Evolving timber school building design in Norway.

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ABSTRACT: Due to the eminent importance of global sustainability, Norwegian municipalities as acting clients for school buildings, have initiated the usage of massive timber (Cross Laminated Timber) in new buildings. This paper is aiming to gain knowledge regarding the construction of massive timber school buildings by examining three case studies located in Norway. The findings suggest that appear to be four main factors that determine the choice and placement of material in the selected buildings: sustainability, topography, function and structure. Sustainability goals advocate maximization of usage of massive timber in the school buildings. Topography indicates that underground volumes are constructed in concrete and steel. Function and structure restrict the usage of CLT in main teaching spaces that have smaller spans, while acoustically challenging spaces like music rooms and auditoriums are constructed in steel and concrete. Literature also showed an evolution of massive timber construction in Norway, with contemporary architects and engineers achieving larger room spans than 10 years ago. Based on the findings, CLT construction is increasing and can change the way schools are being built in the Nordics.

1 INTRODUCTION

In Europe the energy consumed in the building sector is applicable for the 40% of the total energy consumption and 36% of the greenhouse gas emissions.(EuropeanComission) Nonresidential buildings occupy 24.2% of the total building floor area from which 18% corresponds to school buildings. (EuropeanComission). Consequently, school buildings play a major role in EU total energy consumption and CO2 emissions and by improving them countries can be able lower their CO2 emissions.

As far as Norway is concerned, public authorities in compliance with the EU directions have been trying to promote sustainability values in the building sector. Since school buildings mostly are publicly funded buildings, it is easy to approach this typology when implementing regulations into the building sector. Except for buildings that need minor renovations, it is obligatory for the new school buildings to follow EU threshold values, from the architectural competition stage already. Local municipalities, who are the acting clients in the school projects, request in every architectural competition that the requirements of new schools include predetermined sustainability acts regarding its construction method, CO_2 emissions and energy consumption. This results in all future school buildings to be compliant to an environmental program such as BREEAM, Passive house or ZEB (Fufa et al., 2016)from the competition stage.(Meziani, 2018) (Houck, 2016)

For architects to be able to tackle the environmental standards, massive timber is often used in construction instead of more traditional material such as steel and concrete. This has resulted in great opportunities for the forest industry, as the usage of timber construction has been gaining popularity especially in the Nordics, the last decade. In Norway, according to recent statistics gathered by the building industry (Byggfakta, 2021) CLT construction was used only in 12% of the new school buildings (2013) while this number raised over 40% in 2021. (Figure 1)

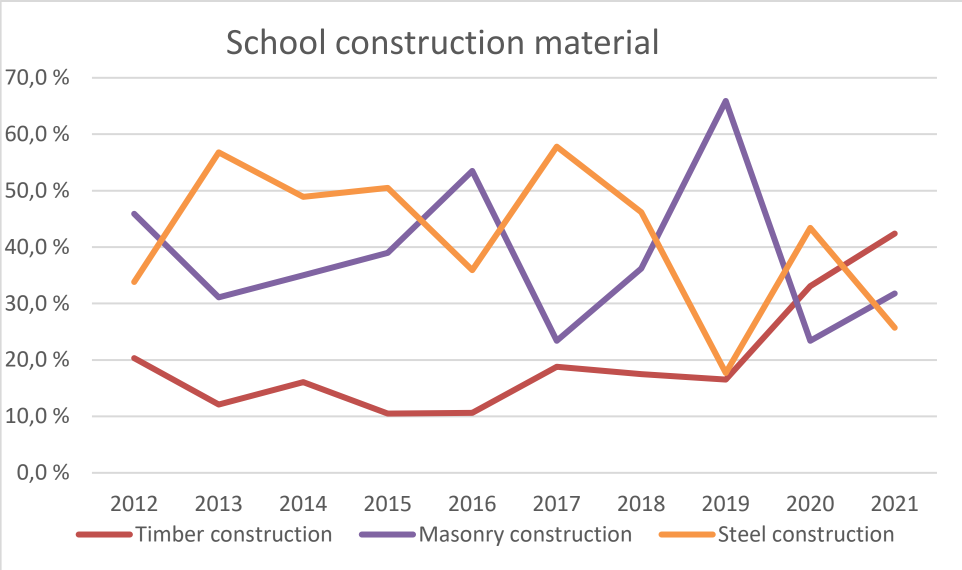

Figure 1. Different types of school construction material in Norway (Byggfakta 2021)

