Experiences with CLT Construction in Norway

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Abstract. The use of cross-laminated timber (CLT) elements in buildings is an innovative and upcoming construction method. In Norway, due to its eco-friendly potential, more widespread use of the method is expected despite limited experience to date. The lack of a domestic guiding literature related to issues such as moisture behaviour is creating uncertainties in achieving sustainable buildings and, taken together, such issues are creating a demand for more information about CLT construction in Norway. Qualitative in-depth interviews were used to obtain views based on the hands-on experience of skilled actors in the Norwegian construction industry. The informants (owner-builders, consultants, contractors and CLT suppliers) revealed different outlooks to the CLT construction process. In general, these actors experienced no more challenges with CLT construction than they did with other construction systems. In Norway, the major barrier to the more widespread use of CLT is compliance with fire safety and acoustics regulations. Differences in focus between the industry and Norwegian literature regarding moisture safety is clear. There is a lack of consistent guiding literature. Closer collaboration between industry and the research community is recommended in order to develop workable solutions. It is important to clarify the risks linked to built-in moisture and its impact on buildings. Research institutions should also focus their research on fire safety and acoustics.

1 Introduction

Of all types of solid wood materials, cross-laminated timber (CLT) elements are the most commonly used for building purposes [1]. CLT elements consist of layers of wood lamellae that are laminated perpendicular to each other. In Norway, a typical CLT element consists of 3, 5, 7 or 9 layers, glued together. Element thicknesses range from 60 to 320 mm [2]. CLT elements typically exhibit widths and lengths of up to 3.5 and 16 metres, respectively [3]. Dimensions are typically tailored to the building purpose in question. CLT elements may be incorporated in building components such as walls (both interior and exterior), flat and sloped roofs, terraces, slabs, mezzanines and shafts [1], and may function as both loadbearing and non-loadbearing components.

The extensive use of CLT elements in buildings must be regarded as a construction system that requires its own design principles and construction methods. To satisfy basic functions regarding energy efficiency and moisture safety for a building component, a CLT element must be used in combination with layers of additional materials [4]. A basic exterior CLT construction wall assembly normally consists of a CLT panel (interior surface), thermal insulation, a wind barrier, a drainage gap and exterior cladding. The literature includes examples of typical wall assemblies [1, 5]. In order to achieve interior airtightness, either a vapour barrier (VB) is added between the CLT panel and the thermal insulation, or the element joints are taped. However, airtightness and moisture safety are controversial issues in relation to CLT exterior wall and roof assemblies, and both parameters have been investigated as part of several research projects [6 - 9].

The development of solid timber elements for building construction started in Central Europe in the 1990s [10]. Since that time, the use of CLT as a construction system has gradually become more widespread, and it is currently challenging traditional construction materials such as concrete, steel and brickwork [1]. The past decade has seen a gradual increase in interest and in the use of CLT for building construction, also in Norway [11].

Research shows that the use of CLT in the construction process has a less negative impact on greenhouse gas emissions compared with other materials such as concrete and steel [12]. The process of photosynthesis in trees absorbs CO2, and the gas is thus stored temporarily as carbon in the building structure during its functional lifetime [13]. Timber materials are thus often referred to as being “carbon neutral” [12] because CO_2 storage in CLT elements results in a low carbon footprint [14]. The eco-friendly potential of timber materials, combined with a desire to promote

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local timber production and processing industries, is encouraging the Norwegian government to boost production and encourage the more widespread use of CLT elements in construction [15]. In recent years, the use of CLT has attained some commercial prestige, exemplified by the construction of the tallest timber building in the world [16]. It is thus reasonable to expect the widespread use of CLT in the Norwegian construction industry in the future. Up until 2014, CLT made up only 2% of the total building mass in Norway, although this is expected to increase to between 6 and 9% in the coming years [17]. To date, domestic Norwegian production of CLT elements has been low. Only 900 m^3 of the 36,000 m^3 of the CLT elements used in Norway in 2016 was supplied by Norwegian manufacturers. The remainder were imported from countries such as Austria, Germany, Sweden, Latvia and Lithuania [17].

