meanings or themes were grouped together to form sub-categories.
- Creating the main categories.
  - ◦ Sub-categories were analysed to determine overarching themes, forming the main categories that represent the key findings of the research.

This analysis was performed for each of the groups of interviewees (Section 4) and thereafter across the groups (Section 5). These results are subsequently summarized in Figure 3 in Section 6.

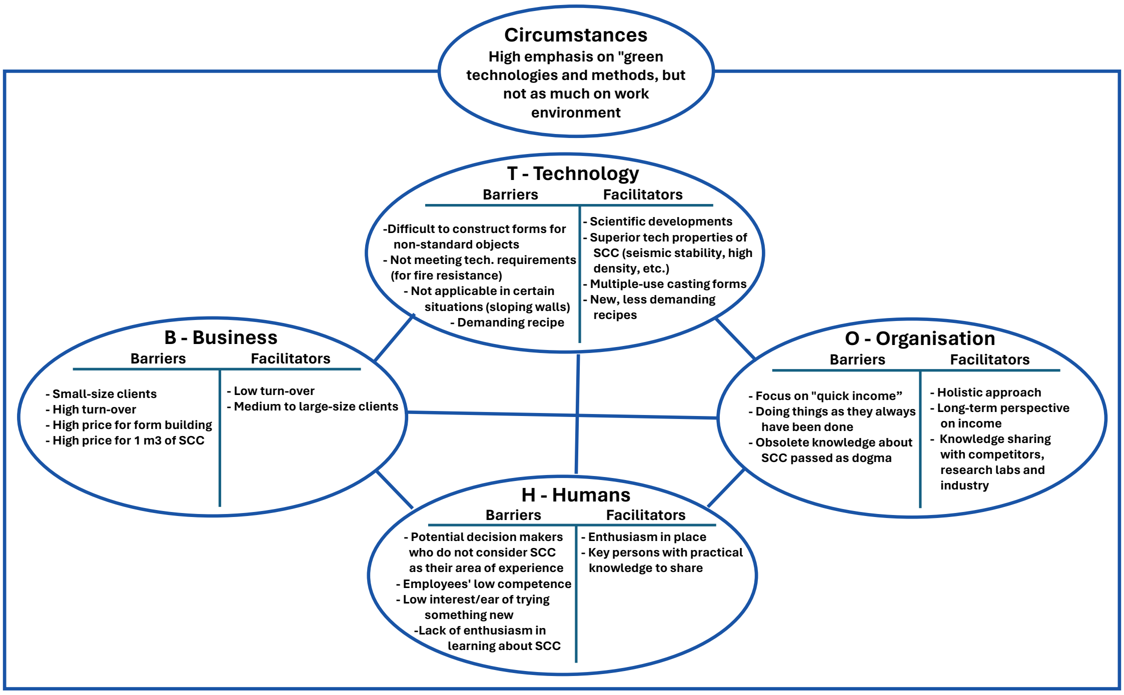

Figure 3. Aspects that are facilitators or barriers for the broader use of SCC applied to the BTOH model.

4. Results

In this chapter, the processed, grouped, and summarized data extracted from the interviews with the different professional groups are presented. For each of these subchapters, the answers and opinions of the three persons included in that specific group are described.

4.1. University Teachers

The two interviews with those who teach in a programme for a Bachelor's of Engineering (BE) (courses in construction technology) and one with someone that teaches in a programme for Master of Engineering (ME) (concrete construction) explained a difference in content between the teaching programs. The BE program includes a separate course on work environment, focusing on regulations and safety equipment. Both programs cover construction and materials, including self-compacting concrete (SCC) and carpet reinforcement.

One interviewee mentioned that he frequently teaches on the importance of material choice for efficiency: "*...materials need to be safe, reliable, and compliant with norms and regulations. Wrong choice of materials causes errors*". Another one trained his students to consider cost analysis when selecting construction techniques and materials, aiming for high quality at a lower cost: "*...decreasing costs is always urgent for any construction project. Lowering the cost of the project by choosing cheaper but still high-quality materials is very efficient*". The respondent who teaches ME stated that his course does not specifically focus on efficiency: "*The students probably learn about this in other courses. The emphasis in my course is on the strength of the construction and the correctness of the calculations*".

The benefits of SCC for the work environment were highlighted by both BE teachers, mentioning its ability to reduce vibrations. The ME teacher did not mention SCC but praised the liquid concrete's ability to fill every crevice in constructions with a lot of reinforcement, thus adding to the construction's overall strength.

All three teachers said that work environment and SCC are elective topics not included in the requirements for the program content, and that elective topics are only taught when a teacher's knowledge, experience, and interest are present. Additionally, the interviewees noted the influence of "fashionable" topics that come and go, such as economy and, currently, green technology.

4.2. Construction Engineers with Less Than 1 Year's Experience

In this group of interviewees, one was a recent graduate with no work experience, and two were project managers—one working from the office and the other in the field. All three had classes on work environment during their studies and learned about injury prevention and safety equipment. They acknowledged the dangers associated with working with concrete, including slips, inhalation of dust, and back injuries, but did not mention vibration-related risks. Safety equipment was highlighted by the interviewees as a primary method of injury prevention, although its discomfort, interference with workflow, and high cost were too mentioned.

When asked about healthy working methods, the construction engineers admitted a lack of knowledge, with one interviewee expressing hesitancy towards adopting new methods due to the risk of trials going wrong and potential financial losses. The interviewees emphasized project costs, construction quality, safety, and calculation accuracy as important aspects of their job. While they recognized the potential for increased efficiency in concrete work through better planning, organization, and material usage, they did not discuss the relationship between efficiency, the work environment, and cost savings from accident prevention. Furthermore, none of these construction engineers were familiar with SCC and its benefits.

4.3. Construction Engineers with More Than 1 Year's Experience

The interviews included a construction consultant, a foreman, and a project manager. Only the foreman highlighted the importance of the work environment, acknowledging its impact on work efficiency but also stating "*...the more environmental requirements there are, the more expensive the whole project gets. On the other hand, workers' injuries also cost money, but a price tag for health, who knows how much it is*". The other two group members claimed that the work environment was not their concern.

