Jørgensen, O., Lædre, O., Lohne, J. (2025). Quality Assurance of Prefabricated Concrete Elements. In O. Seppänen, L. Koskela, & K. Murata (Eds.), *Proceedings of the 33rd Annual Conference of the International Group for Lean Construction* (IGLC33) (pp. 669-680). https://doi.org/10.24928/2025/0130

QUALITY ASSURANCE OF PREFABRICATED CONCRETE ELEMENTS

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ABSTRACT

Workplace crime in Norway's construction industry is a growing concern, with social dumping, poor working conditions, and economic crime identified as major issues. Counterfeit materials and their risks to the environment, safety, and health receive less attention. Little research has examined how quality assurance (QA) systems in the prefabricated concrete supply chain address these risks. Quality failures pose a substantial threat to Lean Construction practices. This exploratory research aims to answer how QA systems in the value chain of precast concrete elements can be improved. This was investigated through 10 interviews, focusing on the strengths and weaknesses of current QA systems. The QA systems of producers, contractors, and clients include factory visits, deviation management systems, audits, and certification checks. Most interviewees believe the industry is well-regulated and not likely to produce false materials, though one noted that "if they want to trick us, they can". Key weaknesses include untested materials, trust-based inspections, emissions manipulation, and lack of destructive testing. Taking into account limits to generalization, the study identified 24 improvement measures, targeting suppliers, producers, transporters, installers, contractors, and clients. Recommendations focus on addressing these gaps to strengthen QA systems and expanding the analysis to other materials in the supply chain.

KEYWORDS

Lean construction, prefabrication, concrete elements, quality assurance, counterfeit.

INTRODUCTION

Crime in the construction industry is a significant issue encompassing various forms of illegal activities. These include fraud, tax evasion, poor health and safety practices, underpayment of workers (Davies, 2021), organised theft of heavy equipment (Thomas, 1977), and bid-rigging (Reeves-Latour & Morselli, 2017). These forms of illegal activities should be prevented, as directly countering Lean Construction principles (for example described by Howell and Ballard, 1998). The industry's complex structure and processes create opportunities for work-related crime, particularly in the transition from procurement to production (Selvik et al., 2021). Agency problems and criminogenic industry structures contribute to the prevalence of criminal behavior (Lohne et al., 2021; Davies, 2021). The impact of such activities on a company's reputation can be severe, necessitating effective reputation management strategies (Engebø et al., 2018). Quality assurers also have opportunities to engage in criminal activities, highlighting the need for third-party controls and stricter sanctions (Øversveen et al., 2021). Addressing

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these issues requires a comprehensive understanding of the root causes and implementation of targeted countermeasures (Lohne et al., 2021).

Internationally, research on crime in the AEC industry has focused on corruption issues. Corruption is widespread in the construction industry, particularly in developing countries (Bowen et al., 2015; Kenny, 2009). Common forms include bribery, kickbacks, collusion, and conflicts of interest (Bowen et al., 2012; Ameyaw et al., 2017). Government officials, contractors, and subcontractors are often perceived as the most involved parties (Bowen et al., 2015). Corruption is prevalent during bid evaluation and tendering phases (Bowen et al., 2012) and can lead to poor-quality infrastructure and low economic returns (Kenny, 2007). Factors facilitating corruption include lack of transparency, skills shortages, and weak deterrents (Bowen et al., 2012). Barriers to reporting corruption include lack of confidence in the justice system and inadequate whistleblower protection (Bowen et al., 2015). Addressing corruption requires improved procurement processes, higher ethical standards, and greater transparency (Bowen et al., 2012). Industry-wide efforts, including education, training, and collaborative anti-corruption initiatives, are necessary to combat this pervasive issue (Jong et al., 2009).

The Norwegian government defines workplace crime as profit-driven criminal activities in the labour market, focusing on issues like social dumping, poor working conditions, and economic crime. The construction industry is particularly vulnerable, with workplace crime often linked to counterfeit materials – a widespread issue in industries such as fashion, electronics, and pharmaceuticals. Im et al. (2018) estimate that 7% of global trade involves counterfeit materials, which affect jobs and revenue. While usually associated with other sectors, counterfeit materials also impact construction.

