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User perspectives on reuse of construction products in Norway: Results of a national survey

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ABSTRACT

Construction industry is one of the main contributors to the world's emissions and material footprints. Reuse of construction products is one way to lower the sector's embodied emissions and increase resource utilisation. The aim of this study is to identify the main drivers and challenges affecting reuse of construction products as well as assess success factors, reuse potential, and potential measures which should be considered to overcome these obstacles. An online national survey was conducted on reuse of construction products among actors from the Norwegian construction industry. The valid responses obtained from 260 participants show 'emission reduction' as the most important driver for reuse of construction products by all user groups. Even if regulatory and economic components were listed under drivers in the survey questions, they were considered as barriers rather than drivers by some of the respondents. All user groups, except suppliers of reused products, rated 'lack of documentation' as the most important barrier, and 'good planning' as the most important success factor. Suppliers of reused products rated 'high cost' and 'good planning' as the most challenging and the most important success factor for reuse, respectively. The findings also reveal different perceptions and levels of optimism among actors. Most respondents were optimistic about availability of reusable products (within less than 5 y), but least optimistic about finding cheaper reusable products in the near future (assuming it might take 9 to 17 y). Laws and regulations, testing, documentation and certification, and economic subsidies are mentioned as the top three measures to address the current barriers. Concerning the definition of the term 'Reuse', the findings indicate a lack of common understanding – and the need to create a clear description and a harmonised definition. The findings from the study show the need to take several actions to address the current challenges of reuse.

1. Introduction

The construction industry is responsible for about 35% of total global energy use and 38% of energy related greenhouse gas (GHG) emissions (UNEP, 2020). Of these emissions, ca. 28% is from operational energy use and 10% from the construction and manufacturing of building materials. In Norway, energy related emission from the construction sector is relatively low, accounting for about 15% of the national direct GHG emissions, due to a higher level of renewable energy utilisation (Larsen, 2019). Increase in energy efficiency strategies and use of renewable energy measures have showed large potential in the life cycle GHG emissions reduction due to improved operational energy (Sandberg et al., 2021; Xiang et al., 2022). However, those changes also resulted in increasing the proportions of the embodied energy from production, construction, maintenance, and end-of-life of the buildings showing the importance of considering measures which enable to reduce GHG emissions through optimisation of both operational and embodied impacts (Röck et al., 2020).

The industry is also responsible for 40% of raw material extraction (IRP, 2020), and 25–30% of the total waste generated in the EU. Norwegian construction sites generate an average of 40–60 kg waste per m^2 gross floor area (Nordby and Wærner, 2017). The national statistics data from 2015 to 2019 show that the construction industry generated about 1.87 million tons of construction and demolition (CDW) waste annually. Only 46% of this waste was recycled, while hazardous waste accounted for only 2.1% (Statistics Norway, 2021), implying that there is a large potential for reuse and recovery of waste without requiring special treatment.

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The circular economy concept is an approach to increasing resource efficiency and reducing waste, while providing other positive potential environmental and social impacts. As the concept of the circular economy has progressed from the 1970s to today, the original "3R's" (reduce, reuse, recycle) have been revised and expanded to include up to 10R's (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover) (Reike et al., 2018). Reuse of construction products is on the top of the circular economy framework hierarchy, as it enables the prevention of all impacts related to the production and transport of new products, as well as construction and demolition waste. However, circular economy application in the construction industry is still mainly focused on recycling, which is now considered the second to last "R" in of the 10R's (Circle Economy, 2021). Reuse is not a new concept and it is assumed to have large environmental and economic potential. A Nordic study estimated the potential of construction products reuse to be about 20% reduction in resource utilisation and 900 000 tons less GHG emissions (Høibye and Sand, 2018). However, the reuse rate from construction or demolition activities remains unknown or extremely low – estimated at less than 1% in north west Europe (Deweerdt and Mertens, 2020).

Different aspects seem to hinder its widespread application, including regulations (e.g., lack of regulations promoting reuse, or regulations actively hindering reuse (Nordby, 2019)), lack of documentation, economic issues (e.g., lack of incentives), lack of knowledge, and absent infrastructure (e.g., lack of physical and digital marketplaces) (Condotta and Zatta, 2021; Gobert et al., 2021; Knoth et al., 2022; Sandberg et al., 2022). The current regulations promote waste management measures, focusing more on waste sorting and recycling practices as a means of increasing material recovery rates, rather than for reuse or other waste prevention measures (Giorgi et al., 2022). In Norway, the Norwegian building regulation (TEK) requires a minimum of 70% waste sorting, and for reuse mapping before rehabilitation and demolition of existing buildings, where there is lack of requirements related to reuse (e.g., percentage of reuse) (Kommunal-og distriktsdepartementet, 2022). Moreover, the requirement related to the transfer of responsibility for documentation of reuse products from the product owner (producers/suppliers of reuse products) to different end users in the TEK can further limit the reuse of construction products.

Despite the growing interest from industry and regulations to increase reuse rate, reuse of construction products is still in the early stage in Norway. Rigorous studies considering the barriers and drivers related to reuse of construction products in a Norwegian context remain scarce (Knoth et al., 2022; Nordby, 2019; Sandberg et al., 2022); some of existing studies are typically industry reports written for practitioners (Kilvær et al., 2019; Sørnes et al., 2014). To the authors knowledge, there is no nationwide survey conducted in a Norwegian context to explore the perception of different user groups on the challenges, motivations, and measures to increase reuse of construction products. The research project REBUS (2020) aim to address the aforementioned gaps by developing, among others, research-based knowledge on reuse of existing construction products from different user aspects through literature review (Sandberg et al., 2022), interviews (Knoth et al., 2022), and a national survey. This article presents the findings from the national survey on challenges and opportunities for reuse of construction products.

The main goal of this study is to explore the challenges (barriers), motivations (drivers and success factors), and potential measures to enable the increases reuse of construction products in Norway, revealed through a national survey. The study investigates 1) the perceptions of different professional occupations (user groups) across the Norwegian construction industry regarding the current trends which support or prevent the reuse of construction products, 2) highlight potential measures that enables to overcome the current challenges. The contribution of the study is providing a robust basis for promoting the reuse of construction products prior to being labelled as waste, providing guidance for policy makers and different actors by bridging the gap between R&D activities, industry practices, and regulations.

This article consists of 7 sections. After this introduction part (Section 1), Section 2 gives a short background on reuse definitions, challenges, and potentials. In Section 3, an overview of the methods used for survey design, data collection, and statistical analysis is provided. Section 4 presents the survey results, focusing on respondents' background, challenges, and motivations, as well as their opinion on reuse potential. In Section 5, a detailed analysis of the findings from the definitions and measures are presented along with the findings from the explorative principal component analysis (PCA). Section 6 discusses the main findings, limitations, and suggestions for further work – followed by a conclusion presented in section 7.

2. Background

This section introduces important terminologies used when discussing reuse of construction products, as well as providing an overview of existing studies on reuse barriers and drivers.

2.1. Definitions

The definition of the term reuse is perceived differently in different contexts and by different actors. For example, the EU Waste Framework Directive (WFD) uses a waste hierarchy to set priorities for waste legislation and policy, with prevention (waste prevention measures) and preparation for reuse (waste management measures) as better choices than other waste management options (recycling or energy recovery) (European Commission, 2018). The EU WFD defines reuse as "any operation by which products and components that are not waste are used again for the same purpose for which they were conceived" (European Commission, 2018). The directive also defines "preparation for reuse" referring to the preparation of products or components that have already become waste so that they can be reused without major pre-processing (i.e., with only checking, cleaning, or repairing). That means, in the EU WFD, reuse is included under both waste prevention and waste management hierarchy (Condotta and Zatta, 2021). Similarly, ISO 20887 defines reuse as "use of products or components for more than once for the same purposes without reprocessing" (ISO, 2020). The standard also mentions that preparation for reuse (such as removal of connectors, cleaning, trimming, stripping of coating) is not part of reprocessing (ISO, 2020). On the other hand, reuse is defined as both reuse of a material or product for its intended purpose, or for another purpose without processing in the 10R framework of circular economy principles (Circle Economy, 2021). From a design perspective, Fivet and Brütting (2020) defined reuse in to two parts: 1) *design with upstream reuse,* in which new products are created from existing and reclaimed components from previous buildings or infrastructure; and 2) *design for downstream reuse,* in which new products are designed for reuse through easy repair, replacement, disassembly, transport, and reassembly. Thus, clarification of the definition of reuse, for the same or different purpose, as well as the scope of reuse, as reuse of existing products or future reuse, is important.