CLT as a construction method has only been applied extensively in Norway during the last decade. As such, the Norwegian construction industry has accumulated relatively little experience in applying the method. A study currently mapping the research needs for CLT construction in Europe supports this claim [18]. Results from a study carried out by Espinoza et al. (2016) implies that general levels of knowledge about CLT construction among engineers and research institutions are low [18]. It is pointed out that factors such as moisture behaviour and structural performance in particular should be key fields for further research.

The results from research needs mapping are supported by reviews of existing Norwegian literature on CLT. Firstly, preliminary investigations have discovered very few domestic reports addressing CLT construction and moisture behaviour. Secondly, the existing literature is on average more than 10 years old and is in part outdated due to more recent technological developments in the field of CLT construction. Moreover, this literature is inconsistent in its guidance on important topics, such as the use or non-use of a vapour barrier as an exterior enclosure.

Limited experience, low levels of knowledge, and shortcomings in existing literature constitute a significant barrier to the more extensive use of CLT in Norway. However, a number of actors in the Norwegian construction industry have accumulated extensive experience, and data gathered from such actors ought to be an important source for revealing the challenges and research needs related to CLT construction in Norway.

This paper summarizes the findings of an interview-based survey conducted among Norwegian CLT construction industry organisations. The purpose of the study was to reveal challenges and mapping research needs by means of interviews with actors with relevant experience with CLT construction. On this basis, three research questions were developed, and these constitute the background to our approach to this study:

1. What written knowledge foundation is lacking and preventing the more consistent and widespread use of CLT elements?

2. What building physical details are identified as the most challenging in terms of the construction and design of CLT buildings?

3. Are identified challenges related to a lack of knowledge, and would an increase in research generate better knowledge as a basis for meeting these challenges?

The study limits its scope to a consideration of construction projects in which CLT elements are used, excluding bridges and timber houses. Data gathering related to an organisation's experience generates a large amount of information for analysis. For this reason, the approach to the study and its interview guide are restricted to a primary focus on building physical and technical construction challenges. Issues related to statics, fire safety, acoustics, economics, progress and the environment, are alluded to but are not discussed extensively. These topics are addressed in the interview guide and are important because they provide the authors with general and contextual understanding. This paper is written as a part of a M.Sc thesis entitled "Guidelines for CLT Construction", carried out within the Building and Material Engineering division at the Department of Civil and Environmental Engineering at *NTNU* in Trondheim, Norway, in the academic year 2018/2019 [5].

2 Research method

2.1 Research model

The interviews were carried out in collaboration with the Norwegian research institution *SINTEF Community*, which was concurrently conducting a similar project. The premise for this research is to obtain a direct record of the industry's hands-on experience. The authors concluded, following a series of meetings involving brainstorming and discussions of different survey methods, that the qualitative in-depth interview approach as described in Yin [19], should be applied. Such interviews are based on prepared guides and are designed to function as conversations. The method provides in-depth explanations to the issues raised because the nuances of the questions can be adjusted as the interviews are taking place. A qualitative approach was chosen in order to obtain in-depth explanations. A quantitative mapping of the frequency of different phenomena was not carried out [20], although it is recognised that such an approach may help reveal other aspects and challenges that are not identified in the literature published by research institutions.

Even if the focus of this study is directed at building physical challenges, it was decided to develop a comprehensive interview guide that would provide results of universal character. The interview guide is available in a more extensive report [21]. In this way, it allows the study to consider challenges related to moisture behaviour in a holistic context, which is also reflected in the desire to gather experience from actors with different outlooks on CLT construction. For this reason, owner-builders, consultants (including architects), contractors and CLT suppliers were all asked to participate in the study (see Table 1). It was decided that the interview guide should have a flexible format, allowing it to be tailored to the category of informant. This was entirely possible due to the interview method selected.

Informant organisations were chosen by means of a brainstorming process based on one of the author's preliminary work and knowledge of the construction industry. Some informants were recommended by participants that had already been selected. The main aim was to interview persons with experience of using CLT construction in at least one project. For this reason, organisations were asked to send people with hands-on experience. Many of the participant informants are leading actors in Norwegian CLT construction, resulting in a high level of credibility in the information collected.

Table 1. Overview of interviewed informants.

