Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 9, No. 01, January, 2023

Important Criteria for Swedish Construction Companies to Choose Environmentally Friendly Concrete

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Received 06 September 2022; Revised 17 November 2022; Accepted 06 December 2022; Published 01 January 2023

Abstract

Today, ordinary Portland cement-based concrete is one of the most important building materials and is widely used in new building construction, which is an environmental problem, as cement production accounts for 5%-8% of the world's carbon dioxide emissions. Thus, the need for using more environmentally friendly concrete (EFC) is growing. However, it is stated that Swedish construction companies are reluctant to change and adopt new construction methods and materials. This research aims to map the important criteria for Swedish construction companies to choose EFC for use in their projects. The study is carried out based on a literature study and a questionnaire survey. The questionnaire is designed considering the significant criteria of EFC derived from the literature study. The respondents from the Swedish construction companies were asked to rate these various criteria. The collected results are presented with bar graphs. The results show that the highest valued criterion by the respondents for the use of EFC in the projects is its long-term properties, while the lowest one is the possibility of introducing a specific ceiling for greenhouse gas emissions by the companies.

Keywords: Environmentally Friendly Concrete; Ordinary Portland Cement-Based Concrete; Long-Term Properties; Strength; Carbon Dioxide; Greenhouse Gas Emissions.

1. Introduction

Ordinary Portland Cement-Based Concrete (OCBC) is extensively utilised in single-family houses and large buildings. OCBC is by far the most common building material in the world [1]. There are high demands on the technical properties of OCBC, as it is primarily used for load bearing elements and is expected to be able to withstand several different stresses imposed on the elements. Therefore, lack of the appropriate function of concrete can result in serious consequences, both financially and for human safety. The cement used in OCBC causes high carbon dioxide emissions during its production [2, 3]. This source of carbon emissions contributes to approximately 5%-8% of the total anthropogenic carbon dioxide emissions [4].

Since carbon dioxide emissions have the greatest impact on the greenhouse effect, modern society works to limit these emissions. As stated in Sweden's contribution to the European Union's (EU) climate goals, the construction sector currently contributes significantly to Sweden's greenhouse gas (GHG) emissions [2] and aspires to reduce emissions to reach a cleaner future. The EU hopes to achieve climate neutrality by 2050, meaning that all the continent's countries are going to have net-zero GHG emissions. The EU wants to make a shift that is both urgent and important for the planet's future. According to Sweden's climate target, the country must have reached net-zero GHG emissions by 2045. In accordance with the net-zero target, Sweden's emissions in 2045 must be at least 85% lower than they were in 1990. For the remaining emissions, there are supplementary measures as well.

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http://dx.doi.org/10.28991/CEJ-2023-09-01-015

A 10%–30% portion of the overall environmental effect of Swedish production is attributable to the Swedish construction sector. The import of building materials further contributes to the sector's emissions from other countries. This point places a heavy burden on the construction sector, which also aspires to meet housing demand by 2025, when it comes to selecting environmentally friendly materials. To reach the net-zero objective, the cement industry must significantly reduce, or better yet eliminate, the carbon dioxide impact that results from cement production. This lofty objective indicates that, to achieve it, the law must be modified to conform to the established environmental standards.

The construction of numerous infrastructure projects and homes, as well as achieving the aim of a climate-neutral Sweden, are two significant problems for the Swedish construction sector. Obtaining a commercially usable emission-reduced cement would offer an efficient method for carbon dioxide capture and storage [5]. Environmentally friendly concrete (EFC) is a collective name for concrete that, in various ways, has less climate impact than OCBC, for example by replacing some of the cement by by-products from industries. The most common variant is that part of the clinker, the bonding material that makes up about 90% of the cement, is replaced by fly ash from coal-fired heating and power plants [6], but the used by-products can also be recycled concrete that acts as aggregate [7]. Using EFC is a considerable step towards achieving Sweden's environmental quality goals, limited climate impact in particular, in accordance with the UN Agenda 2030 [8].