The type and source of reuse materials and products varies, and this can affect procurement strategies, logistics, and actors involved (Geerts et al., 2020). Preservation of existing buildings and building parts through refurbishment (improving an existing building through maintenance, repair, upgrading, and/or incorporating energy efficiency measures, including retrofitting, renovation, and rehabilitation (Shahi et al., 2020)) and adaptive reuse (extension of the service life of old, historic, obsolete, and/or abandoned buildings by conversion or change of their original function and/or through reuse of materials from existing building through partial repair or refurbishment (Shahi et al., 2020)) are also often considered as one approach to increase reuse (Sandberg et al., 2022). Geerts et al. (2020) categorised the source of reuse as reclamation market, same site or in-situ reuse, and site-to-site reuse. Høydahl and Walter (2020) categorised according to the physical source of reuse as on-site/local reuse (which requires the movement of reused products), or off-site reuse (of materials or products obtained from other buildings), as well as according to the business relationship, where reuse could be internal (within an organisation), or external (from another organisation). Preservation of existing buildings or building parts and internal or local reuse are described as measures which should be prioritised to avoid the need for a third party to supply building parts (Ibenholt et al., 2020; Sandberg et al., 2022). This shows the need for using harmonised terminology when discussing the reuse of construction products to increase transparency and create a common understanding of the goal and scope of different activities.

2.2. Existing studies on barriers and drivers

Several international and national studies on barriers and challenges for reuse of construction products have been conducted to identify possible pathways to increase reuse.

Through the literature review conducted by Hart et al. (2019), lack of collaborative business models and actor' behaviours and attitudes are described as the main barriers. The authors also summarise drivers or enablers as cultural, regulatory, financial, and sectoral. Through a systematic review, Rakhshan et al. (2020) identified 57 drivers and 130 barriers that can affect reuse of construction products. Cost saving, energy and GHG emissions, and willingness are identified as the most reported drivers, whereas cost is identified as the most reported barrier. Through a qualitative analysis, Condotta and Zatta (2021) illustrate the consequences of existing legal vacuums and inconsistencies to increasing construction process time frames and process costs, causing performance assessment needs, and increasing negative end users perception. Similarly, the results from a semi-structured interviews with different actors regarding circular economy strategies across five European countries (Belgium, Netherlands, United Kingdom, Denmark and Italy) highlighted different and fragmented strategies and recommended improvements and coordinated actions in policy framework, practices and enabling tools such as digital data, platforms and traceability (Giorgi et al., 2022).

In other study, many reuse challenges are described as being related to the availability and robustness of data (Hobbs and Adams, 2017). The authors recommend supply and demand management, mandatory pre-demolition and renovation audits, innovation in reuse, construction product declaration and recertification, support for the reclamation sector, better impact data, and better data management as opportunities which could increase reuse by improving data access, management, and evaluation. Similarly, Deloitte (2017) identified design for deconstruction, pre-demolition audits and on-site sorting, waste exchange and industrial symbiosis, testing, planning and procurement, and role of municipal sector as opportunities to increase the reuse of materials from the refurbishment and demolition stages. This is also in line with the 5 circular economy enabling elements; 1) design for the future, 2) new circular business models, 3) digital technology, 4) collaboration in the value chain to create joint values, and 5) strengthen and develop advanced knowledge (Circle Economy, 2021).

There are some country specific studies on reuse barriers and success factors. For example, based on the experience from 10 case studies and interviews with different stakeholders, Gerhardsson et al. (2020) identified lack of knowledge followed by immature reuse market as the key barriers for reuse of construction products in the Swedish construction industry. Early phase material inventory, setting specific and measurable targets, encourage reuse through incentives and requirements in procurement as well as developing digital documentation strategies are identified as some of the main working practices to enable reuse in building and deconstruction projects. Similarly, lack of knowledge/standards, under developed market for reused CDW as well as lack of guidance for effective collection and sorting of CDW are identified as the main barriers for reuse in the China (Huang et al., 2018). The results from a systematic review of the perceptions of homeowners, architects, contractors, developers and legislative bodies in Australia identified economic reluctance due to high costs of reusing materials, negative attitude of stakeholders mainly driven by economic barriers, and lack of consistent and clear legislation as the main barriers for reuse of construction products in Australia (Park and Tucker, 2017). Encouraging sharing responsibilities, increasing communication, awareness and interest through education and training as well as effective legislation and incentives are the main strategies suggested to increase reuse of construction waste in Australia.

A Norwegian study, conducted based on experience and literature review, identified underdeveloped market due to lack of economic drivers, lack of information, and lack of a regulatory framework adapted to reuse as main barriers to reuse of construction products (Nordby, 2019). GHG emission reduction and increased resource utilisation from buildings are described as the main drivers. The study also highlighted adjustments in the regulations, economic incentives, raising competence and awareness, establishing a marketplace and joint risk management system as measures that could increase reuse of construction products. The findings from the interviews conducted through the research project REBUS with actors involved in actual reuse projects categorised several barriers and success factors identified in four groups: mindset and knowledge, reuse infrastructure, business framework, and legal framework (Knoth et al., 2022). The study emphasises the need for collaboration and effective communication in the value chain, especially the importance of involving manufacturers in the reuse process, and the adjustment of regulations to promote reuse. Moreover, an overlap between barriers and drivers has been pointed out, as drivers are frequently considered as enablers of the barriers or success factors. A parallel study conducted within the REBUS project, based on a literature review of the lessons learned from 6 exemplary reuse projects from Norway, Belgium, and Denmark, identified current regulations and lack of documentation as the main barriers and the importance of setting ambitious reuse goals as the main success factor (Sandberg et al., 2022). The study also highlighted the potential cost and time reduction of material reuse achieved through experience, digitalisation, and the establishment of marketplaces.

Overall, previous studies investigated barriers and measures for reuse of construction products nationally or internationally, where only few studies provide an insight from different actors' perspective, and most studies highlighted the need for further research on this topic. There are limited studies on the drivers and barriers to reuse of construction products in Norway, where existing few studies are based on literature review (Nordby, 2019; Sandberg et al., 2022) or interviews of limited actors (Knoth et al., 2022). There is no nationwide survey that encompasses different user groups, and there has been a research gap for identification of drivers and barriers for reuse from different users perspective. This study contributes to these less studied topics through a national survey collected from different actors in the Norwegian construction industry.

3. Methods

3.1. Survey design and data collection

The research method used in this study was an online self-reported national survey, available in English and Norwegian. Prior to its distribution, the survey was tested and refined based on feedback from project partners through a pilot survey carried out in 2020. The final survey consists of 20 multiple-choice questions (with options for clarification or adding missing information) and 3 open-ended questions (Appendix A). The final survey was divided into four sections: 1) general information about respondents, 2) respondents experience with reuse, 3) ambitions and challenges for reuse, and 4) opinion on reuse of construction products. A link to the online survey was distributed through partner networks and different channels. Participation was voluntary, and respondents were initially given six weeks to respond the survey invitation. The survey was reopened in 2021 and early 2022 for an additional 8 weeks in total due to lower response rate, and after an announcement in a REBUS project webinar and REBUS network members meeting, created renewed interest.

3.2. Data analysis

The findings from the survey are divided in to two parts. This article covers the technical part of the survey and presents findings from questions related to general information about respondents (Q1.1-2, Q2.1-4, & Q2.6), ambitions and challenges (Q3.4-6), as well as opinion on reuse (Q4.1- 4). The second part will be covered in a separate upcoming article, focusing on how social and personal norms affect pro-environmental behaviour and reuse of construction products in an organizational context.

There were 340 participants that consented to take part, of which 80 did not answer any questions, leaving a final sample of 260. Missing data was assessed and the valid sample size (n) per analysis/category is provided in the appendix. The quantitative data analyses of the survey was conducted using SPSS 26 (IBM Corp, 2019) and graphs were produced using Excel. The qualitative data analysis was performed using MAXQDA (VERBI Software, 2019).