Lohne et al. (2019) highlight the serious risks counterfeit materials pose in construction, especially to life and safety, but note the lack of in-depth research. Evidence suggests counterfeit materials, including those in concrete structures, may be present globally and in Norway. As a barrier against the use of counterfeit materials, supply chain management issues are fundamental for effective combatting of crime. The paper explores the QA systems used in producing and applying precast concrete elements, particularly concerning counterfeit materials. The research aims to answer: "How can the QA system in the supply chain of precast concrete elements be improved?" This will be addressed by analysing how industry actors use QA systems and identifying their strengths and weaknesses. The specific research questions are:

- What is the QA system for precast concrete elements?
- What are the strengths and weaknesses of the current QA system?

The study is limited to interviews with representatives from a manufacturer, contractor, and client – key players in the Norwegian market – and focuses on prefabricated concrete elements.

THEORY

The Norwegian construction industry faces various forms of work-related crime, including social dumping, poor working conditions, and economic crime, which the government identifies as key challenges (Norwegian Government, 2022). In its action plan against social dumping and work-related crime, the government defines work-related crime as: "*profit-driven crime in the workplace that undermines employees' rights and working conditions, while also affecting the tax base and welfare system. Criminal actors exploiting tax and social security schemes erode trust in Norwegian authorities and the welfare system*" (ibid.).

FALSE MATERIALS

The construction industry provides society with jobs, infrastructure, economic growth, and scientific advancements (Minchin et al., 2017). However, it faces challenges related to work-related crime, particularly the issue of false materials, which account for an estimated 7% of global trade and impact all sectors. Engebø et al. (2016) define false materials in construction as, 1) inadequate materials (quality deviations, possibly with false documentation), 2) fraudulent materials (false documentation, possibly with quality issues) and 3) counterfeit materials (illegal use of intellectual property). Kjesbu et al. (2017) found that false steel materials appear in all three categories in the construction industry. Lohne et al. (2019) note that research on false materials in construction is limited. The industry is especially vulnerable due to its project-based nature, extensive subcontracting, and the potentially fatal risks of using counterfeit materials (Im et al., 2018).

According to Lohne et al. (2023), efforts to combat work-related crime focus on employee-level issues, with little attention paid to aspects like the supply chains of building materials. Counterfeit materials receive minimal attention. Fang et al. (2011) identify differences in management practices between developed and developing countries as a driver of counterfeit materials. They argue that Western companies' focus on cost-cutting at all levels contributes to the spread of such materials. Measures include reassessing trust in the supply chain, implementing third-party controls and closely monitoring the supply chain, including thorough final inspections. Liu et al. (2023) discuss how the nature of the construction industry can lead actors to exploit weaknesses. Hu et al. (2021) note that contractors are more likely to engage in fraudulent behaviour when under financial or time pressure. They highlight a conflict of interest, where participants bend the rules if the benefits outweigh the risks.

Ghadge et al. (2021) emphasise the need for a robust QA system including inspections and testing and based on standards, to prevent the use of false materials in global supply chains. Silvestre et al. (2020) argue that strong legislation can reduce corruption in supply chains if properly enforced. They identify three drivers of corruption: weak enforcement (institutional vacuums), the personal nature of business deals, and social isomorphism ("everyone does it"). Corruption can compromise product quality and sustainability, and companies can mitigate this when understanding where corruption arises in the supply chain.

QUALITY ASSURANCE AS A TOOL AGAINST COUNTERFEIT MATERIALS

Quality is defined as meeting a project's legal, visual, and functional requirements (Arditi & Gunaydin, 1997). Regarding Lean construction, it involves fulfilling standards set by industry players like architects, contractors, authorities, and project owners (Vrijhof and Koskela, 1999; Pinho et al., 2008; Broft and Koskela, 2018). The American National Standards Institute (ANSI, 2011) developed an action plan to combat the rise of counterfeit materials, particularly in the aerospace industry. It identified three key factors contributing to the issue, notably 1) poor communication within the supply chain, 2) a lack of accountability for product safety, and 3) a need for stricter testing protocols. Though focused on aerospace, these issues apply across industries with global supply chains. ANSI has held conferences to improve existing measures and establish new ones, highlighting four areas for improvement: collaboration, training, enforcement of laws, and standards. ANSI's action plan recommends seven measures to combat counterfeit materials in supply chains across industries, notably to 1) set documentation and certification requirements for quality, 2) ensure subcontractors use quality assurance (QA) systems via contract clauses, 3) implement third-party testing, inspection, and audits to monitor supply chains, 3) maintain continuous QA and third-party oversight to ensure long-term product quality, 4) train personnel to recognise counterfeit materials, 5) share information on experiences with false materials, and 6) analyse the entire supply chain to identify risks and solutions. Minchin et al. (2011a; 2011b) note that existing QA systems is not enough to combat counterfeit materials due to the sophistication of fraudulent actors.