2. Literature Review

Some studies have been conducted on EFC, i.e., green concrete. Duxson et al. [9] examined the role of inorganic polymer technology in the development of green concrete. By utilising a combination of natural fine aggregates, short and fine steel fibres, and composite mineral admixtures, Yunsheng et al. [10] created a green reactive powder concrete with a compressive strength of 200 MPa. Design of green concrete made of plant-derived aggregates and a pumice-lime binder was done by Nozahic et al. [11]. Fly ash may be used in concrete pavement instead of cement, according to the research by Ondova et al. [12].

Müller et al. [13] suggested approaches to assess and lessen concrete's environmental impact as well as ways to improve its performance. Sheen et al. [14] published findings of a study on self-compacting concrete built with stainless steel decreasing slag. Golewski [15] evaluated the improvement of fracture toughness of green concrete as a result of adding coal fly ash. Durability of ultra-high-performance Polyethylene Terephthalate green concrete was assessed by Alani et al. [16]. Li et al. [17] examined the substitution of up to 40% of the highly reactive pozzolanic diatomaceous earth with ample deposit for Portland cement in mortar and concrete mixes. Li et al. [18] studied the mechanical properties and hydration of green concrete with ground granulated blast-furnace slag activated by desulfurization gypsum and electric arc furnace reducing slag. Khan et al. [19] designed green concrete by partially replacing cement by fly ash.

Elaqra et al. [20] evaluated the effects of varying the water-to-cement ratios and glass powder soaking time on the activation of the pozzolanic reactivity and the mechanical properties of green concrete. The feasibility of developing a green concrete product from municipal solid wastes incineration residues was examined by Zhang et al. [21]. Bahrami et al. [22] investigated how aware and active the Swedish building and real estate sector is in climate-smart concrete through a survey and comparison of environmental product declarations. The potential of EFC to reduce the environmental impact of OCBC through different ways has been resulted in most of the mentioned studies, however, despite this valuable potential and the importance of reducing the climate impact of OCBC in line with achieving the Sweden's climate target, the Swedish construction industry has not widely used EFC yet, therefore, the purpose of this research is to explore important criteria for the Swedish construction companies to use EFC instead of OCBC in their projects. It is said that the industry is generally reluctant to make changes with a lack of willingness to take knowledge or adjust. The investigations of the current research are further done by basing a questionnaire survey from the literature study.

3. Method

A literature study and a questionnaire survey were carried out in this research to find out what criteria the Swedish construction companies could consider important to choose EFC for their use. Figure 1 presents the flowchart of current research workflow.

3.1. Literature Study

The purposes of studying the scientific articles mentioned in Sections 1, 2, and 3 of this article are threefold: (1) to collect in-depth scientific information on EFC's technical properties, climate impact, advantages, and disadvantages in comparison with OCBC, and challenges that EFC faces both technically and market wise, (2) to get an overall picture of the research front because it is necessary to know what knowledge already exists in order to be able to contribute to the knowledge development, and (3) to provide a scientific basis for the arguments that guide the choice of EFC.