The results for the overall frequency data for drivers, barriers, and success factors are presented using diverging stacked bar charts where negative categories are represented on the left side and positive categories on the right side of the centre line. In addition, to get a centred nonaligned category, half of the neutral frequency values are represented on the left and right side of the centre line, respectively. Moreover, spider charts are used to presents results by different professional occupation. Paired-samples t-tests were then conducted to explore whether there were statistically significant differences in how the different questions were answered (i.e., Q3.4-6, and Q4.2-3). Furthermore, several Chi square tests and one Multivariate Analysis of Variance (MANOVA) were conducted by professional occupation to explore potential differences between different user groups.

The aim of the current paper is exploratory. Therefore, the main data analysis was conducted based on a priori scales; however, a Principal Component Analysis (PCA) using oblique (Promax) rotation was undertaken post hoc to explore if there is a meaningful way in which respondents view barriers, drivers, and success factors. Detailed results are given under Appendix B and C. Additionally, the paper further categorised and qualitatively analysed open ended questions on how participants define reuse and what they consider important measures for reuse.

4. Results

This section presents the findings from the survey focusing on respondents' background, ambitions, and challenges, as well as their opinion on reuse potential.

4.1. Respondents' background

Fig. 1 illustrates the frequency data of professional occupation of the respondents (top), their position in the company (middle), and company size (bottom). Designers/architects (17%), manufacturers and suppliers of construction products (15.3%), and others (14,4%) accounted for a substantial amount of the responses. Most of responses that answered 'other' were consultants.

Furthermore, almost half of the respondents represented large companies (49.4%), followed by medium (14.4%). Most of the respondents were project leaders (24.1%), followed by middle managers (16.2%), and employees with an operational role (12.9%) (Fig. 1).

Fig. 2 illustrates the frequency data of the geographical location of the company the respondents represent (top), as well as their age group (middle) and educational background (bottom). Most of the respondents has a Master's (38.8%) or Bachelor's (17.6%) degree or equivalent educational background. The responses are dominated by respondents

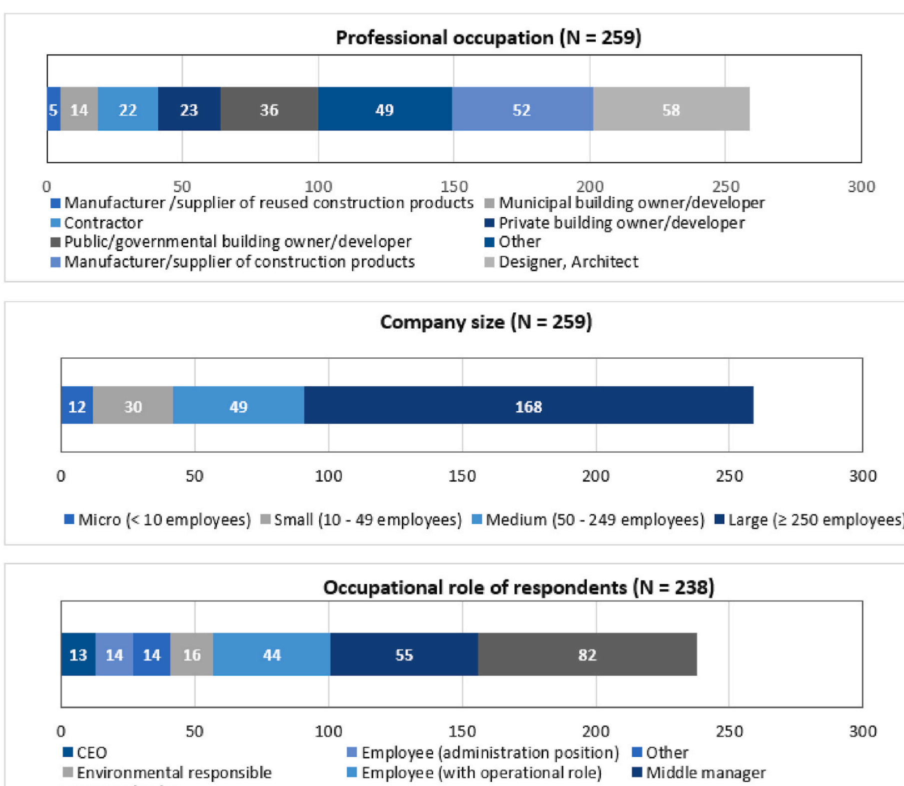

Fig. 1. Frequency distribution of professions (top), company size (middle) and occupational role (bottom).

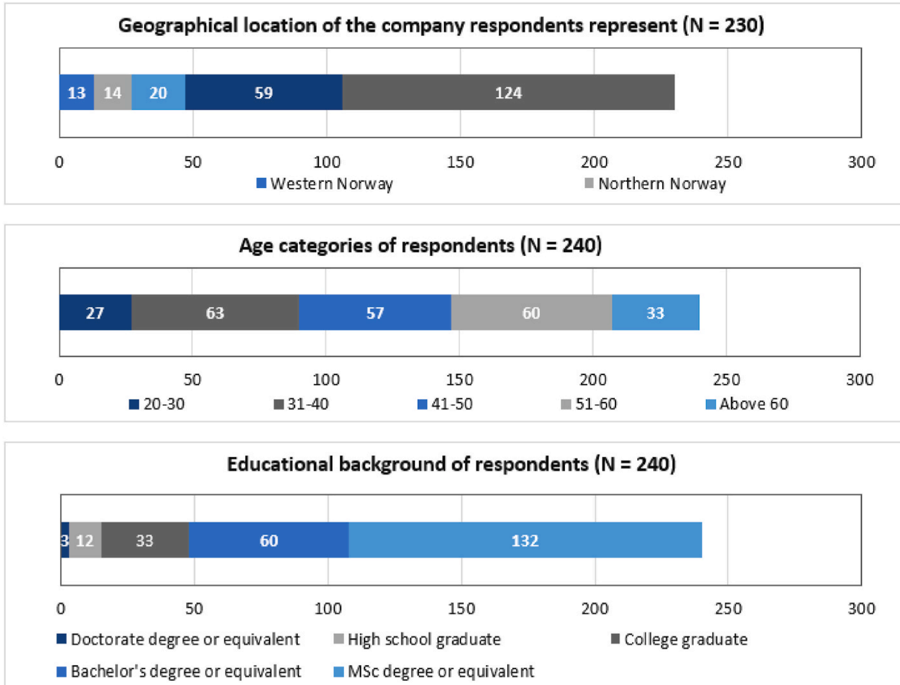

Fig. 2. Frequency distribution of geographical location of the company(top), age group (middle), and educational background (bottom).

working in Central (36.5%) or Eastern (17.4%) Norway. The respondents are not dominated by one age group, however, the smallest groups are between 20 and 30 y (7.9%) and above 60 y (9.7%).

Moreover, a substantial amount of the respondents have limited (23.2%) or no experience (13.5%) with reuse of construction products (Fig. 3).

4.2. *Drivers for increasing reuse*

Survey respondents were asked to rate a list of drivers for reuse of construction products as shown in Fig. 4. Overall, the listed items were mostly rated as important drivers for reuse of construction products (i.e., mean responses on all items are above the middle value). 'Emission reduction' ($M = 4.45$, $SD = 0.70$) was rated as the most important driver. The difference between 'emission reduction' and the second highest rated driver, 'increased resource efficiency' ($M = 4.19$, $SD = 0.86$), was statistically significant, $t\,(214) = 4.84$, $p < .001$ [0.15,0.37], with a small effect size (Cohen's $d = 0.33$). This means that 'emission reduction' stands out as more important for the respondents than other drivers on the list.

The mean importance score of drivers derived by company profession indicates that manufacturers/suppliers of reused construction products were very positive towards all drivers, except for 'cost saving' as shown in Fig. 5. However, the results should be interpreted with caution due to the low number of respondents in this category. Municipal building owners/developers did not see 'new emerging markets' as an important driver (M = 2.82, SD = 1.17). No other mean scores were below neutral. All professions rated 'emission reduction' as their top driver.

Even if cost saving and regulations were listed under drivers, some of the respondents considered them as challenges rather than drivers. For example, one respondent described cost saving as "difficult to rate it as a driver, as the current market is too immature and fragmented for reuse to be considered as cost saving yet. In addition, several pilot projects must drive a larger scale of turnover for the price to go down". The respondent described the need for establishment of physical marketplaces for intermediate storage of reuse construction products as an example of enabler. Another respondent commented that "the cost saving potential depends on the building product, as it varies from very cost driving to cost saving". Moreover, one respondent described regulations as "currently being a hindrance for reuse rather than driver". In addition, some respondents reported that some drivers might become increasingly important in upcoming years.