Category	Number of interviews
Owner-builder	3
Consultant/architect	7
Contractor	6
Supplier	3

2.2 Implementation

The interviews were conducted between September and November 2018, so the responses can thus be regarded as a fair reflection of the current status of the Norwegian CLT construction sector. Nineteen of a total of 21 actors that were initially contacted were interviewed. This was considered to be manageable number in view of the amount of time available and the working capacity of the research group. Even so, the interview process presented some challenges. Firstly, the interviews were conducted over a short interval due to a predefined project period and other deadlines. Secondly, geographical distance and personnel availability, as well as factors such as travel logistics, made it difficult to conduct as many face-to-face interviews as the authors had intended. The authors are located in Trondheim in Norway, but many of the organisations were based in the Oslo region. As a result, most of the interviews were conducted by telephone, with the exception of six or seven one-hour face-to-face interviews conducted by the first author. Telephone interviews lasted from between 15 and 45 minutes, depending in part on the informant's knowledge of the subject. No direct transcripts were taken, but a report was written following each interview. The face-to-face interviews were taped in order to facilitate report writing, and to ensuring quality of the content. The reports were then sent to the informant for approval. The researchers archived the reports in a shared database. These reports represent the main source of information for this study, and constitute the foundation of its results. Information from 19 interviews provides a large database and the sorting process carried out to identify the most relevant information presented a major challenge.

2.3 Triangulation through literature research

Ideally, a qualitative study should seek at least two sources of evidence by means of triangulation. This is an important principle in research studies of this type. This means that researchers should use a combination of different data sources and methods in their study of the same phenomenon [22]. Triangulation of observations can be used to evaluate the credibility of the information collected. Credibility depends in turn on the extent to which phenomena observed in data from the different sources converges or diverges. For this reason, in addition to the interviews, a structured literature survey was conducted early in the study as a means of generating a supplementary source of information. Such a survey was also intended to assist the research group in understanding any discrepancies that may arise in challenges as described by the literature compared with those input by participating informants. This would strengthen the authors' universal view and bias related to the state-of-the-art of CLT research. Triangulation is important to the credibility of our findings in terms of the research questions because the questions themselves focus on mapping knowledge gaps in the literature and the challenges facing the industry.

The aim of the literature survey was to obtain an overview of existing knowledge in the field of CLT construction. Particular focus was directed at Norwegian literature covering building physical topics. Methods involved searches in academic search engines, so-called "snowballing" in investigated literature, and reviews of familiar reports and books. A qualitative and bibliometric selection of the most relevant literature was carried out with credibility, objectivity, accuracy and suitability in mind. The literature reviewed was mainly in Norwegian or English. Moreover, literature on systematic work and similar studies covering experience accumulated in the Norwegian construction industry was reviewed for inspiration, e.g. Hauge *et al*. [20].

3 Results

This chapter presents the results from the interviews, categorised according to subject. The nature of the qualitative method selected means that results must reflect the opinion of the majority of informants. In the following, this is expressed as the opinion of the "industry" or the "actors". For this reason, some discrepancies within the different subject categories may exist.

3.1 Motivation for using CLT

The motivation for using CLT in construction projects must be stated, because this impacts on many of the ideas and circumstances that explain why and how CLT is used. The most stated motivation for choosing CLT was because it had a less negative impact on the environment. The actors' experience is that CLT is used mostly in public building projects. Actors experience that success in terms of cost and productivity depends on the type of building under construction. The use of CLT is beneficial in cell-based buildings with relatively short spans, such as student residences and health institutions. Most actors state that CLT is a time-rational construction system, since elements can be erected at faster speeds than other prefabricated materials. In Norway, there exists a conceptual principle that CLT must be used for interior visible surfaces. The industry insists on this principle and architects are happy to use CLT because of its aesthetic properties. Visible CLT in Norway is different from that described in the international literature, where CLT is used because it is an environmentally-friendly material that enables rationality in the construction process.