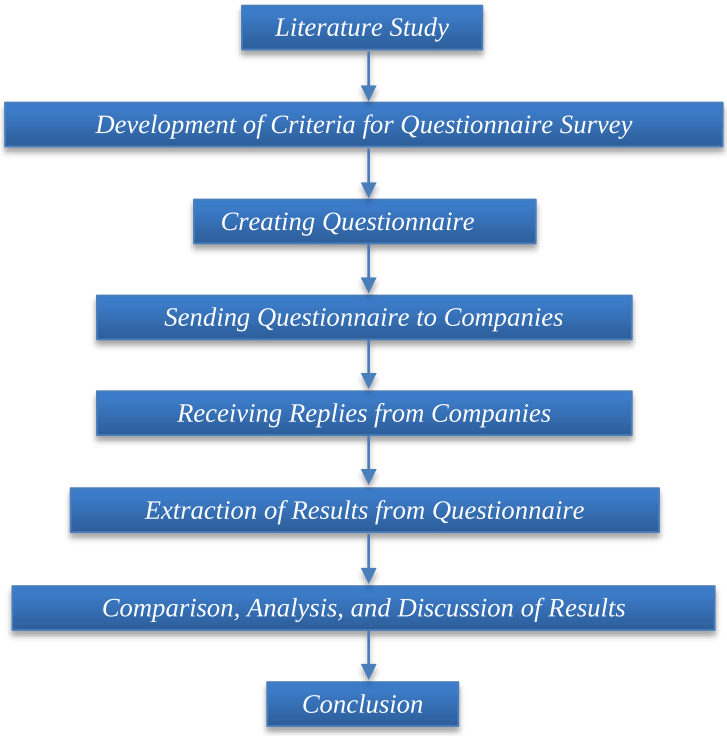

Figure 1. Flowchart of research workflow

Development of Criteria for Survey

The scientific articles were analysed to get inspiration for the choice of criteria, and to provide a scientific basis for the questionnaire's questions. The criteria were chosen independently from the results of the analysed research. In addition to these research-based criteria, additional criteria were chosen, which were not based on the research but were reasoned to be self-evident for this issue. An example of this, is the purchase price; although there is no scientific basis to choose this criterion, it could be considered as an obvious part. The survey included 18 questions. At the end of the survey, the respondents were given the opportunity to fill in a box with free text where they were asked to add criteria that they might think were not included in the survey.

The considered criteria in the survey are mentioned below:

- Strength: Several research works tested the strength of different compositions of EFC which were compared with OCBC, and in all the cases, EFC was found to achieve equivalent or even higher strength than OCBC [1, 7, 23-25]. In addition, in two of these cases, EFC achieved higher strength faster than OCBC [23, 24].
- Long-term properties (e.g., shrinkage, creep, cracking, and fatigue failure) and durability (resistance to moisture, heat, and corrosion): Liew et al. [23] found that there were several obstacles to EFC being able to be implemented in the market, where for example, knowledge of the long-term properties and durability of EFC during periods over 20 years were some of them. A study examined how porous concrete, mainly for parking lots and sidewalks, was affected by replacing some of cement by fly ash. It demonstrated better result than OCBC [26].
- Casting properties: In the tests done by Liew et al. [23] on the strength properties of EFC, they also found that EFC could achieve good casting properties.
- Applicability in harsh environments (e.g., salt water): The effect of chloride diffusion on reinforced EFC having fly ash was compared with OCBC by Nath et al. [27]. The results indicated that EFC had better protection against chloride penetration and could thus lead to longer working life. In addition, this meant that the concrete cover layer could be thinned for EFC.
- Good access to prefabricated elements: Marinković et al. [7] compared five different mixes of concrete with the aim of being used for prefabricated elements. They mentioned that their alkali activated fly ash concrete needed to burn under elevated temperatures, and thus was not suitable for in-situ use, which raised the issue of access to prefabricated elements.
- Appearance of finished surface: Concrete with fly ash may have a lower brightness [28], which may be less desirable in some projects.
- Purchase price: According to Karlsson [29], the project in which Skanska's EFC was used, did not involve any increase in costs.