For concrete structures, the Norwegian Standard NS-EN 206 specifies guidelines to ensure quality and durability. This standard covers different types of concrete (standard, heavy, aerated) and production methods (on-site, ready-mixed, precast). In manufacturing precast concrete elements, producers are responsible for sourcing materials, production, and testing, ensuring the products meet set standards for exposure and environmental classes. NS-EN 206 also requires manufacturers to implement a QA system in their production processes.

CONCRETE AS A BUILDING MATERIAL

Concrete is a key building material in Norway, with around 1 m^3 per capita consumed annually (Jacobsen et al., 2023). This composite material, consisting of aggregates, sand, cement, water, additives, pozzolans, and reinforcement, has properties such as compressive strength, workability, service life, CO_2 footprint, and resistance to aggressive substances. Variations in these components affect performance. The Norwegian Standard NS-EN 206 mandates a quality assurance (QA) system for concrete production, covering purchasing, production, and quality control. For cast-in-place concrete, the standard requires pressure testing of concrete cubes from each delivery. However, no similar system is required for prefabricated concrete elements.

PREFABRICATION

Prefabrication involves producing building materials off-site and transporting them to the construction location (Chen et al., 2024). These elements are often produced in standard sizes, enabling quick and efficient installation. Prefabricated elements are ideal for reuse, as they can be dismantled and repurposed for other projects. Additionally, prefabrication helps reduce on-site contamination from construction waste due to its factory-based production.

However, challenges exist. Engebø et al. (2016) note that prefabrication is relatively new, and standards for documentation and other requirements may be underdeveloped. This can lead to uncertainty for both producers and consumers about the requirements and processes involved.

FAKE MATERIALS CASES ASSOCIATED WITH CONCRETE AND PREFABRICATION

Notable cases of false materials in concrete exist. A prominent example is the Ormen Lange plant in Nyhamna, Norway, built with around 200,000 cubic meters of concrete (NRK, 2011; Romsdals Budstikke, 2011; Teknisk Ukeblad, 2011). In 2005, parts of the facility were constructed with concrete lacking silica dust, intended to resist chloride-induced corrosion. The supplier, Unicon, falsified documentation, claiming silica was included while adding extra cement instead. This issue could compromise the concrete's resistance to saltwater, potentially leading to structural failure. Such examples arise around the world. For instance, construction projects in Africa faced issues such as inadequate testing, poor material quality, and regulatory enforcement, resulting in substandard concrete and construction defects (Boateng, 2020; Ebekozien et al., 2023; Tutu et al., 2022). Additionally, Engebø et al. (2016) report cases in Norway where precast concrete had insufficient reinforcement and quality control.

KNOWLEDGE GAP

Despite the Government’s action plan against work-related crime not highlighting counterfeit materials as a major issue for Norway's construction industry (Norwegian Government, 2022), there have been numerous reports of substandard concrete structures both in Norway and internationally. While research on counterfeit materials largely focuses on industries like fashion, electronics, and pharmaceuticals (Lohne et al., 2019), there is limited exploration into counterfeit materials in construction. This gap is notable for the lean construction industry, as weaknesses in quality assurance (QA) systems can heavily impact flow and waste reduction.

The literature reveals a significant challenge related to false materials in construction, a problem extensively documented in regions such as Africa and Asia, but less so in Norway. Despite some cases of false concrete materials reported, the issue remains underexplored. Here, this knowledge gap is addressed by focusing on the QA systems for prefabricated concrete elements, examining their strengths, weaknesses, and potential improvements.

RESEARCH METHOD

This study adopts a qualitative research design (Creswell, 2018; Bryman, 2016), using semi-structured interviews to explore the quality assurance (QA) systems used in the production and application of prefabricated concrete elements.

Ten interviews were conducted with representatives from key actors in the supply chain, including manufacturers, contractors, and clients, to capture a comprehensive view of QA practices. The semi-structured format allowed for flexibility while maintaining a focus on the research objectives, following Kvale and Brinkmann (2015). An overview of the interview representatives is given in table 1.