When discussing work priorities, both office workers prioritized project costs, with quality and customer satisfaction following closely. The foreman contrasted this with "*We always go for customer satisfaction. They often want to choose less expensive materials, and cheaper methods, and we agree to that, even when we know the result will suffer in quality*".

Carpet reinforcement was known only to the foreman, who mentioned its organizational challenges and cost considerations. None of the respondents were familiar with SCC. The foreman expressed curiosity about the benefits of SCC, both to meet client expectations and understand potential cost advantages, as "*...price is important and always more important than working time*".

4.4. Design Engineers Working on the Client's Side

Three design engineers who work for public clients emphasized following regulations, selecting appropriate materials, and reducing project costs. One engineer had knowledge of SCC, stating "*Before, SCC was difficult to work with, but now concrete factories are much better with their delivery*".

The work environment was not a particular concern for all three, as they believed it was the contractor's responsibility. One mentioned their focus on delivering schematics in line with regulations from the Swedish Work Environment Authority. Another said "*I inspect and comment on others' schematics only if they significantly impact the work environment and health*". The third described how risk assessments of accidents and consideration for the construction site workers' capabilities guided his design process.

None provided suggestions on material choices: "...this is not part of our responsibilities. We only comment on the specifics of a material, its strength or plasticity. The final choice is always the prerogative of the contractor".

When discussing improving concrete work efficiency, the design engineers highlighted proper machinery, contractor competence, and quality record. None mentioned work environment enhancements as a means of increasing efficiency or reducing health risks.

4.5. Consulting Design Engineers

These three interviewees, working in different consultancies, emphasized construction safety and customer satisfaction as the top priorities in their roles. While one acknowledged the importance of the work environment, they considered it just one aspect among many, often conflicting with other project requirements. When discussing efficiency improvements in concrete work, two engineers highlighted the potential through better planning and organization. The third engineer focused on sustainability in terms of material usage rather than labour or working time.

Health risks during concrete construction were associated with accidents and injuries, with one participant noting the risk of back injuries in narrow spaces and emphasizing the importance of simple and cost-effective solutions. None of them mentioned vibrations as a health risk during concrete casting.

Two engineers were unfamiliar with SCC, while the knowledgeable participant refrained from explicitly recommending it, since "*...vibrating during casting is not a question of design, but of execution, and thus not within my responsibility*". They mentioned ecological concerns and fire safety requirements as reasons why contractors may not always opt for SCC. Additionally, the consulting design engineers noted that SCC recipes, logistics, and casting methods were still developing, with clients desiring quicker construction completion conflicting with longer drying times for SCC.

4.6. Contractors Who Seldom Use SCC in Their Work

Three contractors were interviewed, including a project leader, a project manager, and a foreman. While none had learned about SCC in college, they had heard about it from colleagues and superiors. The project leader mentioned the rare usage of SCC: "*At most of our sites, it is easier and cheaper to use conventional concrete. The staff know how to handle it, it is more reliable, with a lower risk of segregation*".

The project manager noted a single instance of SCC usage, which led to worker uncertainty and the need to hire an SCC specialist. The foreman and his company had never worked with SCC, citing concerns about cost and risk avoidance. All three recognized the importance of the working environment in reducing accidents, with the foreman observing worker fatigue and body aches. "*Not much to be done*", he mused, "*you can't build a house without that*".

None of these contractors associated a good working environment with efficiency but emphasized achieving efficiency through material choice, improved logistics, streamlined processes, and error-free blueprints. Working priorities included quality, meeting deadlines, cost control, and client satisfaction.

4.7. Contractors Who Often Use SCC in Their Work

Three contractors, including two project chiefs and a foreman, who frequently utilized SCC in their projects, were interviewed. While quality was deemed important, project cost and delivery deadlines were considered the top priorities. One project chief emphasized the avoidance of errors in planning and organizing to prevent cost overruns and delays.

The project chiefs thought efficiency improvements in concrete work could be achieved through meticulous planning, simplifying blueprints, and finding ways to make production easier and faster. The use of carpet reinforcement was highlighted: "*When it comes to reinforcement or casting forms, there is not much to be done. It costs precisely what it costs. What you can do is find ways to make production easier: saving time, changing the blueprint to reduce the amount of climbing... It is good to use carpet reinforcement as it saves time. Unfortunately, it is not always possible because of the construction complexity*".

Considerations of working hours and the working environment were seen by these contractors as conflicting factors, with improvements aimed at avoiding errors and reducing complexity. One of the chiefs identified reusing equipment, comprehensive planning, and matching workers' competence with tasks as his go-to for improving efficiency.

Regarding the working environment, the contractors primarily focused on preventing accidents and injuries, but acknowledged longer-term risks related to vibrations, noise levels, and stress. The foreman considered the working environment a responsibility but focused solely on accidents and injuries.

When discussing SCC, all three contractors acknowledged its benefits, particularly its vibration-free nature and the positive feedback from workers on its ease of use. However, they also recognized specific challenges and cautioned against overestimating the superiority of SCC. These contractors noted that SCC should be used in specific technical application areas and that claims of SCC significantly improving construction efficiency could be exaggerated. Videos and information about SCC were deemed as potentially sugarcoating its actual challenges and complexities.

4.8. Work Environment Managers

Three work environment managers were interviewed, representing a client, a large contractor company, and a consultant working for a client. Despite their companies prioritizing cost concerns over safety considerations and favouring short construction time spans, the interviewees focused on accident prevention, protecting lives, safety equipment, and training. The managers acknowledged that a poor work environment is costly, resulting in sick leave absences and construction delays due to accidents. All three claimed that while large companies were involved in preventive measures and regular health checks, they displayed less interest in improving construction methods and materials, and that smaller companies would disregard this altogether.

When discussing efficiency improvements on construction sites, the managers emphasized planning, high-quality documents, design drawings, and qualified personnel. None explicitly mentioned the work environment as a factor for improving efficiency.