3.2 Existing literature and knowledge basis

The literature survey shows that only a few Norwegian reports exist that address CLT construction in relation to building physics and moisture behaviour. All such technical reports have been published by the research institution *SINTEF Community*, regarded both in Norway and Europe as a leading and credible research institution. These include two reports that address moisture behaviour from 2008 and 2011, respectively [8, 9]. However, these reports are inconsistent in their guidance regarding the use of vapour barriers (VB). Time et al. [8] conclude that CLT used in roof assemblies may use a VB in order to achieve adequate moisture safety, but that it is not a requirement. Skogstad et al. [9], after studying air leakages through dried CLT elements, conclude that the use of a VB in CLT wall design is recommended. There also exists a limited amount of guiding literature in the form of handbooks and construction guides. The only handbook in existence dates back to 2006 [2]. Thus, it is likely that some of the content of existing literature is in part outdated in the light of more recent developments in the CLT construction method. This issue is reflected in reference [8], which addresses thermal insulation systems and measures designed to achieve local airtightness. A further report addressing CLT and acoustics was published in 2014 [23].

Indications of the existence of only a limited amount of Norwegian literature on this topic is confirmed throughout the interviews conducted in this study. The industry states that there is little guiding literature available that is helpful for everyday use in a Norwegian context. There is a major lack of guiding literature showing principles and standard solutions such as those required to comply with fire safety and acoustics regulations. This lack has forced the industry to seek out other sources of information as a basis for designing CLT buildings. Most commonly, experience from previous CLT projects is used as a reference for the design of new solutions. Guidance in the form of product specifications (technical brochures) from CLT suppliers is also used. This often consists of imported design solutions from Central European (German or Austrian) suppliers. There is much uncertainty and a lack of standardisation linked to the processes required to adapt to the Norwegian climate and building traditions. A general lack of expertise, and in particular of consultants with a global outlook, presents a challenge and results in a more complex design process. High levels of expertise and experience are key to a successful design process.

3.3 Fire safety and acoustics

The major finding of this study is the identification of challenges linked to fire safety and acoustics. These aspects have much in common and can be discussed together. Our interviews have revealed that the major challenge related to CLT building construction is the requirement to comply with fire safety and acoustics regulations. This is due primarily to the absence of standard solutions that are pre-designed to comply with such regulations. The problem applies mainly to taller buildings (greater than four storeys). Some actors maintain that some regulations are outdated and conservative, and discriminatory against CLT as a building material. Compliance with regulations is pointed out as the major barrier to the more widespread use of CLT in Norway. It is also regarded as problematic that a number of fire safety consultants prefer and approve other types of design solution. The industry states that current regulations require a thorough overhaul and adjustments that take the existence of CLT as a material into account. Such regulatory changes are essential if the use of CLT is to become more widespread. Compliance with regulations, especially those governing non-burning surfaces, requires the addition of more layers. However, this may reduce the positive aesthetic and environmental benefits linked to CLT, and is often costly and detrimental to project productivity.

3.4 Moisture behaviour and airtightness

Issues regarding moisture behaviour are granted proportionately less attention in the industry than they are in the literature produced by Norwegian and international research institutions. Much focus in the literature is directed on the use or non-use of vapour barriers in exterior assemblies in order to achieve moisture safety. The industry seems to be more relaxed in relation to this issue. The actors generally follow the instructions and recommendations provided by CLT suppliers. However, the industry also states that it encounters variations in the design and types of solutions for exterior assemblies in terms of the use or non-use of VB. The most common CLT element application in exterior wall components is when it is used as an interior surface element combined with exterior thermal insulation and cladding. According to the industry, the most important measure that can be taken to achieve a moisture-safe building is to ensure that it is entirely airtight. The most common means of achieving adequate and effective airtightness is to use tape on the element joints, combined with an exterior wind barrier (WB) installed outside the thermal insulation layer. Some actors also use a water-permeable WB located between the CLT element and the thermal insulation, in combination with another WB installed exterior to the thermal insulation. If a continuous rigid thermal insulation system is used, the wind barrier is frequently omitted on both the interior and exterior sides. On larger projects, continuous rigid thermal insulation systems are often preferred to standard framework systems for reasons of faster installation. A shorter installation period may also reduce the amount of time during which the elements are exposed to rain and snow. Moreover, some actors normally use a VB in wall assemblies. The decision on whether or not to install a VB also depends on the level of moisture encountered on the building site. Thus, the moisture content of CLT elements always depends to some degree on the extent of exposure to weather during the construction process.