4.3. *Main challenges hindering reuse of construction products*

Respondents were asked to rate a list of challenges which affect the reuse of construction products as shown in Fig. 6. All listed items were mostly rated as important barriers for reuse of construction products. A Paired samples *t*-test indicated a statistically significant difference

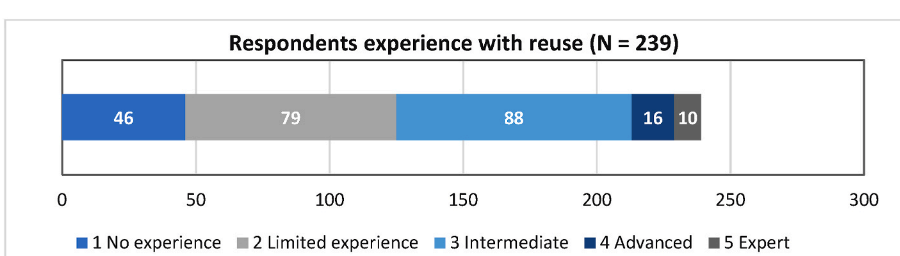

Fig. 3. Frequency distribution of experience with reuse.

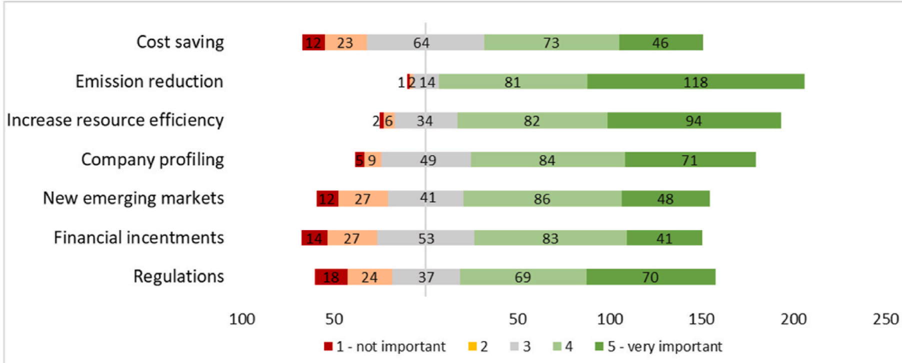

Fig. 4. Overall frequency data for drivers or motivation for reuse of building products.

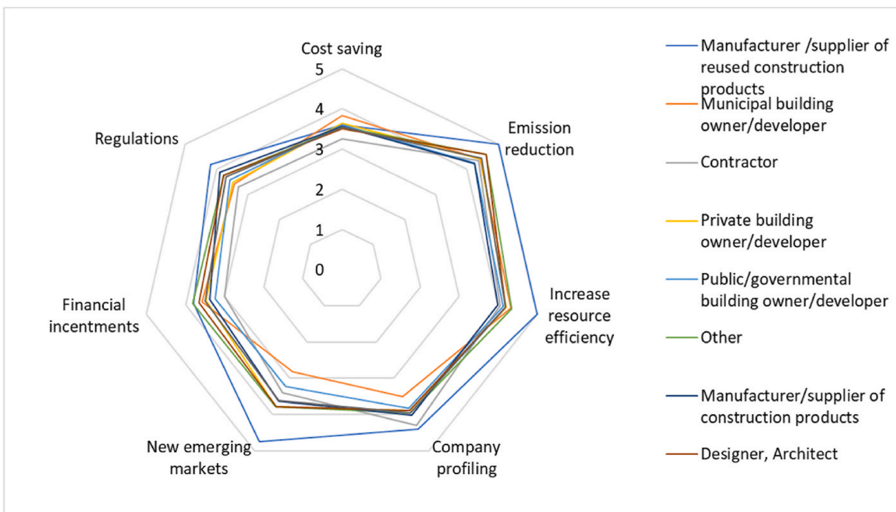

Fig. 5. Mean drivers for reuse by occupational profession. The inner circle represents the value 1 (not important) and the outer circle represents the value 5 (very important).

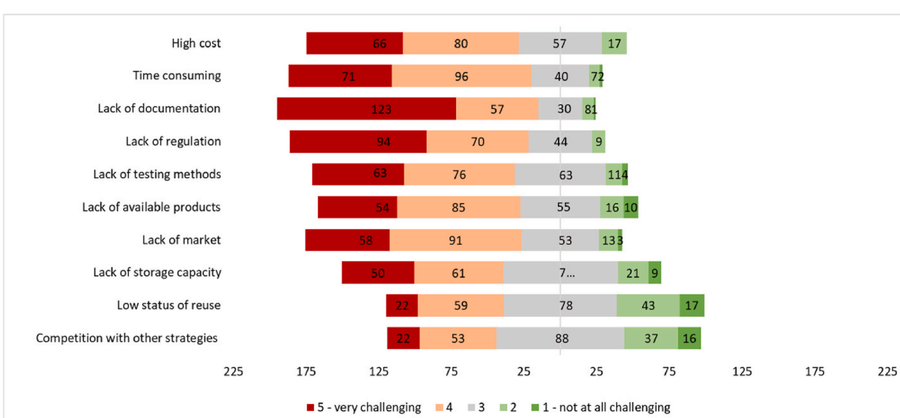

Fig. 6. Overall frequency data for barriers of reuse of construction products.

between the highest rated and second highest rated barrier, 'lack of documentation' ($M = 4.34$, $SD = 0.88$), and 'regulation' ($M = 4.16$, $SD = 0.06$), $t\,(215) = 3.25$, $p < .001$, [0.07,0.30], with a small effect size, Cohen's $d = 0.22$. This shows that 'lack of documentation' stands out as the most challenging barrier.

The results of barriers by profession indicates that manufacturers/suppliers of reused construction products do not rate the listed barriers as particularly challenging, compared to the other professions as shown in Fig. 7. Except for manufacturers/suppliers of reused construction products who rated 'high cost' as most challenging and 'lack of available products' as least challenging, the different occupational professions seem to agree about which barriers are the least challenging for reuse of construction products: 'competition with other strategies' and 'low status of reuse', and which is the most challenging barrier: 'lack of

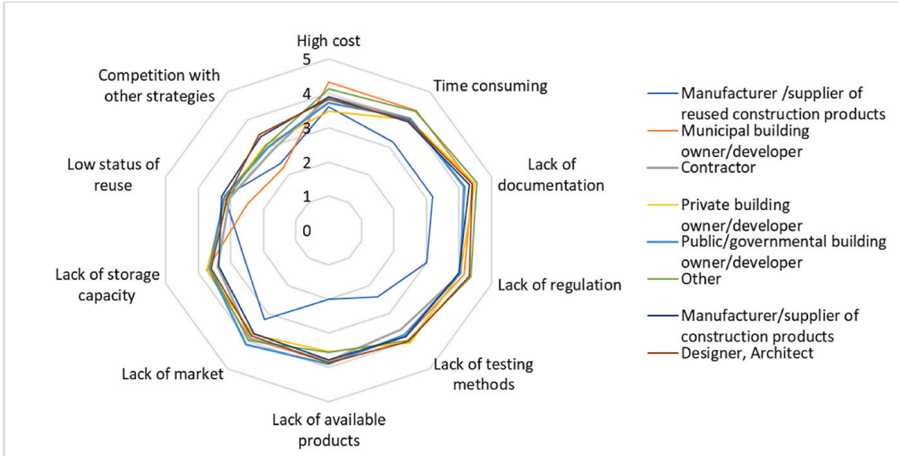

Fig. 7. Mean barriers for reuse by occupational profession. The inner circle represents the value 1 (not at all challenging) and the outer circle represents the value 5 (very challenging).

documentation'. In addition, most regarded 'lack of regulation' as challenging. Moreover, municipal building owners/developers and other professions regarded both 'high cost' ($M = 4.33$, $SD = 0.99$/$M = 4.14$, SD = 0.82) and 'time consuming' ($M = 4.33$, $SD = 0.49$/$M = 4.30$, $SD = 0.71$) as quite challenging.

Some of the respondents commented that "the regulations on certification make it almost hopeless to reuse today " and that " … there is a double-regulation which prohibits the development of safe reuse". Furthermore, " … since there is limited experience, no standards have been drawn up, which means that those who want to reuse have all the risk and thus the threshold is high". One of the respondents commented on lack of testing methods as "most testing procedures are aligned with current norms and regulation. But many products are not guaranteed by the current norms and practices due to different quality of production".