- Existence of standards for use: Liew et al. [23] explained that standards, together with laws and regulations, can promote the use of EFC. As early as 2013, when the General Material and Work Description (AMA) allowed the use of Portland fly ash cement in Sweden, a new EFC began to be developed to meet the Swedish Transport Administration's requirements for concrete [29], but its implementation has been delayed may be due to the point that large construction projects are planned well in advance and use earlier versions of AMA.
- Introducing a specific ceiling for GHG emissions of companies: Imbabi et al. [5] investigated different types of EFC and compared them with OCBC to provide suggestions on how EFC should be developed and implemented for a market dominated by OCBC. They discussed the introduction of a carbon dioxide tax. Such a tax was implemented in the UK in 2013, but the lack of a commercially applicable EFC would only lead to higher prices for OCBC. Makul [25] stated that the challenges facing the implementation of EFC are the lack of political guidelines on carbon dioxide emissions in many countries and the fact that EFC does not yet have a significant place in the market.
- Subsidy: Financial incentives for companies, universities, and research institutes can contribute to increased research and application of EFC in their projects [23].
- Possibility of utilising existing mechanical equipment: Mahmoud et al. [24] found from their tests on the strength of EFC that they could use the same tools and equipment to cast their variant of EFC as OCBC. In accordance with Karlsson [29], Skanska's bridge construction in Veddesta did not involve any other ways of working.
- Significance of research results: The literature study provided many positive properties of EFC, both in terms of its technical properties and climate impact. All the studies showed a lower climate impact of EFC compared with OCBC.
- Field studies and that other construction projects have used EFC with positive results: The existing knowledge about EFC comes out of laboratory tests where concrete is tested under controlled conditions. Liew et al. [23] suggested that EFC needs to be tested in the field to generate the long-term knowledge that changes of standard require.
- Access to education on technical properties and lower climate impact of EFC: Are internal or external educations available for companies on technical properties and lower climate impact of EFC? Liew et al. [23] mentioned that an effective way to spread the use of EFC is to educate people in the construction industry in order to increase their knowledge about many benefits of EFC.

3.2. Survey

A questionnaire survey was chosen since the survey questions can best be answered with a wide study, i.e., a survey with several survey objects (respondents) and a few variables (criteria).

Structure of Survey

The literature study resulted in the aforementioned criteria to which the respondents would reply how much they agreed with them. The scale for the responses was from one to four (1-4), where one and four corresponded to "do not agree at all" and "agree completely", respectively. The survey was designed in Google Forms under Google Docs. The questionnaire is presented in the Appendix I. A cover letter was attached to the questionnaire, which provided a quick overview of the content of the research. A list of 200 companies related to construction and concrete was compiled, and the questionnaire along with the cover letter was sent to their contact e-mail addresses. Many of the questionnaires were sent to those who, according to the companies' websites, worked as managers and project managers, who were also assumed to be the ones replied to the questionnaire. Finally, 26 companies participated in the questionnaire. Their responses were compiled as bar graphs and are presented and discussed in the following.

4. Results and Discussion

Based on the obtained results from the questionnaire survey, Figure 2 illustrates how the different criteria have been evaluated on a scale of 1-4 in the survey. It can be seen from the figure that the distribution of ones and fours varies greatly between the different criteria. The criterion of "long-term properties" has received the maximum number of fours which demonstrates its extreme importance. Thereafter, strength, durability, existence of standards for use have received the same number of fours, which denotes their importance. Consequently, technical properties of EFC and their related issues are the most important criteria considered by the respondents.