All three managers were familiar with vibration and noise damage, improper body postures, and heavy lifting during concrete casting. Preventive measures such as shorter work shifts, rotation, and the use of earplugs were mentioned. All three were aware of self-compacting concrete (SCC) and carpet reinforcement. However, they claimed that SCC was more established in building construction rather than in infrastructure projects. The managers explained that large contractors have the knowledge, experience, and economic strength to utilize SCC sporadically, but that the large contractors avoid exclusive use in infrastructure projects due to complexity and technical challenges. These work environment managers said that competition regulations also play a role in the choice of working methodology. While providing advice to project managers, the work environment managers focus on work methods and safety compliance, and avoid advising on materials unless they themselves, as the work environment manager, have the necessary expertise.

5. Results Analysis

This chapter presents an analysis of interviews across groups.

5.1. Knowledge about SCC and Other Construction-Related Methodologies (What Do People Know, Where Did They Learn It, and What Do They Associate SCC with?)

The deepest and most extensive knowledge about SCC was demonstrated by the contractors who work with it frequently and by the work environment managers. SCC is not taught in any detail in colleges; people learn about it either in the workplace or while taking specialised certifications (for example, work environment managers).

In the building engineers group, no one had heard about SCC. In the other groups, people either knew about SCC in theory or had worked with it one or two times. Their attitude towards SCC was not positive; they opined that working with it was difficult, risky, and expensive. During their interviews, they emphasised shortcomings of SCC rather than its benefits. The interviewees mainly expressed a low level of interest in learning about and implementing SCC.

Those who work with SCC said the material is good, but its usage only suits specific situations. For them, it was, in the first place, associated with the high strength of the final product and areas of its usage. Work environment improvements that come with the usage of SCC seemed more like a nice bonus to its technical characteristics. They also stressed the necessity of well-defined logistics, as well as solid knowledge and experience among workers.

5.2. Attitudes and Associations about Work Environment, Work Priorities, and Work Efficiency

5.2.1. Work Environment

When the work environment was discussed, it was almost exclusively associated with accident prevention and general safety measures at work. Only one interviewee had some thoughts on work-related illnesses and an awareness of the long-term health risks connected with concrete casting, albeit without mentioning hand–arm vibrations. That person worked at a construction site as a foreman.

The interviewees' attitudes towards the work environment, injuries, accidents, and their prevention as well as workers' health were strongly associated with the economic concerns of their companies and projects (sick leave, idle time, protective equipment). One interviewee who was a project leader with economic responsibilities mused: "*Injuries and accidents are bad for a company's reputation; also work gets halted. At the same time, a lot of rules and regulations impose higher costs; safety measures such as protective equipment and appropriate clothes are also expensive in the beginning but may help to lower costs in the long run*". As the last part of the citation shows, there were a few thoughts of improved economy with work environment investments, but they were indeed few.

5.2.2. Work Priorities

When asked about their firms' or their own specific priorities to ensuring the best delivery, the interviewees' answers converged towards reducing costs, even when discussing time or quality aspects. Several participants mentioned how important it is to satisfy clients' needs. However, they also spoke of how every client is different, how some of them do not understand the consequences of their expectations and requirements, and how others are very aware of all of the details and want to control what materials are to be used. In the end, though, all clients want their projects to be cheaper; thus, all other aspects of the process are reduced to cost considerations.

None except the work environment managers explicitly mentioned priorities such as personnel and workers' health.

5.2.3. Efficiency of Construction Processes

The efficiency of construction processes was associated with better planning, better materials and machinery and raised qualification of workers.

Many participants stated that the work environment and efficiency are related: safer equipment is more expensive, and yet illnesses and accidents also increase the duration and cost of a project. Only one interviewee associated efficiency improvement with a better working environment, a reduction in health risks, or safer, less hazardous work procedures. It is worth noting that even the work environment managers did not mention improving the work environment as a means to lower project costs or shorten a project's execution time—while exposing in detail the negative influence of a bad work environment on deadlines and project costs.

5.3. Decision Making about the Usage of SCC

When a decision on whether to use SCC in a project or not was made, the interviewees mentioned arguments both for and against.

Among the pro arguments, the following were mentioned: technical quality requirements for the final product, special circumstances during casting (narrow reinforcement, casting under water, casting of ceilings and walls with sprayed concrete), the staff's qualifications and competence, and a decision maker's (design engineers, contractors) personal preferences for using new techniques. The vibration-free property of SCC was never listed as a primary reason for its usage in a project, but rather a secondary benefit.

Counterarguments included a lack of knowledge (on the level of both decision makers and workers), costs per m^3, complexity of delivery and usage, risks associated with the unstable SCC recipe, design considerations (such as that a wall or floor is sloped), and fire safety and environmental requirements. Finally, a client's reservations about SCC being too expensive and slower to dry also negatively influence the selection of this material.

Nobody who could influence the choice of concrete during the starting phase of a project, such as the designer engineers and work environment managers, actually does so. Usually, they consider it to be beyond their competence, want to avoid breaking the competition laws, and leave the final decision to the contractors. The work environment managers stated separately that they usually do not attempt to improve the work environment by tweaking the choice of materials, but rather approach it by other methods (increasing the work force, better planning of shifts, etc.).

6. Barriers and Facilitators According to the BTOH Model

This chapter presents an analysis of the interviews according to the synthesis of previous research results on innovations in the construction industry that were produced with the aid of the BTOH model.

It became possible to identify aspects that hinder or support the broader use of SCC (Figure 3).

6.1. B—Business

All of the interviewees said that both size and success in the business/the economic stability of a firm influence how often it uses SCC in its projects. It was evident that medium-to-large companies with high monetary turnover are then able to invest in innovation, to participate in knowledge sharing with other actors in the industry, and even run research labs; these companies use SCC more often. They can also invest in expensive technologies (such as multiple-use iron casting forms) because they have margins and can afford to wait until the return of investment.

On the other hand, small-sized companies with modest monetary turnover are always forced to save money. They are mostly interested in short-term profits and cannot afford economic losses due, for example, to mistakes made during casting. These companies seldom use SCC.

Clients were also mentioned as yet another aspect that influences the choice of building materials. The interviewees were unanimous in pointing out that clients almost always want things performed quickly and cheaply. The price of 1 m^3 of SCC is higher than that for conventional concrete; therefore, clients avoid using it. Small- and medium-sized client companies are often not aware of the advantages of SCC. But, even large and influential clients that know enough about SCC and could "set the tone" for the whole industry refuse to use it.