There are many advantages in the usage of cross laminated timber as a building material in school buildings. As far as the sustainability of the material itself is concerned, wood emit less CO2 and require less energy to be constructed. (Cabeza et al., 2013) (Buchanan and Levine, 1999). Eliassen et al.,2019 have shown that we can achieve a 25% lower GHG emission in the production stage by using CLT construction compared to concrete and steel, while we can have a 13% lower emissions when taking into consideration all stages of construction.(Eliassen et al., 2019, Svortevik et al., 2020) Showed that in the Nordic a cross laminated building has a 16.7% lower total CO_2 emissions compared to a steel/ concrete building .

Added to this, one of the greatest advantages of the CLT construction is its capability of prefabrication as well as its clean construction process and short erection times on site. The panels are being modelled beforehand and then cut to measure in the factory, including openings such as door, windows and ventilation channels when needed. This results in a construction product which is easy to mount, lightweight to carry, and healthier construction site for its users. (Alsen, 2018). Compared to concrete slabs, CLT slabs are less suitable for longer spans. According to the Norwegian Institute of Wood Technology (2009) a 240mm thick CLT slab can span at 7 to 7,5 meters.

For the prefabrication to be accurate and sustainable, digital 3d modelling and Building Information Model (BIM) is being regarded as the most effective way of designing CLT buildings. Norwegian Directorate of Public Construction and Property (Statsbygg) has promoting 3d modeling of buildings, for more than a decade. Since 2009, BIM has been a requirement to all architectural competitions of public buildings and most architects use 3D modelling as their main design and planning tool.

However, through their lifespan, the buildings require frequent renovation in order to prolong their longevity caused by the evolution of needs of its owners and occupants. The change of climate and the rising of temperatures also makes the flexibility in school buildings imminent.(Zheng and Weng, 2019) (Bai and Song, 2021)Research has shown that ' *The three types of changes in a building are in its functions, the capacity of its systems, and the flow of the environment and people within and around the facility* (Slaughter, 2001). Hence the buildings structural systems play a major role in any future upgrade. Due to the requirements of a rigid structural grid system with limited roof span, the CLT construction may show limited possibility of modification, transformation or further reuse of the building, shortening school's permanency.

Moreover, even though CLT has been used in the European building industry for almost 20 years, there is still a lack of experience amongst engineers and architects. The lack of experience has led to the absence of standardized construction detailing, and maybe future construction problems, as there is a deficiency in building references. A group of international experts is currently working on the inclusion of cross laminated timber in the Eurocode 5 (EN 1995-1-1).

Finally, lightweight floors such as CLT , may show undesirable acoustic transmission and vibration performance due to the fact that they contain '*high rations of modal stiffness to mass that makes them prone to resonance and amplifications of motions resulting from surface impacts'*(Onysko, 1986) .Ussher et al. demonstrated that current usage of analytical methods to calculate vibration serviceability on CLT floorings is unsatisfactory, especially for particular building occupancy classifications (Ussher et al., 2017). Although international efforts are being made to tackle the vibrational behavior of CLT flooring, this is still an area with research development.

This article aims to accumulate knowledge on how massive timber schools are been built in the Nordics, as well as to conclude which factors determine the usage and placing of materials in the chosen school buildings.

2 METHOD

In this article the focus is drawn on primarily massive timber buildings due to its advantages and significant increase in the Norwegian market the last 5 years. The study is based on examining three CLT Norwegian schools; Bamble , Flesberg and Huseby (Table 1) . All three schools have been built the last four years and follow the latest Norwegian technical legislation. (DIBK, 2017) which implies that the same legislative framework was used when designing them.

The selection of the case studies is mainly a result of the accessibility of the data. As far as the design and construction techniques are concerned, BIM (Building information modeling) was used in all 3 cases. For this research, data were collected by accessing the BIM files of all 3 schools, and more specifically through the usage of IFC files. Through those files we were able to examine the differentiation in material allocation and quantity, the construction technique used as well as the spatial arrangement of each school.