Other barriers reported in the open-text boxes were: " Lack of good example projects that can set standards and show concrete solutions. Solutions currently require a large degree of personal experience, which is a barrier by itself ".

4.4. Success factors facilitating reuse of construction products

Respondents were asked to rate the importance of a list of success factors for increasing reuse of construction products as shown in Fig. 8. Most items were reported as important (with mean values ranging between 3.75 and 4.52). A paired samples *t*-test indicated a statistically significant difference between the highest rated and second highest rated success factor, 'good planning' ($M = 4.52$, $SD = 0.77$) and 'collaboration' ($M = 4.26$, $SD = 0.88$), t (215) = 4.29, $p < .001$, [0.14,0.38], with a small effect size, Cohen's $d = 0.29$. This means that 'good planning' was regarded as the most important success factor.

One of the respondents regarded "contract type - division of responsibility and collaboration as key factors", while another respondent highlighted "the need for involvement of reuse consultant throughout the project as part of the project team".

Fig. 9 shows how respondents from different professions rated the importance of success factors. All the listed success factors are important for all professions (no scores were below neutral). The pattern of responses is relatively similar for all groups. Most professions scored highest on 'good planning' (Mean range = 4.25–4.79), whereas manufacturer/suppliers of reused construction product rated 'good planning' (M = 4.60, SD = 0.89) as second highest after 'collaboration' (M = 4.80, SD = 0.45). 'Procurement' was rated lowest by all professions (Mean range = 3.47–4.00), except for other professions. However, it was still considered an important success factor.

4.5. Respondents' opinion towards reuse potential

Respondents were asked to write their opinion about the number of years it takes until reuse products become cheaper than new products, as well as when regulation, testing and documentation, availability, and a highly developed market for reuse products are available (Fig. 10).

All respondents on average believed 'availability' of reusable construction products (M = 4.40 year, $SD = 3.56$), 'regulation' (M = 6.36 year, $SD = 4.93$), 'testing and documentation' (M = 6.89 year, SD = 8.54) will be in place within less than 7 y. Whilst respondents believed that getting 'highly developed marketplace' (M = 8.71, SD = 5.59) and

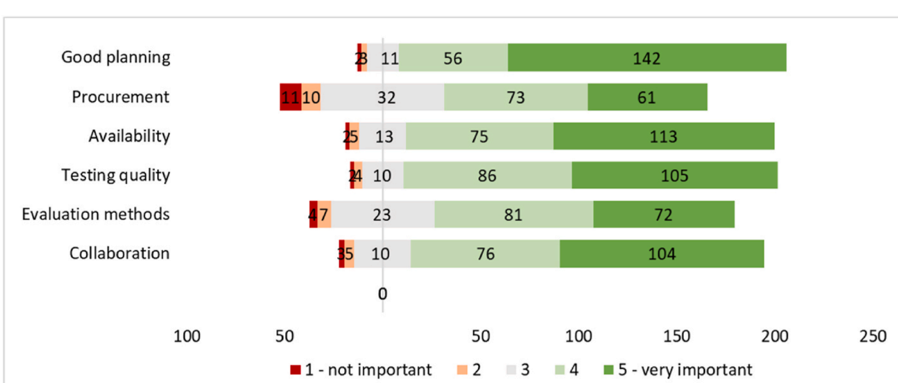

Fig. 8. Overall frequency of success factors for reuse of construction products.

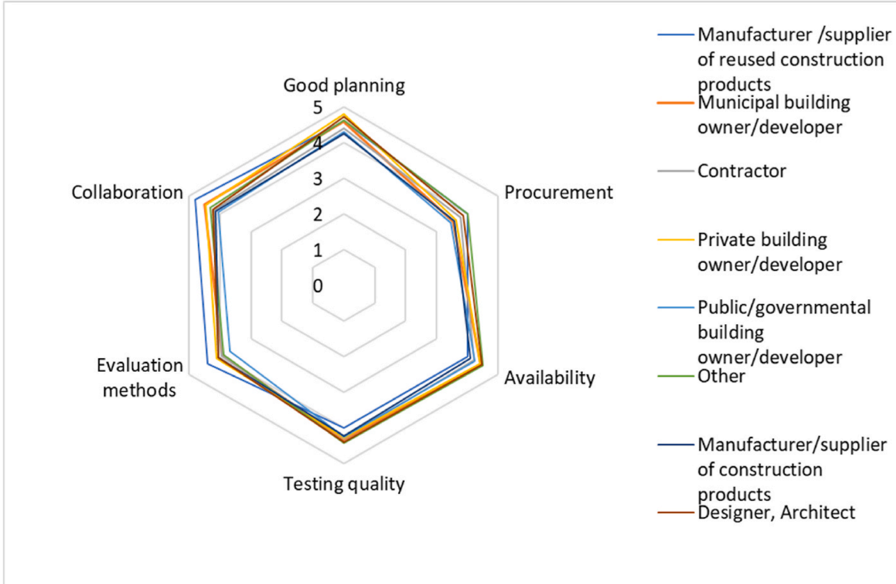

Fig. 9. Mean rating on the importance of success factors by occupational profession. The inner circle represents the value 1 (not important) and the outer circle represents the value 5 (very important).

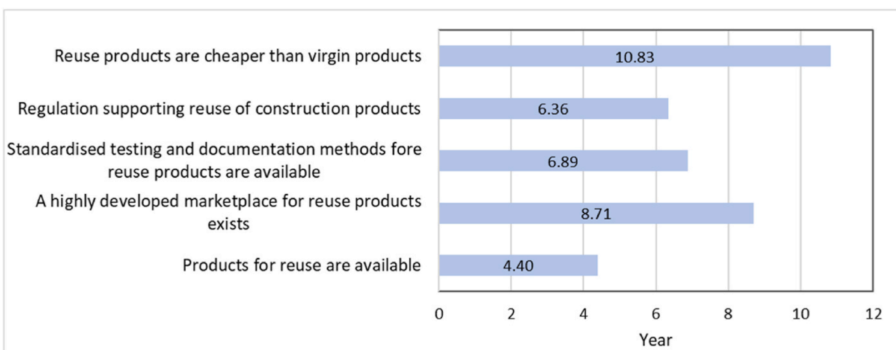

Fig. 10. Overall mean optimism of respondents on the timeline towards reuse of construction products.

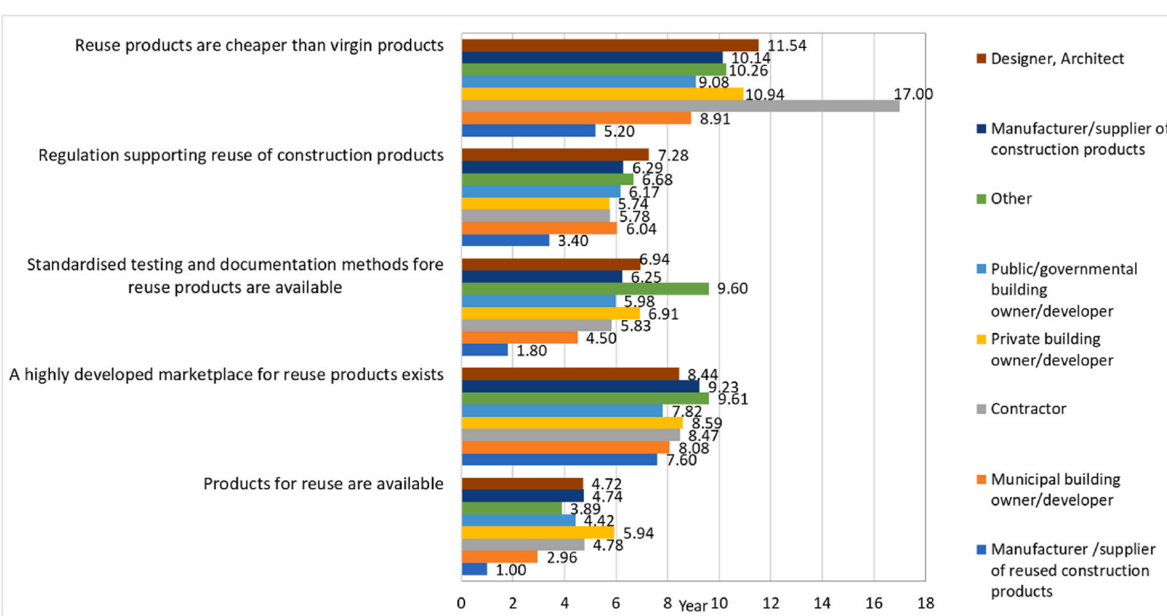

Fig. 11. Mean optimism (years until realised) by occupational profession. N varies between 96 and 99 respondents.