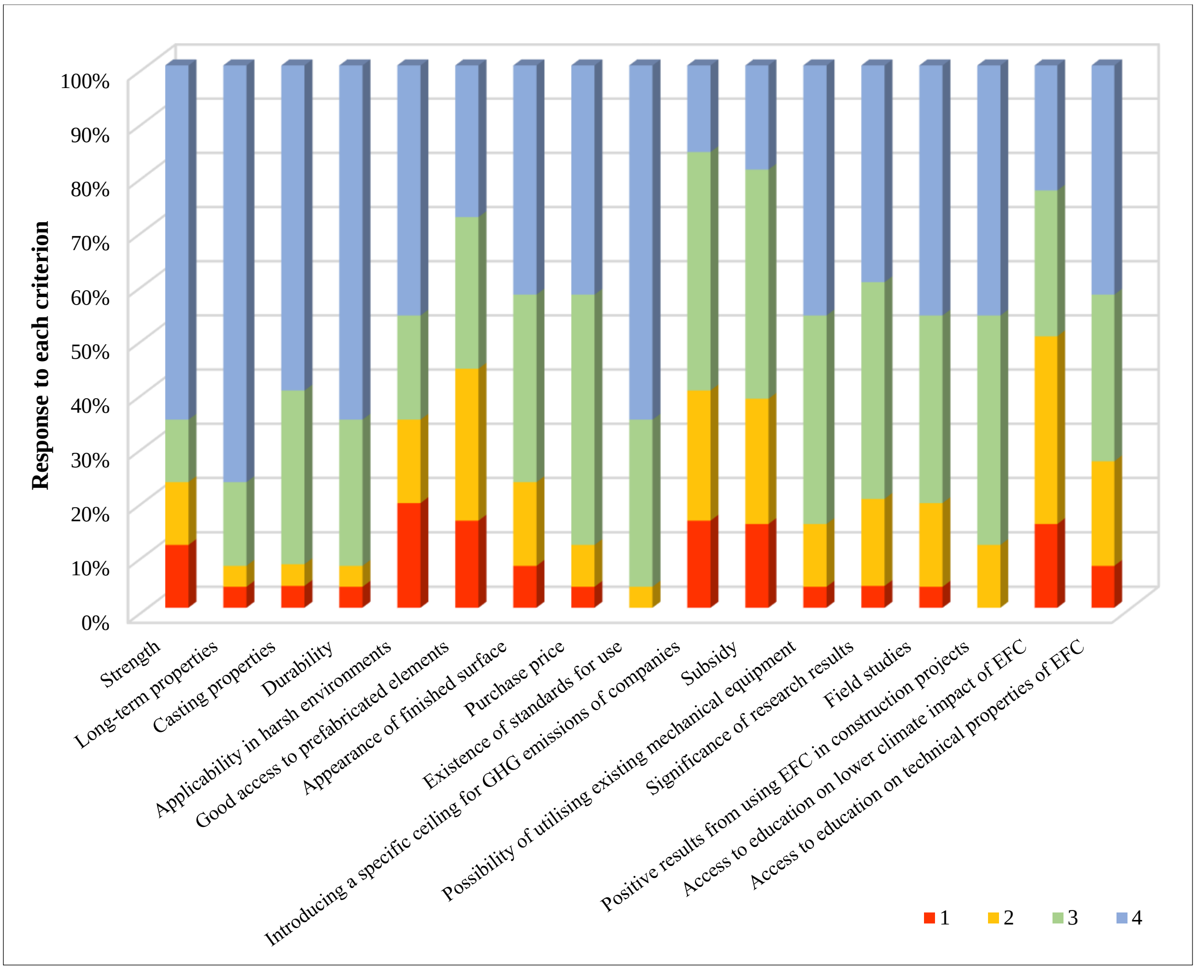

Figure 2. Response to each criterion based on scale 1-4. 1 corresponds to "do not agree at all" and 4 corresponds to "agree completely"

The criterion of obtaining "positive results from using EFC in construction projects" did not get even single one, while the criterion of "good access to prefabricated elements" has a more uniform distribution of scales compared with the other criteria. The criteria of "applicability in harsh environments" and "good access to prefabricated elements" have large proportions of ones and twos, which can be due to the fact that these criteria were perceived as relevant only for a specific target group. Moreover, it was not specified what type of construction project the respondent would refer to, which can also explain the spread.

Figure 3 displays the individual total value for each criterion. The values in the figure were created by taking the numbers 1-4 on each criterion multiplied by the number of votes, and they were then summed. The total value for each criterion should be interpreted as the respondents' attitude towards the significance of the criterion when choosing EFC. As can be seen from Figure 3, the criteria of "access to education on lower climate impact of EFC" and "good access to prefabricated elements" are in the second last place. The low importance of "access to education on lower climate impact of EFC" can be because it is already known that EFC generally has lower climate impact than OCBC or the respondents have chosen it to overlook it in favour of OCBC.

It can be observed from Figure 3 that the differences between the various criteria are relatively small, even though Figure 2 presented a large spread of the responses.