Added to this, information concerning the initial conceptual stages of the projects were obtained by the architectural team that was involved in designing the projects.

Table 1: the table shows accumulative information about presented schools.

	Case A-Flesberg School	**Case B-Bamble School**	**Case C-Huseby School**
Time frame:	2017-2019	2018-2021	2017-2021
Location and client	Flesberg Municipality	Bamble Municipality	Trondheim Municipality
Contract and competition type	Contractor and design team participated in a competitive procedure with negotiations Design Build Contract	Contractor and design team participated in a competitive procedure with negotiations Design Build Contract	Architecture competition Late Design Build Contract
Architect	Spinn Arkitekter AS	Spinn Arkitekter AS	Spinn Arkitekter AS Filter Arkitekter AS

Contractor	Backe Stor	Backe Vestfold	Hent
Size	8.500 m2	14.633 m2	13.800m2
Capacity	450 students	540 students	366 students
Areas	Teaching spaces Sports hall Swimming hall Public library Cultural spaces	Teaching spaces Sports hall Swimming hall Gym Cultural center	Teaching spaces Cultural center Sports hall
Sustainability standard	Passive house	BREEAM Very good	BREEAM Very good
CLT Structural Grid size	7,96 x 8,99 m	4,5 x 8,6 m	8,8 x 7,4 m
Structural system	Load bearing beams and columns (framed)	Load bearing beams and columns (framed)	Load bearing walls
Timber slab thickness	180 mm	160 mm	220 mm
Timber wall thickness	140 mm	120 mm	160 mm

Case A: Flesberg School (2017-2019). The school consists of 4 individual volumes that link together through a connecting area. The concept of this project indicated that each volume has a different purpose; the more acoustically challenging volumes such as the swimming hall, the and the sports hall are isolated from the last two volumes which are used for teaching spaces. The connecting area between the volumes serves as a common area for students as well as library amphitheater and administrative space. The project is placed partly under the terrain due to its topography. The parts of the building which are underground, are constructed in concrete. Above ground level, the construction method is CLT, including the walls of the sports hall and the swimming hall. The roof is constructed with gluelam beams. The project was a so called "competitive procedure with negotiations" where the contractor, architect and engineering team competed against other teams. The competition delivery was both a fixed price and design. The competition form required an extensive use of CLT for reducing the CO_2 emissions of the project. In order to enhance the sustainability of the building, a hybrid ventilation system was chosen, so the excess heat from the swimming pool can be used in heating the communal areas. As far as the structure is concerned, Flesberg school has a CLT structural grid size of 7,96 x 8,99 m, timber slab thickness of 180mm and timber wall thickness of 140mm, while it uses a loadbearing beam and column system. (Table 1)

Case B: Bamble School (2018-2021). The building consists of 3 volumes; the first two ones which inhabit the teaching spaces are connected through a common area, while the third one which accommodates the sports, swimming hall and the gym, is independent. The concept has separated the volumes in order to protect the main teaching spaces (classrooms) from the more acoustically challenging volumes (sports hall, swimming hall, gym) The building is made from CLT, but for the swimming hall concrete was used. The project was again developed in collaboration of the architect and the contractor, and it was described as a massive timber building from the early competition stage. Both Flesberg and Bamble projects were designed by the same architectural team (Spinn Arkitekter AS). The topography of the site indicated that no volume needed to be placed under the terrain. As far as the construction and structure is concerned, Bamble school has a structural grid size of 4,5m x8,6m, timber slab thickness of 160mm and timber wall thickness of 120 mm. It also uses a loadbearing beam and column system. (Table 1)

Case C: Huseby School (2017-2021). The building consists of 2 different school volumes that connect through a concert hall and a sports hall. The school's concept was to separate the different age groups (each school has a different entrance) but on the same time unite them under the cultural and activity spaces. The main teaching spaces (classrooms) are made of massive timber while the common spaces (sports hall, concert hall) are constructed out of steel placed under the terrain. Concerning its construction and structure, Huseby school has a structural grid size of 8,8 x7,4 m, timber slab thickness of 220mm and timber wall thickness of 160mm and uses a load bearing wall system. (Table 1)