6.2. T—Technology

Everyone noted the difficulties with the recipe and with the design of the casting forms, as well as the risks associated with the casting methodology (you are not supposed to pour a lot of concrete at once). All of these aspects stop many builders and firms from using SCC. Some of the technical features of SCC that restrict its broader use were mentioned: lower fire resistance, it not being applicable in certain situations (such as sloping walls), long drying times, and a high percentage of cement that is not environmentally friendly.

At the same time, many of those who had worked with SCC stated that these concerns are "obsolete knowledge", and referred to scientific developments, new stable recipes, and new well-tested methods of casting with multiple-use casting forms. They also recounted that the superior technical characteristics of SCC (such as seismic stability, high density, possibility to cast under water) promote a broader usage of it.

6.3. O—Organisation

After analysing the information that the interviewees shared about their companies, it became evident that the organisations that worked with SCC generally have a more holistic approach and a long-term perspective on income. They also have a larger share of permanent staff, teach their workers—both internal and external—and have well-organised processes from receiving and sharing knowledge about SCC and creating their own recipes to produce their own SCC at their own factories.

Organisations that only focus on quick income often have a high employee turnover and the lack necessary knowledge about SCC. They also neither have the time nor the interest in teaching their workers any new methods and prefer doing things "as they have always done". Such organisations avoid using SCC.

6.4. H—Humans

The participants who said that SCC was often used in their companies mentioned that they have in-place enthusiasts who are pushing for more and extended usage of SCC. These are either senior managers or other key players who convince the company leaders to bet on the development and usage of SCC. They also talked about certain employees who have practical knowledge of SCC and actively participate in knowledge sharing in the company.

Several of the potential decision makers among the interviewees stressed that they do not consider choosing SCC to be within their area of competence. Several others stated that they lack competence in SCC and are afraid of taking risks and trying something new—and thus explained why their companies avoid using SCC.

An overall low interest in SCC was identified as well as the interviewees' general unwillingness to learn more about the product.

6.5. Circumstances

Several aspects indirectly influencing the awareness and usage of SCC that could not be categorised into any of the groupings of the BTOH model were identified. In the expanded model of this study, these are called "circumstances". Participants who occupied higher positions in their organisations, as well as participants who were teachers, recounted that there is a change in attitudes from society, politicians, and in overall global trends: a high level of environmental awareness is expected—in projects and in their teaching courses as well. There is a high emphasis on "green technologies and methods", but less on a good work environment. SCC is associated with not being very environmentally friendly, rather than being vibration-free. This trend leads to a lower overall interest in a good work environment, both in the industry and in the related education, and in turn to a low level of general knowledge about SCC in higher education.

7. Discussion

For this qualitative study, 24 representatives of the Swedish construction industry were interviewed. The interviewees associated a good work environment during concrete casting with the prevention of accidents. The level of awareness about work-related injuries such as musculoskeletal disorders (MSDs) and hand–arm vibration syndrome (HAVS) was low for many of the interviewees. This is not at all surprising, as people are generally more aware of risks they have been previously exposed to [59], and if the construction engineers have not been construction workers themselves, they may not be familiar with the physical exposures. On the other hand, being aware of MSDs is natural for construction workers who are engaged in physical labour [60]. It is, however, a distant problem for engineers and managers. Accidents, on the other hand, are visible to everybody and affect a whole company "here and now". Managing accidents and their consequences are a part of our respondents' responsibilities and so, as engineers and managers, they are highly aware of them. The overall understanding of the risks concerning MSDs and HAVS has been found to be low in many Swedish companies, as shown in a report by the Swedish Work Environment Authority [61].

The main priority for planning and executing a construction project for almost all of the interviewees was cost control. This is entirely in line with other studies that confirm the construction industry's orientation towards short-term profit and disregard for long-term investments [60,62–66].Therefore, it can be concluded that finances are one of many possible explanations for the respondents' lack of interest in the new methods and technologies and are a reason for the lack of mention of anything related to workers' long-term health as either a priority or a method of raising construction process efficiency.

Another explanation for the respondents' lack of interest in SCC lies in it not being a universal product. It is a more expensive material that requires sturdier casting forms and has a m^3 price approximately EUR 10–15 higher than traditional concrete [12,67]. Its successful usage requires specialised knowledge and experience, higher investments, and more complicated overall process organisation and logistics. For inexperienced users, these aspects create an insurmountable obstacle to the broader adoption of SCC. Such conclusions are also backed by the theory of innovation diffusion [68], which details a wide variety of factors that influence the adoption of innovations. According to this theory, potential adopters always assess qualities such as the cost of innovation, implementation time, and effectiveness when replacing existing products, and the ease of use for successful adoption, so these qualities need to be seen as beneficial.

On the other hand, the more experienced users stressed the unique technical characteristics of SCC, which make it easy to use and economically viable in certain specific situations, provided that knowledge about SCC, the logistics, and overall process organisation are already in place. The main finding of this study is precisely the broad lack of knowledge about SCC and its usage at all levels of the construction industry. The theory of innovation diffusion [68] states that information dissemination is an essential factor in the successful adoption of innovation; furthermore, as seen in this study, information about SCC is scarce and poorly disseminated. Knowledge exchange was named as the most influential promoter of innovation adoption [29,30,35]; thus, it seems that a lack of systematic propagation of knowledge about SCC is the biggest obstacle to its broader adoption.