However, enclosure design also depends on the types of construction and the components used. Almost all actors install a VB in CLT roof assemblies. The principle that airtightness is the most important measure required to achieve moisture safety correlates with the emphasis we observe in the international literature, but is hardly ever mentioned in Norwegian references. According to the industry, it is easier to achieve airtight buildings using CLT than with other materials using the same investment in effort. However, there is some uncertainty as to whether the airtightness achieved persists after the CLT elements have finished shrinking. Consultants in particular were curious about this phenomenon. Cracks and air leaks that develop as a result of the drying and consequent shrinkage of CLT elements are discussed in reference [9].

In general, and despite variations in design, the actors do not experience increased levels of moisture-related damage and repair projects in CLT constructions compared with other projects. If such damage occurs, it is often due to ordinary exterior leakage issues that are unrelated to diffusion or convection.

3.5 Building site moisture and weather protection

A topic frequently mentioned in the literature involves the weather protection systems (WPS) used on building sites as key measures implemented to avoid the wetting of CLT elements by direct contact with liquid water. In general, the industry finds that WPS are too costly and impractical due to the logistics of crane lifting of the CLT elements, and uses a variety of other means to carry out moisture-safe building processes. However, methods and procedures vary from actor to actor depending on the type of project, previous experience, available space on site, and the degree of prefabrication of the CLT elements. Procedures and measures also depend on the season and weather conditions. The most important of these involves the delivery logistics of CLT elements to the building site. If transport and delivery are well coordinated in relation to project progress, CLT elements are stored for less time, and in some cases can be erected immediately following delivery. This reduces the period during which the elements will be exposed to damaging weather conditions such as rain and snow. In cases where CLT elements are stored after arrival on the building site, actors make every effort to keep the elements dry, protected either by roofs or under water-resistant coverings. Ideally, roof protection should be provided by the builder. After erection, procedures vary from actor to actor and, in general, CLT supplier advice is followed. Roofing should be provided immediately. However, if this is not possible, some actors insist on the use of some other form of weather protection, either a water-resistant plastic cover or temporary protective sheeting provided on delivery by the supplier. Other actors are more relaxed about this and do not cover the CLT elements, leaving them exposed to rain and snow. Their argument is that the hygroscopic characteristics of the CLT will facilitate adequate drying and mitigate damage.

Contractors state that they do not receive many claims related to moisture damage in buildings with CLT. Their experience is that standard quality assurance systems ensure that moisture is usually absorbed in the outermost layer of the element, and that in most cases moisture content is later reduced to acceptable values. If this is not the case, measures are taken to dry out the elements, and extended quality assurance actions are implemented. Some actors experience a discolouring of CLT elements that have been subject to prolonged exposure to water. Consultants, in particular, state that guiding literature containing principles for moisture control on CLT building sites is lacking. A number of consultants also express a desire for a greater focus on building moisture control at an early phase of projects.

4 Discussion

Our aim in this paper is to address the research questions listed in Section 1. The first question implies that existing Norwegian literature in the field of CLT is somewhat limited. This is confirmed by our literature survey and the qualitative interviews, both of which reveal weaknesses inherent in the Norwegian literature. The number of reports that address CLT and its associated building physical challenges, as expressed by the industry, is very limited. Only two reports exist that address CLT moisture behaviour, and these have an average age of ten years. One of these reports addresses CLT and acoustics. However, no reports have been published that address CLT in the context of fire safety. Informants confirmed a general lack of guiding literature and handbooks that are of practical use for everyday purposes. A number of CLT assembly design and principles also support this lack of guidelines. An investigation of current standard industrial construction principles strengthens our belief that existing reports and literature are outdated in terms of the methods and solutions they present.

The consequence of this lack of guidance is that historical and outdated CLT projects are being used as references for design and construction in contemporary settings. This means that the various actors keep CLT-related research results in-house and do not share their knowledge or experience. This situation provides experienced actors with clear competitive advantages during tender rounds for new CLT projects. Competent and experienced people are key to a successful project, especially in the design phase, and experience sharing represents an important potential source of information for research institutions when they develop guiding literature. An elevation of the general levels of knowledge about CLT will highlight current industry insecurities related to CLT construction, which in turn may promote more widespread and universal use. For this reason, the creation of new guidelines and handbooks that contain clearer details of construction methods may represent an important success criterion in the design phase, which is currently experienced as complex. In general terms, the potential for knowledge improvement correlates with the results presented in reference [18] and with the indications regarding limited levels of experience as described in Section 1.