Table 1: Overview of interview representatives

Representative	Position	Experience [years]
P1	General manager (manufacturer)	8
P2	Procurement responsible (manufacturer)	30
P3	Logistics responsible (manufacturer)	13
P4	Quality, Safety, Health and Environment responsible (manufacturer)	1
P5	Concrete Expert (manufacturer)	4
E1	Quality, Safety, Health and Environment manager (contractor)	16
E2	Sustainability Advisor (contractor)	10
B1	Senior Advisor, Criminal activity prevention (client)	7
B2	Project manager, Quality and Risk (client)	15
B3	Construction manager (client)	10

Data analysis followed a thematic approach, as described by Braun and Clarke (2006), involving coding, categorising, and identifying patterns across interview responses. This method enabled the systematic identification of strengths, weaknesses, and potential improvements in QA systems.

To ensure reliability, the study employed cross-verification of interview findings with existing documentation and standards, such as NS-EN 206. Ethical considerations, including informed consent and data anonymisation, were upheld (Silverman, 2020; Bazeley, 2013). A potential weakness is the reliance on self-reported data, introducing the potential for bias, as participants may have presented their practices in an overly favourable light.

RESULTS

To address the research question, "How can the quality assurance system in the prefabricated concrete elements supply chain be improved?" interviews were conducted with employees from a manufacturer, contractor, and client. These interviews mapped the QA systems in use, highlighting their strengths and weaknesses. Additionally, information was gathered on the challenges associated with suppliers, carriers, and installers.

REINFORCEMENT

Interviews revealed challenges in quality assurance for reinforcement materials. According to interviewee P2, reinforcement is not tested for quality unless processed in the factory. For instance, while factory-processed tension ropes are documented, common reinforcement steel undergoes minimal testing beyond visual inspection and documentation verification. This reliance on trust makes quality assurance vulnerable.

Interviewees noted that Norwegian suppliers are well-regulated, and documentation like CE markings is required. Despite factory visits, the manufacturer relies heavily on trust. However, there have been issues with foreign reinforcement lacking satisfactory quality and documentation. Additionally, interviewee P2 highlighted concerns about corrosion affecting reinforcement, with insufficient documentation on its impact. Interviewee P4 suggested that structural deliveries might warrant more thorough checks, which are currently lacking for reinforcement.

CEMENT

Interviews revealed challenges in quality assurance for cement used in concrete elements. Interviewee P5 noted that only documentation is reviewed upon delivery, as in-depth testing of the large quantities received is unmanageable. This reliance on documentation has led to issues, such as receiving the wrong type of cement, which was only detected during use. Heidelberg Materials Sement Norway (previous Norcem) owns the two only cement production plants in Norway and holds a monopoly-like position. With one sole supplier, trust is essential due to the lack of alternatives.

Despite these challenges, the manufacturer benefits from using a single type of cement, making it easier to monitor deliveries. Documentation from all deliveries must be reviewed, but no additional testing is performed. This reliance on trust could pose risks, though no issues have been reported with the supplier.

Interviewee E2 also pointed out potential challenges with verifying greenhouse gas emissions in cement. Thorough investigations of the emissions throughout the supply chain are costly for the contractor. Thus, quality assurance of the emissions is largely based on trust.

AGGREGATES

Aggregates, which make up 65-75% of concrete's volume, are minimally controlled by manufacturers. Interviewees noted that due to the high volume of deliveries – up to 15 truckloads daily – it's impractical for manufacturers to perform extensive checks themselves. Instead, they rely on the supplier's testing and documentation.

While aggregates are tested for water content, size, and grading by the supplier, manufacturers have limited capacity to verify these checks. Interviewee P5 suggested that digitalisation could improve aggregate control. Random checks are planned but are not in place.

The documentation from the approved supplier and adherence to NS-EN standards are seen as strengths. However, issues such as receiving incorrect-sized aggregates despite accurate documentation have arisen. This reliance on supplier documentation means manufacturers have minimal control over the actual quality of delivered aggregates.

POZZOLANS

Pozzolans, like fly ash and silica dust, face quality assurance challenges due to a lack of testing. Interviewee E2 highlighted that absence of pozzolans testing means there is no composition control, which can lead to issues in prefabricated concrete. For example, a case involving hollow core slabs revealed high heavy metal content from fly ash, resulting in the concrete being landfilled rather than recycled. This issue might go unnoticed without a testing regime.