Another explanation for the low usage of SCC may be its technical imperfections. These include high levels of cement, low refractoriness, and the instability of the recipe. The first two aspects limit the use of SCC in projects where a client sets the requirements regarding the CO_2 footprint of the whole construction process or the fire resistance of the construction object. Self-compacting concrete is prone to spalling when heated rapidly [69]. The spalling effect is especially detrimental during fires in tunnels where SCC is used [22,70]. However, adding polypropylene fibres to the recipe alleviates that problem [22,70]. There are also several methods for reducing the CO_2 footprint of SCC. A lack of awareness about these methods can hinder its adoption. Even if people are aware of these methods, there are still challenges. For example, not all factories have "green recipes" for SCC, and the cost of concrete made with these recipes can be higher than that of ordinary SCC. Additionally, the quality of "green recipes" can be questionable. These factors can adversely affect decision making regarding the use of SCC. However, successful cooperation between a local concrete plant and a contractor can make things easier and influence the decision in favour of SCC [6]. The unstable recipe and day-to-day unpredictability of the mixture were frequently mentioned by the interviewees who use SCC often. They countered that there are ways to minimise these shortcomings, for example, by using regular check-ups of the primary ingredients, factory mixtures, and (and this is of high necessity) the mixtures delivered on site. However, the imperfections of the recipe are hard to remove entirely, and even the building companies with their own labs and concrete plants have reported problems with the recipe. Thus, the technical imperfections of SCC can be counted as an additional obstacle to its wider adoption.

According to the theory of innovation diffusion [68,71], the mass adoption of innovation cannot start without early adopters acting as opinion leaders, meaning that they are trusted, expert, and accessible. The importance of a key person (people in key positions, enthusiasts, and leaders) in the facilitation of innovation is also described by Xue et al. [35], Teräväinen and Junnonen [41], Skovgaard et al. [72], and Valtonen et al. [73]. Broad usage of SCC was reported by the interviewees at companies where such key persons were present and active. They initiated and stimulated research, aided knowledge exchange about SCC, and organized logistics in a way that facilitated its usage. This aligns with the observations mentioned in Chung et al. [74], Yu et al. [75], Braunerhjelm et al. [76], and Papa et al. [77]. Thus, the presence of enthusiasts, active early adopters, and interested people in key positions in construction companies may be considered a facilitator for broader SCC use.

This study includes a majority of male interviewees (only one woman), which could be seen as a limitation. However, this mirrors the gender distribution in the Swedish construction sector. There are efforts from universities and vocational school to increase the number of female students, and hopefully there will be a better gender-balance in the future.

Many studies confirm that public opinion as well as government support influence the adoption process of innovation [40,78–80]. There is a well-observed attitude trend in Sweden, wherein the focus is moving from interest and care for the workplace environment to a higher awareness of global environmental issues instead. Work environment considerations are not included in education programs' requirements and, notably, SCC is an elective topic. The laws and traditions of the Swedish construction industry delegate final decisions on material choices to entrepreneurs. This accounts for the avoidance of SCC and the implementation of alternative (and often less effective) ways to lower exposures to vibration and noise (such as shorter passes or more frequent worker rotation). In summary, SCC usage is not encouraged either top–down or bottom–up.

8. Conclusions

This qualitative interview study identified barriers and facilitators of SCC use. The results also describe the use of SCC and the work environment regarding during concrete casting through the views, opinions, and knowledge of 24 representatives from several levels of the construction industry in Sweden, including university teachers, construction engineers, contractors, design engineers, and work environment managers.

This study identified barriers and facilitators of the adoption of SCC. The main barriers are a lack of interest in SCC usage among practitioners and a low level of knowledge about SCC across all levels of the construction industry, including educational institutions. These barriers hinder the broader adoption of SCC. The construction engineers had the lowest level of knowledge about SCC, while the contractors had the highest level of knowledge and experience with SCC. Another barrier that was expressed by the interviewees was the technical properties of SCC, which were perceived to be ambiguous. The following were mentioned as problematic: the unstable recipe, specific nuances in the casting process, lower fire resistance, and environmental issues. Further, small-sized companies with small revenues, a lack of knowledge, reduced experience sharing with other actors in science and industry, and a focus on quick short-term profit were all identified as barriers.

A facilitator to broader SCC adoption is the presence of key persons in companies that can aid in the propagation of knowledge about SCC and work at improving it. This study observed that SCC is mainly used by large companies that have SCC enthusiasts in place who cooperate with other branches of industry and science, invent and develop their own recipes, refine and improve logistics when using SCC, and generally have a more holistic approach and a long-term perspective on income.

With regard to the opinions and views of the interviewees, the concept of a good work environment was almost exclusively associated with accident prevention and general safety measures at work, and not with work-related illnesses and an awareness of the long-term health risks connected with concrete casting. The means of achieving a good work environment were presented in terms of spending on safety equipment, and less in terms of keeping sick leave at a minimum. Improvements in the work environment were not stated as a means of achieving efficiency, and a good work environment was not named as a work priority either. The vibration-free property of SCC was never listed as a primary reason for its usage in a project, but it was seen as a secondary benefit, and work environmental considerations have little influence on the choice between regular concrete or SCC.

This study provides insights into the reasons for the low usage of SCC and thereby points to different ways of increasing it. It uses an HTO-based model for identifying barriers and facilitators of a broader usage of SCC. The results can help both the construction industry and the scientific community to better understand both the process driving SCC adoption in construction firms and how to improve it. The data utilized in this study are from Sweden, but the revealed reasons for low usage of SCC may however be similar in other countries, as the construction industry is generally known to be conservative. However, this is an important field worldwide, and knowledge about long-term health risks, the adoption of SCC, and connected issues should be examined at a larger scale in different countries.