'cheaper reuse products' (M = 10.83 year, SD = 11.83) might take longer time. Some participants commented that the variation of the timeline depends on the product type.

The results of optimism by profession (Fig. 11) shows that most professions were least optimistic about the cost of reused products, believing it will take between 9 and 17 y. Manufacturers of reused construction products were most optimistic about all scenarios. All professions agreed it may take between 8 and 10 y for a marketplace to develop. Most professions were most optimistic about availability of reuse of construction products.

The respondents were also asked to rate reuse potential of specific products as shown in Fig. 12. 'Steel' ($M = 4.24$, $SD = 0.98$) and 'brick' ($M = 4.18$, $SD = 0.99$) were rated as the top two best products for reuse. A paired samples *t*-test indicated no statistical difference between 'steel' with the second highest rated material, 'brick', $t\,(189) = 0.769$, $p = .44$ [−0.11, 0.24], with a trivial effect size, Cohen's $d = 0.06$. However, there was a statistically significant difference between the third highest rated material, 'wood' (M = 3.93, SD = 0.88), and both 'steel', $t\,(190) = 3.161$, $p = .002$ [0.11, 0.47], Cohen's d = 0.23, and 'brick', $t\,(190) = 2.83$, $p = .005$ [0.07, 0.41], Cohen's d = 0.2.

The reuse potential results by occupational profession presented in Fig. 13 shows that the different professions are fairly in agreement about the reuse potential of different materials.

Some of the respondents commented that the reuse potential of products depends on the product type and application area. Lack of products designed for reuse is also mentioned as one of the current challenges.

4.6. Differences between professional groups

Several chi-square χ^2-tests were conducted to investigate if there are any meaningful links between professional groups on drivers, suitability of materials, barriers, success factors, and optimism. For this purpose, optimism was categorised into five: a) 5 y or less, b) 6–10, c) 11–15, d) 16–20, and e) 20 y and above. There were no statistically significant association between profession and different drivers, success factors, and optimism ($p > .05$). There was an association between occupational profession and how respondents rated the barriers 'lack of documentation', $\chi^2(28) = 47.934$, $p = .011$, 'lack of regulation', $\chi^2(21) = 39.852$, $p = .008$, and 'lack of available products', $\chi^2(28) = 57.330$, $p < .001$. There were no statistically significant association between profession and any of the other barriers ($p > .05$). Moreover, there was an association between occupational profession and how respondents rated the reuse potential of 'concrete', $\chi^2(28) = 44.387$, $p = .025$, but there was no other statistically significant relationship between profession and any other materials ($p > .05$).

Furthermore, a MANOVA was undertaken to check if there was a statistical difference between professional groups on how they rate reuse potential, success factors, barriers, and drivers. Mean scores were calculated for each of the variables. Equal covariance matrices are not assumed, Box's M = 109.69, $F\,(70, 3416.13)$, $p = .028$. Using Pillai's trace, there was a statistically significant effect of company professions on barriers, drivers, success factors, and suitability of materials, $V = 0.986$, $F\,(4,185) = 3180.94$, $p < .001$, with a large effect size, partial $\eta^2 = 0.99$. However, separate Bonferroni corrected univariate ANOVAs (0.05/4 = 0.01) indicated no statistically significant difference between professional groups, except for barriers, $F\,(7, 49.8) = 2.57$, $p = .01$, with a medium effect size, partial $\eta^2 = 0.09$. Homogeneity of variances were assumed for all variables (Levene's tests = $p > .05$). A post-hoc analysis using Tukey HSD was performed to check where group differences lie. Manufacturers/suppliers of reused construction products score significantly lower on barriers than all other professions (Mean diff. between = 1.00 and 0.80, $p < .05$). There were no other statistically significant group differences. Assumptions were violated for the optimism variable, and we conducted a Kruskal-Wall test to explore whether there were group differences in optimism, the test was non-significant.

5. Analysis

This section covers analysis and discussion on open-ended survey questions (Q4.1, Q4.4) and findings from explorative PCA on barriers, drivers, and success factors.

5.1. Definitions and measures to increase reuse

To find out how respondents understand the term reuse, they were asked to write how they define reuse in an open-ended question (Q4.1). Most common in the respondents' definitions on reuse, are the words "use materials again", however, the respondents' definitions also vary according to two main aspects: function and location. Some said that the function of reuse compared to the original use must be for the same purpose or in the same form, whilst others said that the reused product must be for a new function. Many of the respondents stated that the location of reuse can be *both* the original location and/or a new building project, but most respondents said it had to be a new location.

The respondents also have different opinions on the degree of processing of a product to be "reuse" (from no processing to recycling). Reducing environmental impact and resource efficiency are also mentioned, in addition to the importance of including use/reuse of new surplus material in the definition. As shown in the background, many of the same aspects discussed in the literature on definitions (European Commission, 2018; Fivet and Brütting, 2020) and categorization of types of reuse (Geerts et al., 2020; Høydahl and Walter, 2020; Sandberg et al., 2022), are the same aspects the respondents have different opinions on. This illustrates the need for, and the challenges with, having a harmonised definition when discussing reuse. Some of the respondents also used the open-ended question to complain about the many challenges to reuse.

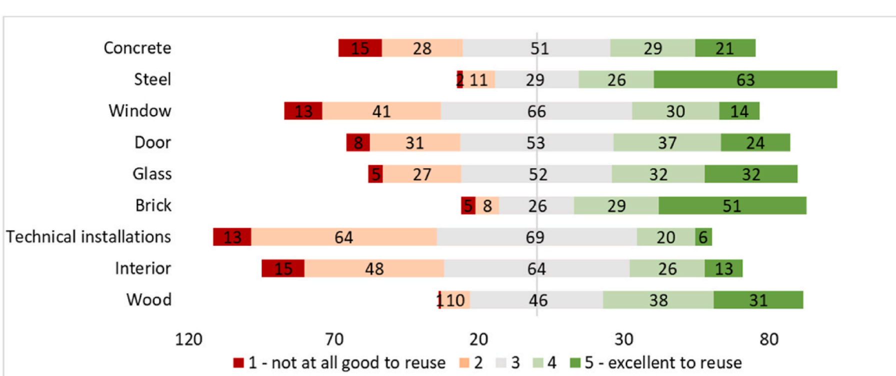

Fig. 12. Overall frequency on reuse potential of the listed construction products.

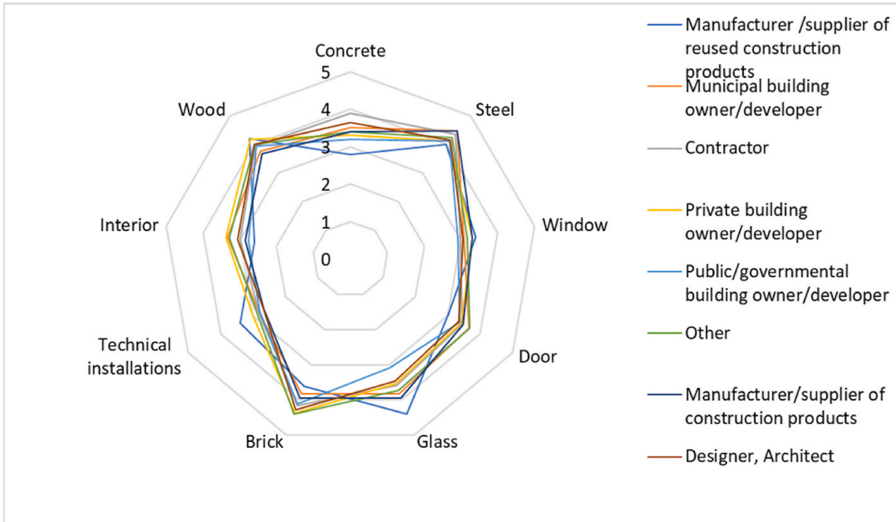

Fig. 13. Mean perception of different occupational professions towards reuse potential of listed construction products.