As can be observed from Figure 3, the results indicated that the most important criterion was considered as "long-term properties" of EFC, while the criterion of "introducing a specific ceiling for GHG emissions of companies" was evaluated as the least. The criteria related to technical properties of EFC such as the "long-term properties", "durability", and "casting properties" along with the "existence of standards for use" have achieved high values. Once again, this issue supports the point that technical properties of EFC are the most important criteria for the construction companies. The companies seem to want to know that industry representatives support the use of EFC through standards and previously successful projects. They want to feel safe with the product, to trust its technical properties, and to have support in the form of guidelines for the safe use. However, the criterion of "existence of standards for use" requires wide and deep research investigations, field studies, and experience on EFC which can then create a sense of safety for use. Meanwhile, the criteria concerning the economy and climate, such as "subsidy", "access to education on lower climate impact" and "introducing a specific ceiling for GHG emissions of companies" were assessed with low values.

Thus, it is confirmed that the financial motivation such as subsidy and also restrictions on GHG emissions of companies are not among the greatly important criteria. In addition, the respondents did not consider education on lower climate impact of EFC very necessary, which might be owing to the fact that they are already well aware of its impact.

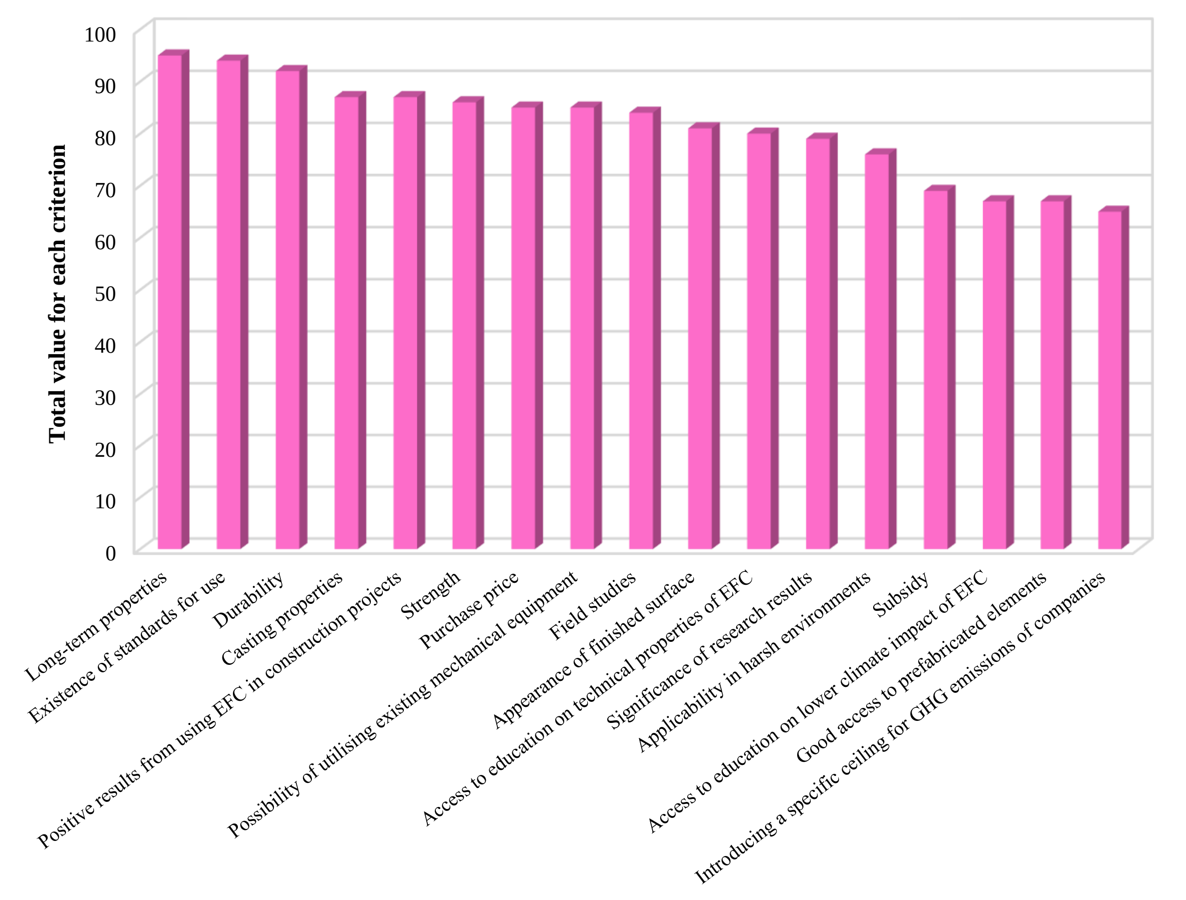

Figure 3. Total value for each criterion

The results illustrated that the difference between the highest and lowest total values is 30% (Figure 3). This can reflect the point that the respondents may use concrete for very various purposes and thus had different requirements for concrete. Had the survey focused on one type of construction activity, for instance, infrastructure or single-family house construction, the total values could have shown some other properties of concrete for this purpose. However, this study intended to provide an overall picture of the construction industry's views, which the current results report.

Figure 4 represents how the total numbers of generated ones, twos, threes, and fours from all the responses are distributed. The numbers of ones-fours from all the questionnaire responses were individually summed up in the figure. It can be seen from the figure that 77% of the respondents' total views on a scale of 1-4 consist of threes and fours, which can imply a generally positive attitude towards the idea of using EFC. The proportion of views in the form of ones and twos had instead indicated a lack of commitment or disinterest from the companies, which can clarify the low percentage of the respondents' disagreement with the questions of the questionnaire.

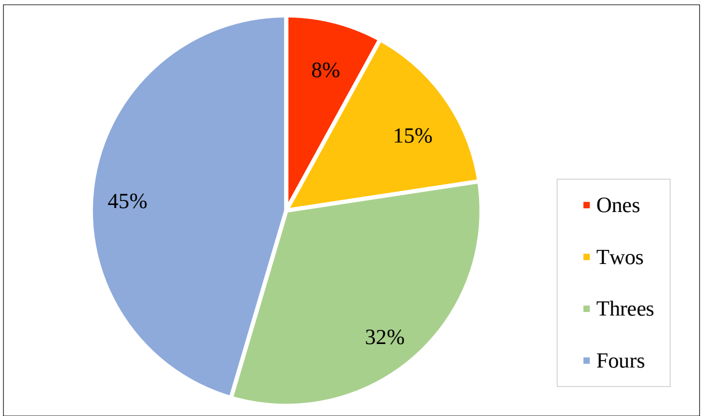

Figure 4. Distribution of total number of ones-fours generated via questionnaire responses. 1 corresponds to "do not agree at all" and 4 corresponds to "agree completely"