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References

1. OECD Database—Gross Domestic Expenditure on R&D (GERD) at National and Regional Level. 2022. Available online: https://ec.europa.eu/eurostat/databrowser/view/rd_e_gerdtot/default/table?lang=en (accessed on 31 March 2024).
2. European Agency for Safety and Health at Work (EU-OSHA). Annual Activity Report 2017. 2017. Available online: https://www.europarl.europa.eu/cmsdata/149260/Annual%20Activity%20Report%202017.pdf (accessed on 1 March 2024).
3. Rwamamara, R.; Simonsson, P. Self-Compacting Concrete Use for Construction Work Environment Sustainability. *J. Civ. Eng. Manag.* **2012**, *18*, 724–734. [CrossRef]
4. Swedish Construction Federation. BCA, Byggindustrins Centrala Arbetsmiljöråd. Arbetsskador Inom Byggindustrin (Report No. BCA 2022:1). 2022. Available online: https://byggforetagen.se/app/uploads/2022/07/Arbetsskador-inom-byggindustrin-2021-.pdf (accessed on 23 January 2022).
5. Afa Försäkring—An Insurance Organisation Owned by Sweden's Labour Market Parties. Allvarliga Arbetsskador Och Långvarig Sjukfrånvaro. 2022. Available online: https://www.afaforsakring.se/globalassets/forebyggande/analys-och-statistik/rapporter/2022/f7060_huvudrapport-statistik-2022.pdf (accessed on 15 May 2023).
6. Swedish Concrete Association. Vägledning för val av exponeringsklass enligt SS-EN 206-1. *Sven. Betongföreningen Betongrapport* **2002**, *11*, 1–36.
7. Lee, Y.-C.; Hong, X.; Man, S.S. Prevalence and Associated Factors of Work-Related Musculoskeletal Disorders Symptoms among Construction Workers: A Cross-Sectional Study in South China. *Int. J. Environ. Res. Public Health* **2023**, *20*, 4653. [CrossRef]
8. Suter, A.H. Construction Noise: Exposure, Effects, and the Potential for Remediation; a Review and Analysis. *AIHA J.* **2002**, *63*, 768–789. [CrossRef]
9. Swedish Work Environment Authority. Hörsel och Hörselskador i Arbetslivet: Kunskapssammanställning Rapport (Report No. 2013:2). Available online: https://www.av.se/globalassets/filer/publikationer/kunskapssammanstallningar/horsel-och-horselskador-i-arbetslivet-kunskapssammanstallning-kunskapssammanstallningar-rap-2013-2.pdf (accessed on 4 March 2024).
10. Lewkowski, K.; Li, I.W.; Fritschi, L.; Williams, W.; Heyworth, J.S. A Systematic Review of Full-Shift, Noise Exposure Levels among Construction Workers: Are We Improving? *Ann. Work Expo. Health* **2018**, *62*, 771–782. [CrossRef]
11. Simonsson, P.; Rwamamara, R. Ergonomic exposures from the usage of conventional and self-compacting concrete. In *Annual Conference of the International Group for Lean Construction: 13/07/2009-19/07/2009*; National Pingtung University of Science and Technology: Pingtung, Taiwan, 2009; pp. 313–322.
12. Mikhaltchouk, I.; Kraft, L.; Nilsson, T.; Forsman, M. A Comparative Study Regarding Noise and Hand-Arm Vibration Exposure during Self-Compacting and Conventional Concrete Casting. In Proceedings of the 51st NES Conference, Uppsala, Sweden, 23–25 October 2022; Lindblom, J., Österman, C., Eds.; Uppsala University and EHSS: Uppsala, Sweden, 2022.
13. Oh, J. Evaluation of Hand-Arm Vibration (HAV) Exposure Levels among Grounds Maintenance Workers: An Observational Human Exposure Measurement Study. *Health Sci. Rep.* **2022**, *5*, e731. [CrossRef]
14. Lawson, I.; Burke, F.; McGeoch, K.; Nilsson, T.; Proud, G. Hand–Arm Vibration Syndrome. In *Hunter's Diseases of Occupations, Tenth Edition*; CRC Press: Boca Raton, FL, USA, 2010; pp. 489–512.
15. EU-OSHA, European Agency for Safety and Health at Work. Directive 2002/44/EC—Vibration. 2021. Available online: https://osha.europa.eu/en/legislation/directives/19 (accessed on 17 August 2023).
16. Nilsson, T.; Wahlström, J.; Burström, L. Hand-Arm Vibration and the Risk of Vascular and Neurological Diseases—A Systematic Review and Meta-Analysis. *PLoS ONE* **2017**, *12*, e0180795. [CrossRef]
17. Cussigh, F. SCC in Practice: Opportunities and Bottlenecks. In *5th International RILEM Symposium on Self-Compacting Concrete*; RILEM Publications SARL: Bagneux, France, 2017.
18. Simonsson, P. Buildability of Concrete Structures—Processes, Methods and Material. Ph.D. Thesis, Division of Structural Engineering of Luleå, University of Technology, Luleå, Sweden, 2011.
19. Betonginitiativet. Färdplan för Klimatneutral Betong (Report No. FFS-Betonginitiativet-2023). 2003. Available online: https://betonginitiativet.se/uppgraderad-fardplan-klimatneutral-betong-2030/ (accessed on 17 August 2023).
20. Campos, H.F.; Klein, N.S.; Marques Filho, J.; Bianchini, M. Low-Cement High-Strength Concrete with Partial Replacement of Portland Cement with Stone Powder and Silica Fume Designed by Particle Packing Optimization. *J. Clean. Prod.* **2020**, *261*, 121228. [CrossRef]
21. European Ready Mixed Concrete Association (ERMCO). Ready-Mixed Concrete Industry Statistics. 2019. Available online: https://ermco.eu/wp-content/uploads/2022/10/ERMCO-Statistics-Report-2019-July-2020-FINAL.pdf (accessed on 1 March 2024).
22. SCA, Swedish Concrete Association. Självkompakterande Betong: Rekommendationer för Användning. 2020. Available online: https://vpp.sbuf.se/Public/Documents/ProjectDocuments/dcfa4256-9293-4730-b1f0-18b1ee243cd5/FinalReport/SBUF%2013058%20Slutrapport%20-%20Revidering%20av%20rapport%20om%20SKB.pdf (accessed on 17 March 2022).
23. Lundqvist, K.; Björkman, T.; Docherty, P.; Hill, J.; Ullmark, P. Företagsperspektivet—En Analys Av Företagens Behov Av Kunskap Om Samspelet Mellan Affärsidéer, Människa, Teknik, Organisation. 1997. Available online: https://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-24409 (accessed on 1 March 2024).
24. Mention, A.-L. Co-Operation and Co-Opetition as Open Innovation Practices in the Service Sector: Which Influence on Innovation Novelty? *Technovation* **2011**, *31*, 44–53. [CrossRef]