Environmental Product Declarations (EPDs) often misrepresent greenhouse gas emissions from pozzolans since they are classified as residual products, leading to inaccurate emission figures. Interviewee P1 felt confident in the quality of pozzolans due to their consistent production methods. However, Interviewee P5 noted that, like cement, pozzolans are only controlled based on supplier documentation, which could lead to problems like elevated heavy metal content in the final product.

EMBEDDED STEEL DETAILS

Interviewee B2 emphasised the importance of quality assurance and documentation for lifting points to ensure safety during lifting and assembly. They recommended that lifting points should be controlled by either the client or the contractor. They reported positive experiences with embedded steel details for lifting.

Interviewee P4 suggested more rigorous control for critical sub-materials, like embedded steel details for lifting, due to their significant impact on safety. They recounted an incident where a bolt failure led to a concrete element falling. Despite recognising the need for enhanced checks, current practices rely solely on documentation and certificates, which are deemed sufficient for Norwegian producers and suppliers due to regular inspections. Both interviewees stressed that safety in lifting is crucial but noted that systematic testing is lacking.

MANUFACTURER

Interviews revealed how the manufacturer manages quality assurance for prefabricated concrete elements. Interviewee P1 noted that while the manufacturer follows Norwegian standards, specific customer requirements can be more stringent. In such cases, the manufacturer must implement stricter quality controls.

Interviewee P5 mentioned the use of Exbet software for traceability and quality documentation, covering material receipts, concrete sampling, compliance checks, and storage. Quality assurance relies heavily on documentation and trust due to the manufacturer's limited capacity to conduct in-depth investigations. Norwegian suppliers are well-regulated, reducing concerns about their products. Interviewees P1 and P2 emphasised that trust is crucial, especially with cement where Heidelberg holds a monopoly-like position. P2 noted that too much reliance on supplier documentation could be problematic.

Interviewee P1 suggested that pressure to meet deadlines might incentivise manufacturers to accept subpar materials to avoid project delays, potentially leading to quality compromises. P4 added that some actors may request documentation without thoroughly reviewing it, though the manufacturer is increasingly addressing these issues.

TRANSPORT

Interviewees noted challenges with transport of prefabricated concrete elements. Interviewee B1 mentioned difficulties in ensuring the correct items are transported, and expressed concern that contractors do not impose requirements on carriers. Interviewee B2 added that seasonal variations can complicate transportation. Interviewee E2 highlighted that the calculated greenhouse gas emissions from transportation of the concrete elements might be manipulated.

INSTALLER

Interviewees from the client and contractor highlighted quality assurance issues related to the installation. Interviewee B2 noted that responsibility for quality assurance can sometimes shift to subcontractors, who may handle installation, control, and reception. This can lead to problems if errors are discovered late in the project, potentially increasing inspection costs and indicating a lack of ownership. Interviewee E1 mentioned that contractors often use subcontractors for concrete element installation, which can lead to inconsistent responsibility for reception control and installation. Interviewee B1 reported several cases of frost cracking in hollow-core slabs, potentially due to assembly errors and concerns about installer competence.

CONTRACTOR

Interviewee E1 described how the contractor ensures the quality of prefabricated concrete elements through factory visits, audits, certification checks, and a non-conformance system. The contractor engages a manufacturer to produce the elements and a subcontractor for assembly. Factory visits and certification reviews ensure the manufacturer's adherence to quality, environmental, and safety standards. While the contractor does not audit the manufacturer's suppliers, the new Transparency Act may necessitate this. The non-conformance system helps identify defects in products and assembly, but underreporting and variability in who handles quality checks can be problematic.

Interviewee E2 noted that Environmental Product Declarations (EPDs) for prefabricated concrete elements may have weaknesses, such as manipulated emission figures, which complicate quality assurance, especially for projects with strict greenhouse gas requirements.

For cast-in-place structures, the contractor performs additional quality checks by pressure testing concrete cubes. For prefabricated elements, reliance on manufacturer documentation is the norm. Interviewee E1 emphasised the vulnerability of relying solely on supplier documentation without independent verification.

CLIENT

Interviews with clients revealed that the quality assurance for prefabricated concrete elements is managed through the contractor's systems. Interviewee B3 noted that the client typically uses turnkey contracts, shifting quality assurance responsibilities to the contractor. Interviewee B1 observed that contractors often try to pass their responsibilities onto subcontractors.