To get additional input from respondents, they were also asked in an open-ended question to write their opinion about measures that enable increased reuse (Q4.4). Most respondents described 1) laws and regulations, 2) testing, documentation, and certification, or 3) economic subsidies as the top measures that enable increased reuse of construction products (the order based on what was mentioned most often). Development of markets of reused products (both digital and physical), increased knowledge and competence, and setting requirements in public or private procurements were also mentioned by many of the respondents. In addition, some respondents mentioned organisation and cooperation as critical, emission tax and emission accounting as drivers, and development of new quality products for reuse as central. The list of measures described by respondents are similar to the success factors given in the survey and in line with measures described in literature

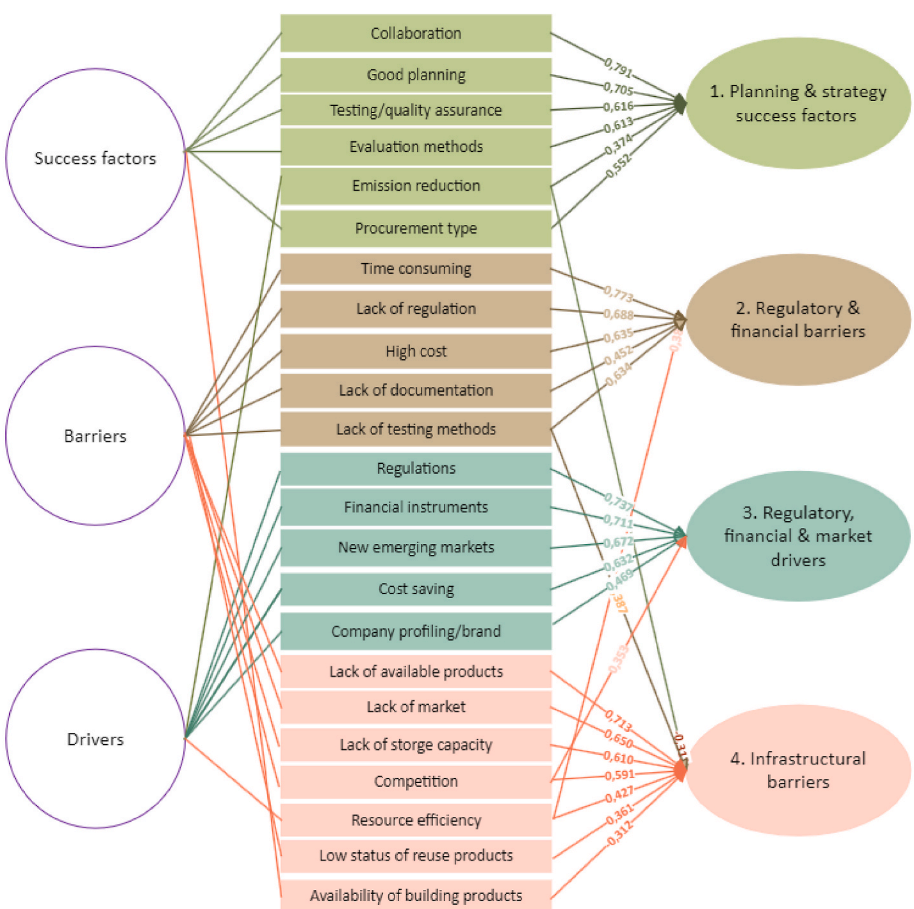

Fig. 14. Exploratory PCA with ProMax rotation for barriers, drivers, and success factors. The figure illustrates our conceptualization of the questions related to drivers, barriers, and success factors (on the left side), and the results from the PCA categorised in four components (on the right side).

(Hobbs and Adams, 2017; Knoth et al., 2022; Nordby, 2019).

5.2. Exploratory principal component analysis

A PCA with oblique rotation was conducted on 23 items from the following a priori scales: barriers (Q3.5), drivers (Q3.4), and success factors (Q3.6) (N = 196). The goal of this procedure was to explore potential meaningful indicator components among the items to check whether the used scales were answered in a systematic pattern. Detailed description of the PCA is given under Appendix C. Fig. 14 illustrates the four-factor solution chosen, and appropriate component names assigned to each component. The pattern of responses seems to be fairly in line with the three original scales. The first component 'Planning and strategy success factors' ($\alpha = 0.75$) mainly included items from the success factor scale, except for 'emission reduction'. Thus, 'emission reduction' as an important driver is positively correlated to success factors related to planning and strategy for reuse. Moreover, the third component 'Regulatory, financial, and market drivers' ($\alpha = 0.72$) is mainly related to drivers for reuse. Furthermore, the response pattern indicates that barriers might be divided into two components: 'Regulatory and financial barriers' ($\alpha = 0.74$), and 'infrastructural barriers' ($\alpha = 0.63$). The importance of 'available building products' loads negatively on the 'infrastructural barriers' component, meaning that is negatively correlated to the other items. With the given sample size, items loading lower than 0.4 might not be of practical significance and should be interpreted with caution (Hair et al., 1998). Moreover, some items cross loaded above 0.3 on a second component (Fig. 14). Low factors loadings should be considered for elimination in further analysis.

6. Discussions

This section summarises and discusses the main findings following the research objectives, discusses the role of different actors in increasing reuse, and considers the limitations and further research aspects.

6.1. Main findings

The respondents mainly represented: 1) designers/architects, manufacturers/suppliers of construction products, and others (mainly represented by consultants), 2) working at large companies located in central or Eastern Norway, 3) within an age group of 31–50 y, having a project leader, middle manager, or employees with an operational role and, 4) having an intermediate or limited knowledge on reuse of construction products. The small number of respondents from manufacturers/suppliers of reused construction products and the level of knowledge of most of respondents perceived as an intermediate or limited show the need for more expertise in reuse, pilot projects to enhance practical knowledge and collaboration between different actors in the value chain to facilitate knowledge/information exchange (Knoth et al., 2022; Sandberg et al., 2022). In addition, respondents dominated from large companies located in large cities can illustrate that the reuse of construction products is driven by private actors due to market competition rather than regulations and public incentives. The survey result where 'emission reduction' and 'good planning' or 'collaboration' (by manufacturers/suppliers of reuse construction products) being considered as the most important drivers and success factors, respectively, support this. The positive correlation between the most important driver, 'emission reduction', to the success factors related to planning and strategy for reuse shows the importance of setting ambitious goals supported by good planning and collaboration. When setting ambitious goals, it should be measurable, realistic, and achievable and there should be a system for regular evaluation and reporting the status of the goals. Kristian Augusts gate 13 (KA13) is a good example where the project owner, with a goal of being a front runner of implementing environmentally friendly solutions, enable to realize the first large scale reuse project in Norway (Entra AS, 2021). KA13 illustrated the importance of good planning, involvement of several actors in the value chain for finding reused materials and solutions which enabled to significantly reduce GHG emissions. The project also pointed out higher project cost in implementing reuse solutions related to among others time consuming project planning process, limited knowledge, logistics, lack of infrastructure, and testing and documentation during the project period.

Even if all listed barriers are mostly rated as important barriers by all actors, 'lack of documentation' and regulation stands out as the first and the second most challenging by most of the respondents, as lack of information about the technical performance of reusable products through testing and documentation can lead to reluctance to reuse products. The survey result where manufacturers/suppliers of reused construction products rated 'high cost' as the most challenging factor, as well as municipal building owners/developers and other professions described 'high cost' as quite challenging, indicates lack of documentation as one of the main contributors to high cost. This is in line with previous studies where high cost is considered as one of the main barriers resulted from lack of knowledge and under developed reuse market (Gerhardsson et al., 2020; Nordby, 2019; Park and Tucker, 2017), lack of harmonised standards and quality assurance routines (Giorgi et al., 2022), and regulations (Condotta and Zatta, 2021).

On the other hand, all respondents showed their optimism on the need for relatively shorter timeline to solve the challenges related to availability of reusable products, regulations, and testing and documentation. However, most of respondents were sceptic about the timeline of getting a well-developed marketplace and cheaper reusable products. Development of reuse guidelines, standard testing and documentation methods can support the advancement of reuse market by offering quality reused products and improve the negative perceptions (Anastasiades et al., 2021; Rakhshan et al., 2020). The requirement for reuse mapping in TEK (Kommunal-og distriktsdepartementet, 2022), and the reuse guidelines developed through the national (Fufa et al., 2021; Kron et al., 2022) and EU (Deweerdt and Mertens, 2020) research projects can help to facilitate availability and accessibility of reusable materials at reasonable cost and quality. The growing number of pilot projects (FutureBuilt, 2022a) and actors providing digital reuse mapping, digital and physical marketplaces for reusable products (FutureBuilt, 2022b) can facilitate knowledge and collaboration in the value chain for increasing availability of cheaper and quality assured reusable construction products. However, there is also a need for transparency, collaboration, and harmonization of the existing and upcoming reuse platforms.