25. Steele, J.; Murray, M. Creating, Supporting and Sustaining a Culture of Innovation. *Eng. Constr. Archit. Manage.* **2004**, *11*, 316–322. [CrossRef]
26. OECD, Organization for Economic Co-Operation and Development. Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data. 2005. Available online: https://www.conicyt.cl/wp-content/uploads/2014/07/Manual-de-Oslo.pdf (accessed on 25 May 2022).
27. Seaden, G.; Manseau, A. Public Policy and Construction Innovation. *Build. Res. Inf.* **2001**, *29*, 182–196. [CrossRef]
28. Dulaimi, M.F.; Nepal, M.P.; Park, M. A Hierarchical Structural Model of Assessing Innovation and Project Performance. *Constr. Manage. Econ.* **2005**, *23*, 565–577. [CrossRef]
29. Bygballe, L.E.; Ingemansson, M. The Logic of Innovation in Construction. *Ind. Mark. Manag.* **2014**, *43*, 512–524. [CrossRef]
30. Ozorhon, B.; Oral, K. Drivers of Innovation in Construction Projects. *J. Constr. Eng. Manag.* **2017**, *143*, 04016118. [CrossRef]
31. Liu, G.; Li, K.; Zhao, D.; Mao, C. Business Model Innovation and Its Drivers in the Chinese Construction Industry during the Shift to Modular Prefabrication. *J. Manage. Eng.* **2017**, *33*, 04016051. [CrossRef]
32. Bamigboye, G.O.; Davies, I.; Nwanko, C.; Michaels, T.; Adeyemi, G.; Ozuor, O. Innovation in construction materials—A review. In *IOP Conference Series: Materials Science and Engineering*; IOP Publishing: Bristol, UK, 2019; Volume 640, p. 012070.
33. Timchuk, O.G.; Nikityuk, L.G.; Bakhtairova, E.A. Integration of innovations in the construction industry. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, UK, 2021; Volume 751, p. 012181.
34. Samarasinghe, D.A.S.; Wood, E. Innovative digital technologies. In *Handbook of Research on Driving Transformational Change in the Digital Built Environment*; IGI Global: Hershey, PA, USA, 2021; pp. 142–163.
35. Xue, X.; Zhang, R.; Yang, R.; Dai, J. Innovation in Construction: A Critical Review and Future Research. *Int. J. Innov. Sci.* **2014**, *6*, 111–126. [CrossRef]
36. Meng, X.; Brown, A. Innovation in Construction Firms of Different Sizes: Drivers and Strategies. *Eng. Constr. Archit. Manag.* **2018**, *25*, 1210–1225. [CrossRef]
37. Noktehdan, M.; Shahbazpour, M.; Wilkinson, S. Driving Innovative Thinking in the New Zealand Construction Industry. *Buildings* **2015**, *5*, 297–309. [CrossRef]
38. Miozzo, M.; Dewick, P. Building Competitive Advantage: Innovation and Corporate Governance in European Construction. *Res. Policy* **2002**, *31*, 989–1008. [CrossRef]
39. Opstad, L.; Valenta, R. Profit Rate and Profit Persistence in the Norwegian Construction Industry—A Sector with Different Segments, Strong Competition and Many Small Companies. *Eurasian J. Econ. Financ.* **2023**, *11*, 52–61. [CrossRef]
40. Chundakkadan, R.; Sasidharan, S. Financial Constraints, Government Support, and Firm Innovation: Empirical Evidence from Developing Economies. *Innov. Dev.* **2020**, *10*, 279–301. [CrossRef]
41. Teräväinen, V.J.; Junnonen, J.-M. The Promoters and the Barriers for Organizational Culture Change in a Finnish Construction Company. *Constr. Innov.* **2019**, *19*, 672–688. [CrossRef]
42. Isaksson, A.; Linderoth, H. Environmental Considerations in the Swedish Building and Construction Industry: The Role of Costs, Institutional Setting, and Information. *J. Hous. Built Environ.* **2018**, *33*, 615–632. [CrossRef]
43. Ozorhorn, B.; Abbott, C.; Aouad, G. Integration and Leadership as Enablers of Innovation in Construction: A Case Study. *J. Manag. Eng.* **2014**, *30*, 256–263. [CrossRef]
44. Ingemansson Havenvid, M.; Hulthén, K.; Linné, Å.; Sundquist, V. Renewal in Construction Projects: Tracing Effects of Client Requirements. *Constr. Manag. Econ.* **2016**, *34*, 790–807. [CrossRef]
45. Lindblad, H.; Karrbom Gustavsson, T. Public Clients Ability to Drive Industry Change: The Case of Implementing BIM. *Constr. Manage. Econ.* **2021**, *39*, 21–35. [CrossRef]
46. De Vergardefabriek. Available online: https://cybe.eu/cases/de-vergaderfabriek/ (accessed on 1 March 2024).
47. Moini, R.; Baghaie, A.; Rodriguez, F.B.; Zavattieri, P.D.; Youngblood, J.P.; Olek, J. Quantitative Microstructural Investigation of 3D-Printed and Cast Cement Pastes Using Micro-Computed Tomography and Image Analysis. *Cem. Concr. Res.* **2021**, *147*, 106493. [CrossRef]
48. Lai, X.; Liu, J.; Shi, Q.; Georgiev, G.; Wu, G. Driving Forces for Low Carbon Technology Innovation in the Building Industry: A Critical Review. *Renew. Sustain. Energy Rev.* **2017**, *74*, 299–315. [CrossRef]
49. Ercan, T. New Three-Part Model of Innovation Activity in Construction Companies. *J. Constr. Eng. Manag.* **2019**, *145*, 04019022. [CrossRef]
50. Gök, O.; Peker, S. Understanding the Links among Innovation Performance, Market Performance and Financial Performance. *Rev. Manag. Sci.* **2017**, *11*, 605–631. [CrossRef]
51. Dulaimi, M.F.; Ling, F.Y.Y.; Ofori, G.; Silva, N.D. Enhancing Integration and Innovation in Construction. *Build. Res. Inf.* **2002**, *30*, 237–247. [CrossRef]
52. Blayse, A.M.; Manley, K. Key Influences on Construction Innovation. *Constr. Innov.* **2004**, *4*, 143–154. [CrossRef]
53. Vnoučková, L.; Urbancová, H. Setting Organisational Culture to Develop Potential and Innovativeness. *Qual. Innov. Prosper.* **2020**, *24*, 54. [CrossRef]
54. Lijauco, F.; Gajendran, T.; Brewer, G.; Rasoolimanesh, S.M. Impacts of Culture on Innovation Propensity in Small to Medium Enterprises in Construction. *J. Constr. Eng. Manag.* **2020**, *146*, 04019116. [CrossRef]
55. Chai, D.S.; Song, J.H.; You, Y.M. Psychological Ownership and Openness to Change: The Mediating Effects of Work Engagement, and Knowledge Creation. *Perform. Improv. Q.* **2020**, *33*, 305–326. [CrossRef]