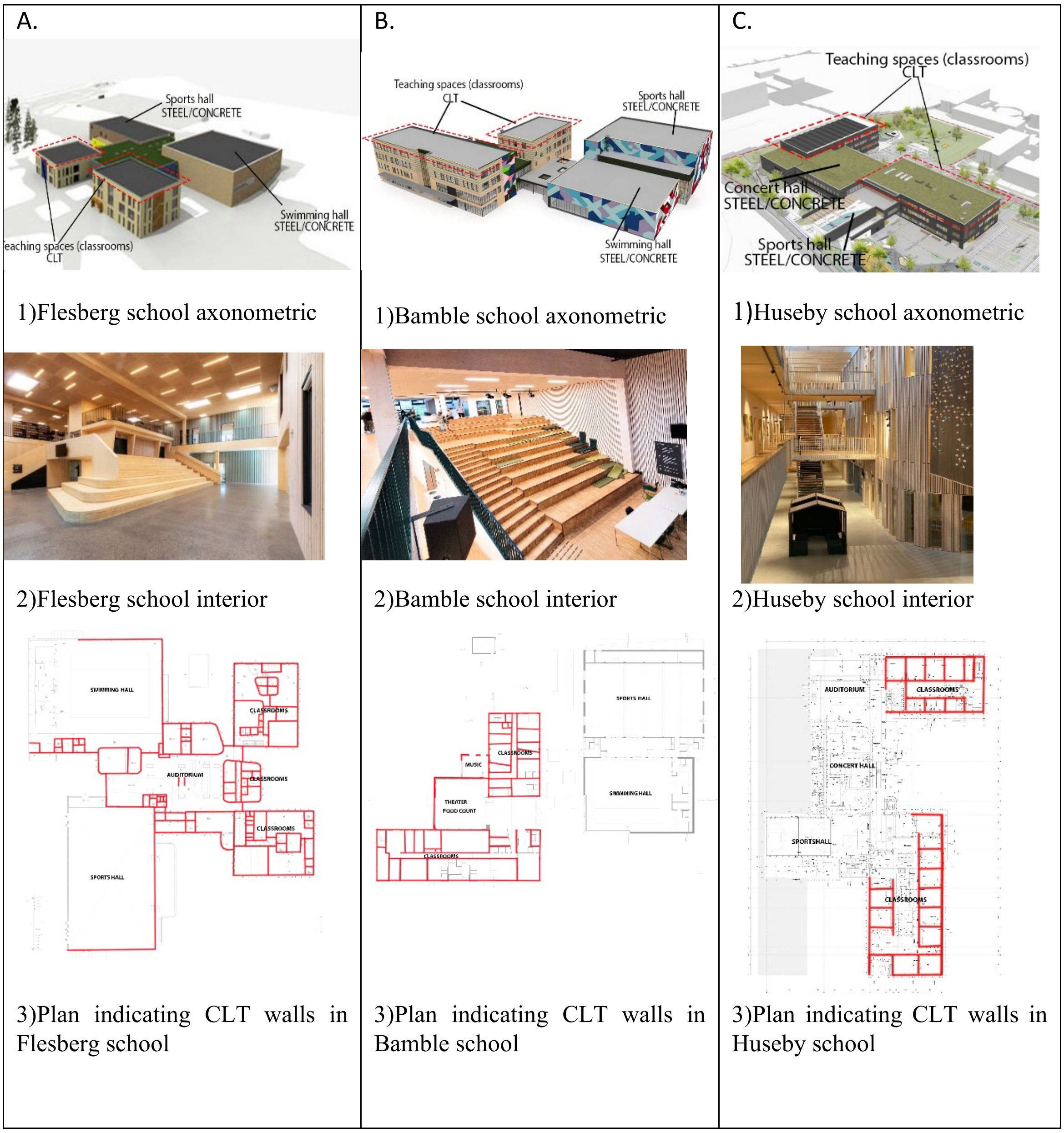

Figure 2: The figure shows visual data of presented case studies. (Spinn Arkitekter AS 2021)