The product type and application area were mentioned as some of the factors which determine the reuse potential of construction products. Overall, 'steel' and 'brick' are considered the two best products for reuse. There are few statistical differences between user groups on how they rate barriers and best products for reuse. This is in-line with the current practices. For example, even if more time and cost was invested in KA13 project to reuse steel, bricks and hollow core slabs, the experience from KA13 shows the reuse potential of those products in other projects (Entra AS, 2021). The procedures established by the Danish company "Gamle Mursten" for CE marking of reused bricks (Gamle Mursten, 2021) and the first Norwegian standard developed for reuse of hollow core slabs (NS 3682:2022, 2022) has drawn up possible routines for testing and documentation of reused brick and concrete, respectively, and good examples for introduction of similar procedure and routines for reuse of other construction products.

Responses concerning definition of reuse show the absence of a harmonised definition. This was also illustrated from the different reuse strategies considered in KA 13 (Entra AS, 2021; Sandberg et al., 2022), including reused materials sourced from donor buildings and reuse material suppliers as well as reuse of residual products and products returned due to incorrect orders (Entra AS, 2021). The finding from KA13 and other studies demonstrated that the EU WFD definition for reuse of construction products to their original function can limit or discourage reuse of construction products (Condotta and Zatta, 2021). Therefore, there is a need for clear description of the reuse strategies considered in projects and harmonization of several aspects of the definition in further studies.

Responses concerning suitable measures to increase reuse corresponds to the listed success factors and are in line with earlier findings (Knoth et al., 2022; Nordby, 2019; Sandberg et al., 2022). This suggests that the current survey has been able to capture some of the key elements for identifying enablers for reuse supporting the findings from previous studies. Moreover, the exploratory PCA indicates that the questions related to challenges, drivers, and success factors for reuse can be categorised into four components based on the pattern of responses. Most of the barriers are related to regulatory, financial and/or infrastructural aspects, whilst the drivers are related to regulatory, financial, and/or market aspects and success factors related to planning and strategies for reuse. The pattern of responses was fairly similar to our original conceptualization of barriers, drivers, and success factors, but suggests that some adjustments could be made to the original scale.

6.2. Role of different actors

One of the main objectives in the present study was to evaluate and compare the barriers and challenges of reuse as they are interpreted by different professional groups. The result from this study shows that all user groups see most of the listed hindrances as quite challenging except manufacturers/suppliers of reuse construction products, with more knowledge on reuse products and were relatively optimistic. The high values given by all actors for 'good planning', and 'collaboration' as success factors shows the importance of early planning to identify and implement best reuse solutions in collaboration and involvement of different actors (Knoth et al., 2022). For example, involving manufacturers/suppliers of new products in the reuse process, can help reduce cost, and time by using their well-established production, logistics, and marketing platforms. Collaboration with construction and demolition contractors and architects can support the exploration of possibilities and create innovative design solutions to increase the availability and application of reuse of construction products.

Despite lack of regulations driving sustainable solutions in the Norwegian construction industry, public and private actors are the one who set ambitious goals and drive the market for new sustainable solutions (FOG Innovation, 2021). Public actors can play major role in addressing the current challenges and paving the way to implement measures to increase reuse (Condotta and Zatta, 2021; Deloitte, 2017; Knoth et al., 2022). They can use their purchasing power to set measurable and achievable requirements or implement rewards in their tender process to support innovative solutions. The requirements from public actors can also encourage involvement of regulatory bodies as several respondents stated that the current regulations can be viewed as one of the main barriers. Pilot projects are a means of collaboration and knowledge platform for actors in the value chain to get practical knowledge through testing, evaluation, and communication of the findings that can be used as references (Sandberg et al., 2022). FutureBuilt is a good example where different actors are involved in ambitious pilot projects to realize reuse of construction products. Thus, improvements of regulations and practices, use of the right regulations, incentives and also international collaboration in policy, practices, and digital and physical supporting tools are needed (Giorgi et al., 2022; Sandberg et al., 2022).

6.3. Limitations and further research

Sample representativeness: Though the survey was distributed through different channels to cover the main actors in the Norwegian construction industry, the response rate from the manufacturers/suppliers of reuse products, medium and small size companies, and employees with operant role was relatively low. This can be due to lack of experience in reuse, limited reuse related activities in small and medium sized companies, and limited activities focused on the strategic level with participation of people at managerial position. Future research should follow the development of reuse and see how the different user groups perception differs from what has been reported here.

Self-reported data: Self-reported survey data could lead to pitfalls, such as interpreting the questions differently, lack of honesty, or biased self-assessment. However, the opportunity to elaborate or clarify their answers might reduce this potential pitfall. Moreover, one could argue that the anonymity of the survey would increase honesty, compared to interviews. Furthermore, the Likert Scale questions could potentially prompt respondents to answer in a specific pattern or close to the middle of the scale.

Generalisation: The scope of the survey was geographically limited to Norway and participation required knowledge about the public and private construction industry. This is because the aim of this study was to provide research-based knowledge for the Norwegian construction industry. Thus, the results cannot be generalised to other countries or industries, nor does it differentiate potential differences between private and public sector. Despite the national focus, the results may be relevant and interesting for the construction sector in similar cultures. Further work with a wider scope covering how different countries at Nordic or EU levels work in this area could be interesting.

7. Conclusions

The main objective of this study was to gain insights into the challenges and motivations related to reuse of construction products in the Norwegian construction industry. Furthermore, the study collect and assess user opinions on measures to increase reuse potential, both in general and for different user groups, to facilitate knowledge about what could foster or hinder a wider implementation of reuse in the industry. This study serves as the extension from previous qualitative interviews and case study analyses conducted through the research project REBUS and provides information about reuse from different users' perceptions based on the data collected through a national survey.

The survey results demonstrated that 'lack of documentation' as the most challenging for reuse of construction products, whereas 'emission reduction' is the most important driver, and 'good planning' or 'collaboration' (by manufacturers/suppliers of reused construction products) is the most important factor to succeed. Emission reduction was also positively correlated with the 'Planning and strategy success factors'. Cost saving and regulations are considered as challenges instead of drivers due to immature and fragmented reuse market, lack of regulation supporting reuse, and lack of pilot or good example projects as mentioned by some of the respondents. Manufacturers/suppliers of reused construction products score significantly lower on all barriers than all other professions, indicating that they see the barriers as less challenging than other user groups. This shows the possibilities of the listed barriers might be solved in the future with increase in experience on reuse of construction products among other actors.

The results reveals that most of the challenges and success factors identified in previous studies alien with respondents' responses. The little difference between user groups and how they rate drivers, success factors, optimism, suitability, and barriers for reuse, show similar opinion between them. Despite the growing interest on reuse of construction products, the importance of all the listed several barriers highlighted by the respondents' illustrated there is still a long way to increase reuse of construction products in the Norwegian construction industry. Several measures such as setting ambitious but realistic goals, early planning with good collaboration with actors in the value chain, establishing physical and digital infrastructures (e.g., marketplaces, testing and documentation) supported by flexible regulations, procurement procedures and incentives should be considered to support the growth of reuse.

This study can give a better overview of the status of reuse for different actors in the Norwegian industry and provide a background for policy makers to enforce effective measures. Although the survey was conducted in Norway, other countries could also learn from the findings from this study. The geographical limited study with few numbers of respondents from manufacturers/suppliers of reused construction products as well as an intermediate or limited knowledge of most of respondents shows the need for further research to follow up the status and progress of practical applications of reuse nationally and internationally.

CRediT authorship contribution statement

Selamawit Mamo Fufa: Conceptualization, Methodology, Visualization, Formal analysis, Writing – original draft, Writing – review & editing. **Marin Kristine Brown:** Methodology, Formal analysis, Visualization, Writing – review & editing. **Åshild Lappegard Hauge:** Writing – review & editing. **Svein Åge Johnsen:** Supervision, Validation. **Kristin Fjellheim:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All relevant research data are shared under the supplementary file.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2023.137067.

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