56. Kaplan, B.; Maxwell, J.A. Qualitative Research Methods for Evaluating Computer Information Systems. In *Health Informatics*; Springer: New York, NY, USA, 2006; pp. 30–55.
57. Bryman, A. *Samhällsvetenskapliga Metoder*, 3rd ed.; Liber: Stockholm, Sweden, 2018.
58. Graneheim, U.H.; Lundman, B. Qualitative Content Analysis in Nursing Research: Concepts, Procedures and Measures to Achieve Trustworthiness. *Nurse Educ. Today* **2004**, *24*, 105–112. [CrossRef]
59. Slovic, P. Understanding Perceived Risk: 1978–2015. *Environment* **2016**, *58*, 25–29. [CrossRef]
60. Village, J.; Ostry, A. Assessing Attitudes, Beliefs and Readiness for Musculoskeletal Injury Prevention in the Construction Industry. *Appl. Ergon.* **2010**, *41*, 771–778. [CrossRef]
61. Swedish Work Environment Authority. Hälsorelaterad Arbetsmiljöövervakning: Kunskapssammanställning (Report No. 2014:1). 2014. Available online: https://www.av.se/globalassets/filer/publikationer/kunskapssammanstallningar/halsorelaterad-arbetsmiljoovervakning-kunskapssammanstallningar-rap-2014-1.pdf (accessed on 20 January 2022).
62. Törner, M.; Pousette, A. Safety in Construction—A Comprehensive Description of the Characteristics of High Safety Standards in Construction Work, from the Combined Perspective of Supervisors and Experienced Workers. *J. Saf. Res.* **2009**, *6*, 399–409. [CrossRef]
63. Breuer, W.; Knetsch, A.; Salzmann, A.J. Short-Termist Investment and Time Preferences. *SSRN Electron. J.* **2020**. [CrossRef]
64. Pordea, D.; David, D.; Mateș, D. The Impact of Operating Cash Flow and Current Ratio on the Profitability in Construction Industry. *Stud. Univ. Vasile Goldis Arad—Econ. Ser.* **2020**, *30*, 22–32. [CrossRef]
65. Yanovski, B.; Lessmann, K.; Tahri, I. The Link between Short-Termism and Risk: Barriers to Investment in Long-Term Projects. 2020. Available online: https://ssrn.com/abstract=3550501 (accessed on 10 April 2024).
66. Barykina, Y. Risks of long-term leasing transactions for construction industry development. In *IOP Conference Series: Materials Science and Engineering*; IOP Publishing: Bristol, UK, 2019; Volume 667, p. 012011. [CrossRef]
67. Simonsson, P.; Emborg, M. Industrialized Construction: Benefits Using SCC in Cast in-Situ Construction. *Nord. Concr. Res.* **2009**, *39*, 33–52.
68. Dearing, J.W.; Cox, J.G. Diffusion of Innovations Theory, Principles, and Practice. *Health Aff.* **2018**, *37*, 183–190. [CrossRef]
69. Boström, L.; Robert, J. *Self-Compacting Concrete Exposed to Fire*; Report 2008:53; Fire Technology SP: Borås, Sweden, 2008.
70. Persson, B. Fire Resistance of Self-Compacting Concrete, SCC. *Mater. Struct.* **2004**, *37*, 575–584. [CrossRef]
71. Rogers, E.M. *Diffusion of Innovations*; Free Press of Glencoe: New York, NY, USA, 1983.
72. Skovgaard, T.; Vestergaard Nielsen, J. The Role of Implementation Leadership in Driving Organizational Innovation–Revisiting a Classic. *Coll. Antropol.* **2023**, *47*, 75–80. [CrossRef]
73. Valtonen, A.; Kimpimäki, J.P.; Malacina, I. From ideas to innovations: The role of individuals in idea implementation. *Creat. Innov. Manag.* **2023**, *32*, 636–658. [CrossRef]
74. Chung, E.; Lee, K. The Necessity of Anterior Knowledge Exchange Activities for Technological Collaboration and Innovation Performance Improvement. *Int. J. Technol. Manag.* **2020**, *82*, 66. [CrossRef]
75. Yu, Q.; Aslam, S.; Murad, M.; Jiatong, W.; Syed, N. The impact of knowledge management process and intellectual capital on entrepreneurial orientation and innovation. *Front. Psychol.* **2022**, *13*, 772668. [CrossRef]
76. Braunerhjelm, P.; Ding, D.; Thulin, P. Labour Market Mobility, Knowledge Diffusion and Innovation. *Eur. Econ. Rev.* **2020**, *123*, 103386. [CrossRef]
77. Papa, A.; Chierici, R.; Ballestra, L.V.; Meissner, D.; Orhan, M.A. Harvesting reflective knowledge exchange for inbound open innovation in complex collaborative networks: An empirical verification in Europe. *J. Knowl. Manag.* **2020**, *25*, 669–692. [CrossRef]
78. Zhang, J.; Xie, H.; Schmidt, K.; Li, H. A New Systematic Approach to Vulnerability Assessment of Innovation Capability of Construction Enterprises. *Sustainability* **2016**, *8*, 17. [CrossRef]
79. Czarnitzki, D.; Delanote, J. Incorporating Innovation Subsidies in the CDM Framework: Empirical Evidence from Belgium. *Econ. Innov. New Technol.* **2017**, *26*, 78–92. [CrossRef]
80. Wang, P.; Lin, X.; Li, S. Evaluation of government–supported provincial innovation competitiveness—Evidence from China. *Growth Chang.* **2019**, *50*, 587–608. [CrossRef]