Although the client does not have a dedicated quality assurance system, the Transparency Act requires knowledge of product origins, helping to identify potential quality issues from regions with known challenges. However, this act does not impose quality standards, only requirements for origin, which may only indirectly indicate quality concerns.

Interviewee B2 stated that Norwegian manufacturers are reliable, while foreign manufacturers must undergo quality audits to ensure compliance. Interviewee B3 cautioned that despite the audits, reliance on trust could lead to issues if manufacturers choose to deceive.

Interviewee B1 also highlighted challenges related to quality assurance in large, fragmented project organisations, where responsibilities may fall through the cracks and tasks might not be adequately addressed. Figure 1 illustrates how quality issues can pass throughout the supply chain without being identified if manufacturers choose to deceive.

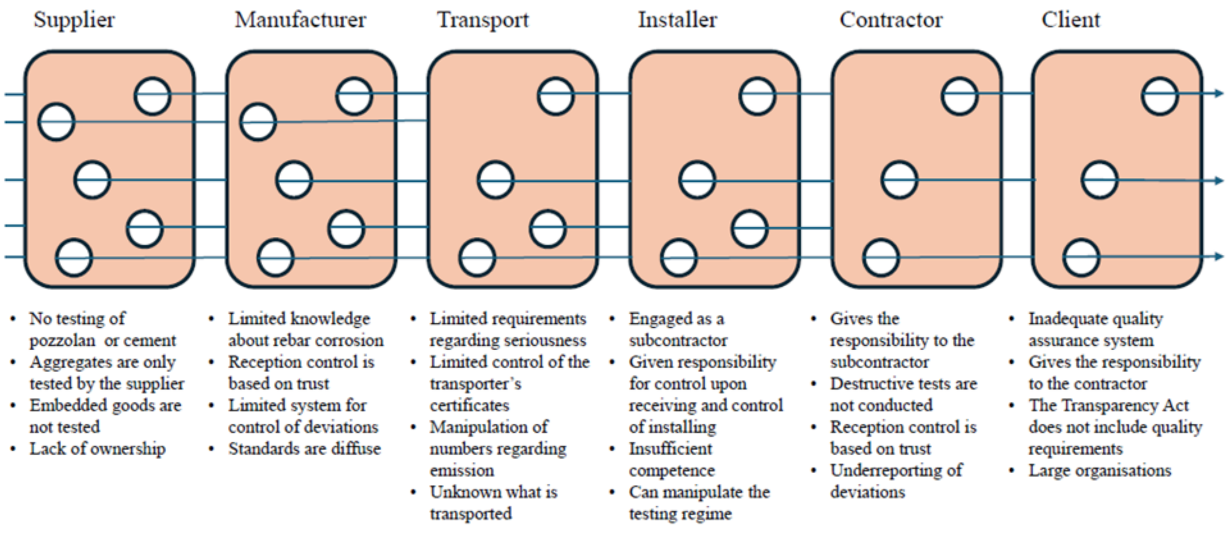

Figure 1: Supply chain with identified weaknesses. The Supply chain illustrates how actors can circumvent or manipulate the quality assurance system for precast concrete elements.

Some quality issues – illustrated by arrows – are stopped, while others pass through the whole supply chain. The quality control can be rigid (few holes) or limited (many holes). Figure 1 also illustrates how prefabricated concrete elements from the studied manufacturer pass through the value chain. Suppliers sell cement, pozzolan, and embedded goods to the manufacturer. The manufacturer hires transport to the construction site, where the installer usually is hired by the contractor. In the end, the element belongs to the client.

DISCUSSION

Interviewees noted that quality assurance for manufacturers, contractors, and clients primarily relies on trust, documentation, and certifications due to limited direct control. Confidence in Norwegian suppliers is high, and no specific quality control requirements for suppliers exist. Engebø et al. (2016) and Kjesbu et al. (2017) revealed that substandard materials can disturb the Lean construction principles of flow and waste reduction. Ghadge et al. (2021) emphasise the importance of inspection and testing to guard against substandard materials, while ANSI's Action Plan stresses continuous quality assurance and employee training to detect counterfeit materials (American National Standards Institute, 2011). Checks on suppliers are typically done reactively rather than proactively, with no regular training for identifying counterfeit materials.