At the end of the questionnaire survey, an empty space was provided for free text where the respondents were asked to leave comments or add criteria that they had but were not included in the survey. There were two comments, which contained the same criteria that the respondents wanted to highlight, the drying time of concrete. Also, another respondent commented that the short-term strength of concrete (demolding time) was important. These comments were included in the criterion "casting properties" in this research. In addition, another respondent added that concrete needs to be eco-labelled for use.

In the literature study, the research works done by Teixeira et al. [1], Marinković et al. [7], Liew et al. [23], Mahmoud et al. [24], and Makul [25] demonstrated that EFC has good performance and, in some cases, even better strength than OCBC.

5. Conclusion

This research examined the criteria that the Swedish construction companies consider important to choose EFC for use. The methodology included a literature study and a questionnaire survey. The literature study showed that EFC had good performance and, in some cases, even better strength than OCBC. The questionnaire survey was created and sent to the companies via email, where they were asked to rate criteria for choosing EFC on a scale from one to four, which corresponded to "do not agree at all" and "agree completely", respectively. The survey was composed of 18 questions. Additionally, an empty space was provided for free text at the end of the survey, where the respondents had the opportunity to mention comments or add criteria that were not included in the survey. 26 companies participated in the survey. The collected responses from the survey were compiled and illustrated with bar graphs. The mutual distribution of ones and fours for each criterion was displayed. The total value between the criteria varied slightly, which led to the conclusion that all criteria were perceived to be approximately equally important by the companies. The highest valued criterion for choosing EFC was its "long-term properties" while the lowest one was the possibility of "introducing a specific ceiling for GHG emissions of companies". The total number of threes and fours for all the responses was 77%, which was interpreted as that the respondents had a generally positive attitude towards EFC as a building material. The reluctance of the construction industry to make this change can be based on their great responsibility to produce safe buildings and high-quality requirements. What would overcome this unwillingness to change does not seem to be incentives in the form of subsidies and taxes, but instead, a safe product that can meet the high demands of users, construction companies, and government agencies from concrete. On the other hand, the industry is being rejuvenated, which can lead to new insights and a changed perspective on the environment and housing. Since the criteria of the questionnaire were obtained and developed from scientific articles in the literature study without restricting the studies to any specific regions, the questionnaire has the potential to be used for research on the same topic in other countries than Sweden, too.