The second research question addressed the identification of the building physical challenges encountered in CLT construction. The question arose in response to industry insecurities related to CLT moisture behaviour, and the use or non-use of vapour barriers (VB) in CLT assemblies.

Since the actors experience no more challenges with CLT construction compared with other, more widely used, materials, we have to conclude a non-discovery in this case. However, because CLT represents a relatively novel construction system, we also recognise new challenges. According to the industry, the most challenging issue linked to CLT construction is compliance with fire safety and acoustics regulations. This is essentially a regulatory problem, as opposed to a materials-related construction issue. Since CLT as a material, and its construction method, are relatively new to Norway, it is possible that some of the principles used to develop fire safety and acoustic regulations were established before CLT elements evolved as standard construction materials. Moreover, the properties of CLT materials vary between suppliers, and this has an impact on predictability in terms of fire safety performance. Thus, the industry has a point when it argues that an overhaul and adjustment of regulations adapted to the introduction of CLT may lead to its more widespread use, assuming that any regulatory changes are not to the detriment of basic health and safety principles. Revisions of standards and regulations do not occur spontaneously. Delay is reasonable and to be expected, especially since a period of time will be needed for the authorities to obtain a full understanding of the characteristics of CLT. However, such revisions will ease the design phase in CLT projects and promote more efficient use of materials. The missing link in terms of the regulatory issue is the documentation of standard solutions. This is why further research into developing such solutions is so important. By limiting the focus on making CLT surfaces visible, this may also make it easier to comply with the regulations, since layers of other materials can more easily be added. However, this reduces the positive effect of less materials usage, so it is important to identify other reasons and incentives for using CLT.

In general, the results are surprising, and deviate from expectations in relation to some topics. The authors did not envisage that challenges related to moisture behaviour and the use or non-use of a moisture barrier would constitute the most controversial issue. Certainly, this topic seems to have been the subject of less attention in the industry than it has in the literature and among the research community. The authors had imagined that, due to the lack of literature, the informants would highlight a greater number of technical challenges related to CLT building construction. On the contrary, the industry experiences no more challenges with CLT construction than it does with other materials, even though some issues are identified that relate to the material characteristics of CLT.

Our results indicate that the issue of moisture behaviour remains an active topic for discussion. This is supported by a comparison of published literature and principles established in the industry, which indicates that there is no clear answer to this issue. Clearly, there is a dependency on the type of project, the experience of the operators and the moisture content of the CLT elements. Variations in methods and procedures in relation to the use or non-use of a vapour barrier, as well as in building site moisture control, reflect a lack of consistent standards and guidelines on these issues. Even if the industry seems to be relaxed on the issue of CLT and moisture behaviour, there are still grounds for further research. There are also uncertainties related to durability in relation to moisture safety and airtightness resulting from CLT element shrinkage. This issue, which is controversial in the literature, has been highlighted by consultants as a problem that may affect moisture safety in CLT buildings. In order to innovate, the industry must first allay the suspicions of the research community, and demonstrate that airtightness in CLT buildings is durable, also after element drying and shrinkage. Once more empirical experience has been obtained, the research community can develop more guiding literature in this field. In view of this, closer collaboration between industry and the research community will be key to the development of clearer guidelines on building site moisture behaviour. Uncertainties linked to this topic are an important field of research [18]. Future research should conduct quantitative measurements on full-scale buildings, and not only on small-scale laboratory elements. Such studies have not as yet been published in the Norwegian or international literature.