Manufacturers' QA systems align with standards or client-specific requirements and focus on documentation for sub-materials and concrete production. Testing is occasional, with reliance on trust throughout the supply chain. Theory suggests that understanding and verifying the supply chain can mitigate risks of counterfeit materials (Fang et al., 2011). Also, a lack of knowledge about reinforcement corrosion could lead to using substandard materials.

Transport was also identified as a challenge, with insufficient seriousness requirements for carriers. The review of quality assurance theory found no specific mention of transport issues. Interviews revealed that emission figures for transport in EPDs for prefabricated concrete elements can be manipulated, a challenge not covered in the literature. Assembly of prefabricated concrete elements presents quality assurance challenges, such as contractors shifting responsibility to subcontractors. This can lead to issues with testing and control, a concern not addressed in the reviewed Lean construction theory.

Contractors' QA systems follow Norwegian standards and ISO certifications, and trust in Norwegian suppliers is high due to stringent regulations. However, interviewee E1 noted vulnerabilities from relying solely on documentation. Unlike cast-in-place concrete, prefabricated elements lack routine testing, exposing contractors to counterfeit materials (Fang et al., 2011; Ghadge et al., 2021). Thorough supply chain investigations are suggested to prevent counterfeiting (American National Standards Institute, 2011), but manufacturers rely on supplier self-checks. Clients lack a specific QA system and do not enforce quality requirements under the Transparency Act. Lean construction involves fulfilling standards set by industry players (Vrijhof and Koskela, 1999; Pinho et al., 2008; Broft and Koskela, 2018), and relying solely on documentation is not sufficient. Silvestre et al. (2020) note that legislation and enforcement can combat fraudulent practices. Interviewee B3 noted that clients delegate QA to contractors through contracts, creating a potential gap for fraudulent activities.

CONCLUSION

The interviews reveal how different actors quality assure prefabricated concrete elements. The manufacturer's QA system, based on Norwegian standards, involves control over suppliers, production routines, environmental practices, and testing of concrete. The manufacturer utilises several systems for this purpose, including for production, concrete, and deviation management.

The contractor's QA system involves audits, factory visits, compliance with Norwegian standards, and documentation control. Interviewees highlighted that control during the reception and assembly of prefabricated elements is crucial, as it is the primary method to ensure product quality and proper installation.

The client relies on the contractor for quality assurance, following turnkey contracts. While the client must adhere to Transparency Act requirements regarding product origin, they rarely engage in factory visits, particularly with Norwegian manufacturers.

The interviewees identified both strengths and weaknesses in the QA systems. Manufacturers highlighted strengths such as third-party control, customer involvement, reception control, and non-conformance systems. These measures ensure supplier products are satisfactory, customer requirements are met, and deviations are learned from.

However, weaknesses were noted, including limited knowledge of reinforcement corrosion, trust-based reception control, inadequate non-conformance systems, and vague standards. These issues can result in uncertainty about reinforcement quality, poor or poorly documented materials, insufficient detail on non-conformities, and ambiguities due to unclear standards.

Contractor interviewees emphasised strengths in their QA system, including non-conformance management, supplier audits, certifications, and employee competence. These measures help ensure learning from deviations, certified suppliers, and effective QA practices.

However, weaknesses were noted, such as under-reporting of non-conformities, EPD manipulation, lack of control for pozzolans, trust-based reception control, and no system for destructive testing. These issues could lead to undetected non-conformities, inaccurate emission figures, hidden heavy metals, and unreliable verification of prefabricated concrete properties.

Client interviewees highlighted strengths like factory visits, foreign supplier inspections, Norwegian control schemes, and the Transparency Act, which ensure supplier compliance and product traceability. Despite these strengths, weaknesses were also identified: inadequate QA systems, shifting responsibility, and the Transparency Act's lack of quality requirements. This can lead to challenges such as subcontractor manipulation of control regimes and fragmented responsibility in large project organisations, which may compromise quality assurance.

The research highlights strengths and weaknesses in the QA systems used by manufacturers, contractors, and clients for prefabricated concrete elements. Although taking into account the limits to generalizability posed by the limited investigation scope, it serves as the starting point of a research agenda, taking into account questions like quantification, geographical specificities, company sizes, and differences between national and international challenges. Future work should include suppliers, transporters, and installers, and testing pozzolans and pressure-tested cores. Additionally, future research could explore other concrete structures and prefabricated materials like windows, modular walls, bathroom cabins, and wooden "hollow slabs". Methodologically, random sample testing would be relevant for future studies.

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