6. Declarations

6.1. Author Contributions

Conceptualization, A.B., M.L., L.L.B. and B.E.; methodology, A.B., M.L., L.L.B. and B.E.; validation, A.B., M.L., L.L.B. and B.E.; formal analysis, A.B., M.L., L.L.B. and B.E.; investigation, A.B., M.L., L.L.B. and B.E.; resources, A.B., M.L., L.L.B. and B.E.; writing—original draft preparation, A.B.; writing—review and editing, A.B; project administration, A.B. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

Data sharing is not applicable to this article.

6.3. Funding

The authors received no external financial support for the research, authorship, and/or publication of this article.

6.4. Conflicts of Interest

The authors declare no conflict of interest.

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Appendix I: Questionnaire

In order to transition to use environmentally friendly concrete, the following would be crucial.

Select the option that best aligns with your company's values.

1. Strength.

	1	2	3	4	
Do not agree at all	☐	☐	☐	☐	Agree completely

2. Long-term properties (e.g., shrinkage, creep, cracking, and fatigue failure).

	1	2	3	4	
Do not agree at all	☐	☐	☐	☐	Agree completely

3. Casting properties.

	1	2	3	4	
Do not agree at all	☐	☐	☐	☐	Agree completely

4. Durability (resistance to moisture, heat, and corrosion).

	1	2	3	4	
Do not agree at all	☐	☐	☐	☐	Agree completely

5. Applicability in harsh environments (e.g., saltwater).

	1	2	3	4	
Do not agree at all	☐	☐	☐	☐	Agree completely

6. Good access to prefabricated elements.

	1	2	3	4	
Do not agree at all	☐	☐	☐	☐	Agree completely

7. Appearance of finished surface.

	1	2	3	4	
Do not agree at all	☐	☐	☐	☐	Agree completely

8. Purchase price.

	1	2	3	4	
Do not agree at all	☐	☐	☐	☐	Agree completely

9. Existence of standards for use.

	1	2	3	4	
Do not agree at all	☐	☐	☐	☐	Agree completely

10. Introducing a specific ceiling for greenhouse gas emissions of companies.

	1	2	3	4	
Do not agree at all	☐	☐	☐	☐	Agree completely

11. Subsidy.

	1	2	3	4	
Do not agree at all	☐	☐	☐	☐	Agree completely

12. Possibility of utilising existing mechanical equipment.

	1	2	3	4	
Do not agree at all	☐	☐	☐	☐	Agree completely

13. Significance of research results.

	1	2	3	4	
Do not agree at all	☐	☐	☐	☐	Agree completely

14. Field studies.

	1	2	3	4	
Do not agree at all	☐	☐	☐	☐	Agree completely

15. Other construction projects have used environmentally friendly concrete with positive results.

	1	2	3	4	
Do not agree at all	☐	☐	☐	☐	Agree completely

16. Your company has access to (internal or external) education on lower climate impact of environmentally friendly concrete.

	1	2	3	4	
Do not agree at all	☐	☐	☐	☐	Agree completely

17. Your company has access to (internal or external) education on technical properties of environmentally friendly concrete.

	1	2	3	4	
Do not agree at all	☐	☐	☐	☐	Agree completely

18. How many employees does your company have?

…………………………………………………………

19. If your company has criteria that are not included in this survey, or if you have comments for us, please leave your comments below.

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………
………