3 FINDINGS

3.1 *CONSTRUCTION*

The investigated buildings although use the same materials (massive timber, steel and concrete) show differences concerning their structural grid system and constructional elements. All three buildings use timber mostly in the educational spaces, while steel and concrete are used in the areas with acoustic difficulties and need for bigger span. In Flesberg, massive timber is also used in the swimming and sports hall while in Bamble and Huseby, swimming, sports and cultural halls are being constructed mostly by steel and concrete. (Figure 2, A3, B3, C3) This is mainly due to the topography of the terrain and maybe due to the structural properties of massive timber. Designers seem reluctant to use massive timber in big rooms with difficult acoustic properties and big spans as currently were lacking construction detailing to tackle the mentioned problems. Flesberg and Bamble use almost the same construction method with the massive timber walls and slabs having similar thickness, while in Huseby both walls and slabs seems to be thicker. (Table 1)

3.2 *STRUCTURAL GRID SYSTEM*

The investigated case studies shows that the design teams managed to achieve longer spans than the Norwegian Institute of Wood Technology assumed in 2009. Flesberg has the longest and widest grid system with 7,96m x 8,99 m while Huseby comes second with 7,4 x 8,8 m. Bamble uses a much narrower span with 4,5 m x8,6 m. Having a broader structural grid system allows better visual quality, teaching spaces uninterrupted by columns and hence better flexibility in the floor plans.

3.3 *SPATIAL ARRANGEMENT*

The Huseby school has the most traditional floor plans in the main teaching areas. Each class level has its own classroom and access to group study rooms. In addition, the corridor widens up and there is a small amphitheater and study spaces. The teaching space for the younger students (1-7 class level) has a double corridor system, whereas the teaching space for the older students (8-10 class level) has a single corridor system. In one volume the classrooms are placed opposite each other with a linear corridor in between, while in the biggest in width volume, classrooms are spaced in a peripheral rotation. At Bamble school, the acting client (municipality) did not want traditional classrooms, and therefore the teaching area consists of a larger free space with a limited set of group study rooms, niches and classroom size spaces attached. It uses a different approach on teaching spaces with most of them being common spaces instead of traditional square shaped classrooms. Team rooms are placed opposite each other in linear direction leaving space for corridors in the middle. As far as Flesberg school is concerned, the client also chose to not have traditional classrooms. The client required that each teaching area should be different to provide the students with a variety of learning environments during their 10 year stay in the school. In this project, buildings are placed peripherical the CLT constructed volumes in order to achieve the best daylight, leaving space for the group rooms in the center of the volume.

4 DISCUSSION

From the overall investigation, we can see that there are four main factors that influence the choice and placement of materials in the chosen buildings: sustainability, topography, function, and structure. In all three buildings the engineers and architects tried to maximize the usage of CLT in order to reach the sustainability goals that were set by the acting client (local Municipalities). In the two case studies (Huseby and Flesberg) that we have inclined terrain the building volumes that are under earth are made in concrete while CLT is used in above terrain levels. The architects and engineers seem to strategically apply timber in teaching spaces that required smaller spans, while use steel and concrete in areas with acoustic or structural challenges.

In Flesberg, the engineering team managed to apply CLT construction on considerably more areas than Bamble and Huseby, including parts of the swimming and sports hall. The same team (architects and contractor) worked on both Flesberg and Bamble, but from investigation it turned out that the engineer working with building physics was different on Bamble and didn't support the usage of massive timber in the swimming hall. That resulted in the usage of steel instead of massive timber. Added to this, we see a considerable difference in the thickness of the timber elements used in the investigated case studies which may also result from different economic requirements of each project.

5 CONCLUSION AND FURTHER RESEARCH

Steel and concrete used to be the dominating materials in the school building construction globally. Nevertheless, the construction of massive timber in school buildings has been increasing in Norway the last five years with the great support of the public authorities. In order to understand this relatively new structural method, three CLT schools were examined with different construction elements and spatial arrangement methods. The findings concluded on the choice of materials being affected by four main factors: sustainability, topography, function and structure. Although engineers and architects try to maximize its usage, massive timber was mostly used in spaces with smaller span requirements, and on above ground levels. Furthermore, we observe an increase of the span length the last 10 years, which might lead in the future usage of CLT in bigger rooms as well.

For the next step it would be interesting to address the limitations of construction methods used in Norwegian school buildings by investigating a greater number of massive timber schools and compare the findings with traditional constructed schools out of steel and concrete. Added to this a study on hybrid systems that include combination of timber and other solutions seems to be of great importance on informing the readers on new construction methods, and how can these impact the function of the space.

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