This leads us to the third and final research question. Some of the challenges noted above can probably be addressed by means of focused research. Moisture behaviour issues require further empirical evidence that will enable the industry and research communities to satisfy their respective information needs. The industry must verify that CLT is a rational and durable construction material, and the research institutions must develop guiding literature that is applicable in the industry. Closer collaboration will reduce existing industry insecurities related to CLT design and construction. However, closer collaboration raises funding issues. Studies into possible amendments to existing fire safety regulations may provide opportunities for the more widespread and standardised use of CLT. On the other hand, novel CLT systems that more easily satisfy existing requirements should also be investigated. An amendment of the principle of CLT visibility may also partially address this challenge. Since new regulations may reduce the environmental benefits of CLT, other benefits and incentives, such as improved health and safety, must be identified to justify its use. Internationally, and as reflected in the construction details set out in references [1, 13], CLT is in widespread use, even if it is not visible. Some of the solutions published in the international literature may therefore be an important source of information. In Norway, there is a need for tailored adaptations to climatic conditions and adjustments to local building traditions.

5 Conclusion

In this study, we have set out to assess the knowledge gap, research needs, and building physical challenges related to the use of CLT methods in the Norwegian construction industry. The study has shown that in-depth interviews with experienced actors in the Norwegian construction sector is a beneficial method of obtaining large amounts of information. The interviews were useful both for an assessment of research needs, and as a means of achieving an overview of shared CLT construction principles. Interviews with actors with divergent approaches to CLT projects was key in enabling us to identify challenges seen through different eyes. Triangulation by means of a literature survey was key to providing a universal view on the status of the CLT sector. Throughout the study, we have experienced that some of our initial impressions and assumptions have been confirmed, while others have been rejected. We have also identified some new challenges related to CLT construction.

The results reveal that there exists a knowledge gap related CLT building construction, within both industry and the research community. Our findings confirm indications from other studies that the general level of knowledge about CLT is low. Existing Norwegian literature is limited, and is virtually redundant. The industry has expressed a clear need for more guiding literature, such as handbooks that provide instructions for CLT construction. Guiding literature addressing the contentious issues of moisture behaviour and rational fire safety and acoustics principles is lacking and/or inconsistent, and such issues constitute important subjects for further research. The need for guidelines is also recognised for the achievement of moisture-safe assemblies, and for the various procedures applied in dealing with building site moisture. More guiding literature could also contribute towards the development of less complex design processes. The current lack of literature in Norway has encouraged a culture that promotes in-house research within stakeholder organisations, rather than more widespread innovation and knowledge sharing.

In general, the industry experiences no more challenges with CLT construction than it does with other materials. However, challenges do exist in relation to the use of a novel construction method by actors with little practical and empirical experience. The largest barrier preventing the more widespread use of CLT in Norway is compliance with existing fire safety and acoustics regulations, and the industry is demanding regulatory overhaul and adjustment. There is also a demand for solutions that comply with existing regulations. The issue of CLT and moisture behaviour is an important topic on which there is some disagreement between industry and the current literature. There are also discrepancies between various actors in the industry. A number of design principles are applied to achieve moisture-safe assembly. There also exists a variety of measures for the handling of building site moisture. There are also uncertainties regarding the durability of airtightness after the drying and shrinkage of CLT elements, and this issue has an impact on decisions regarding the use or non-use of vapour barriers in CLT wall assemblies. There is also a need for more empirical data on air leaks resulting from dimensional change. A project that addresses this subject was launched by *SINTEF Community* during the spring of 2019. The challenges summarised here all indicate that CLT and moisture behaviour is an important field for further research.

We recommend that the industry and the research community increase their collaboration in further research. At present they are behaving as if they were in opposition to each other, and this is inhibiting innovation. Closer collaboration may result in boosting mutual credibility and may assist in elevating general levels of knowledge in the field of CLT construction. The research community should focus its work on topics that can be useful for everyday industrial application. This can be achieved by developing guiding literature such as construction guides and handbooks. This in turn will expand the knowledge base within the industry and highlight the insecurities it faces, leading to the more widespread and standardised use of CLT. For its part, the industry must verify that the CLT elements it uses in exterior assemblies are sustainable with respect to moisture safety and airtightness. It is essential that the research community obtains more empirical data from experience in the construction of full-size buildings. This will require closer collaboration between industry and the research institutions. New economic and financial models must be developed because closer cooperation raises issues about the practicalities of project funding.

Solutions published in the international literature may be an important source of information. In Norway, there is a need for tailored adaptations to climatic conditions and adjustments to local building traditions.

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