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MEETING THE 2050 PARIS AGREEMENT TARGETS USING MASSIVE TIMBER IN SCHOOL BUILDINGS

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ABSTRACT: Due to the importance of global warming and the signature of the Paris agreement, Norway has committed to reducing greenhouse gas emissions by 95% by 2050. Using school buildings that have already been designed with high environmental standards as case studies, one can identify the building elements that contribute the most to embodied energy and develop methods to reduce them even more. This article presents a review of 4 schools that include massive timber elements, the correlation between their CO_2 emissions and the gross floor area per year and compares this ratio to the Paris agreement targets set for 2050. The study revealed that the case studies comply with the current median environmental performance standards but lack to reach the 2050 targets. Added to this, the importance of using more massive timber in school buildings was highlighted and the need for an upgraded timber material was underlined.

KEYWORDS: LCA, timber schools , school buildings, sustainable schools

1 INTRODUCTION

It is widely recognized that the construction industry is greatly contributing to greenhouse gas (GHG) emissions in Europe [1]. The European Union (EU), in recognition of the climatic change and the impact of global warming, decided that impending action is needed to lower GHG emissions in Europe [1]. The Paris Agreement which was signed by a great number of nations represents the decarbonization efforts of the EU and sets a reduction target of GHG emissions by 91-94% of 1990 levels by 2050 [1]. In 2021, Norway updated its intended nationally determined contribution (INDC) to reduce the emissions by 95% in 2050 compared to 1990 levels [2].

The challenge to comply with the Paris Agreement includes reducing the GHG emissions connected with both the operational energy of the building, as well as the embodied emissions associated with the building materials. According to EN 15978:2011 the life cycle of the building materials is divided into different phases: the manufacturing phase (A1-A3), the maintenance phase (B3), the disposal and refurbishment phase (B4-B5) and the end-of-life phase (D) [3].With measures implemented to reduce buildings' operational energy over the last couple of years and with the effort required to reach the Paris Agreement target, the embodied-operational ratio has shifted. Currently, the embodied energy of a building represents a considerable percentage of the total building emissions. [4,5].

In the last 20 years, considerable effort has been made in developing timber structural products which also contributed to the reduction of GHG emissions [6,7]. This has resulted in a variety of engineered wood products (EWP) that have been used broadly in the construction industry. Cross-laminated timber (CLT), also known as massive timber or X-lam [8], is a versatile wood product with properties that make it suitable for the structural support frame of a building [9].

CLT products have been gaining popularity in the Norwegian construction industry. When public buildings and especially schools are concerned, the massive timber usage seems to be increasing. Data indicates that the investment in timber for school buildings from 1,7 billion NOK in 2012 increased to 3,4 billion NOK in 2021 [10].

As sustainability awareness has increased and massive timber construction has risen, a gap has been created in knowledge about whether those newly built school buildings can fulfil the Paris agreement targets.

Scholars have shown that massive timber buildings can have up to 30% lower GHG emissions when compared with conventional materials such as concrete and steel [11, 12]. But even though today much effort has been put

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into designing buildings that hold high environmental standards, it is unclear if these buildings can fulfil the 2050 Paris agreement targets [13].

As the world population rises, a great investment is done in school buildings. Norwegian Municipalities have set up high building standards following sustainability commitments. Data from the industry show that more than 339 billion NOK has been invested in school buildings, and from this amount, 218 billion NOK is invested in new buildings [10].

The objective of this work is to present and study a selection of school buildings that include CLT in their construction. A case study of four schools is used to answer the following research questions:

- How do CLT school buildings with high environmental standards perform regarding their GHG emissions?
- How do those results compare with the Paris Agreement sustainability targets for 2050?

2 METHODS

In Norway, GHG emission targets from embodied energy in buildings until recently have been expressed as percentage reductions relative to so-called reference buildings [14]. This approach turned out to be inconclusive since all case studies were evaluated relatively to a customized reference for each building. The Research Centre for Zero Emission Neighborhoods (ZEN) created the only Norwegian GHG emission database by collecting different building typology case studies for both the material production phase (A1-A3) as well as the replacement phase (B4) of the building process. This was done through the usage of different Life Cycle Analysis (LCA) software such as Powerhouse, OneClickLCA, SimaPro and an MS Excel-based ZEN algorithm. Through this method, ZEN managed to depict the GHG 2050 targets for all building typologies. A benchmark of the environmental impact value of 5,4 $kgCO_2/m^2/year$ was determined as a 2020 starting point, with an endpoint of 0,4 $kgCO_2/m^2/year$ for 95% reduction or 1,4 $kgCO_2/m^2/year$ for 80% reduction [15].

The main objective of this study is to establish the environmental impact ratio ($kgCO_2/m^2/year$) of the chosen school buildings and compare it with the 2050 benchmark that has been established by ZEN.

Additionally, the correlation between the materials used and the GHG emissions of each case study will be explored. This will be done, by a case study of newly constructed elementary schools that also include cross-laminated timber in their building modules. In the analysis, the volume of materials per square meter of heated floor area (HFA) will be highlighted ($\frac{m^3}{m^2}$ HFA), so as to give a justification concerning the association between material usage and GHG emissions in the building envelope.

The criteria for choosing the case studies rely on their similar building timeframe (2019-2021), and construction materials (usage of CLT, steel, and concrete). Added to this, all case studies are considered multi-functional buildings which contain teaching areas, sports halls, and cultural spaces.

2.1 DATA COLLECTION

The first step of this study includes the analysis of the building modules using Building Information Modeling (BIM). Through correspondence with the architects, we could acquire the International Foundation Class (IFC) files of the buildings. From there, we created inventories (schedules) in BIM software such as Archicad v. 25 and Solibri v. 9.12.10 that could differentiate the material quantities used in every part of the building. After that, through correspondence with the architects and contractors of the case studies, we acquired some of the Environmental Product Declaration (EPD) of the materials used in the construction. For the building modules that we were not able to acquire the EPD, a standard benchmark was used from the Ecoinvent database v 3.8 [16, 17]. An EPD, also referred to as type III environmental declaration, is *a standardized (ISO 14025) and LCA-based tool to communicate the environmental performance of a product* (Schmincke, 2007). Through the EPD, information was gathered concerning the GHG emissions of each building component. That information included CO_2 quantities from the raw material production to the transport of the processing facilities and finally to the transport of the building site (A1-A3 phase). Additionally, information regarding the replacement and refurbishment phase (B4-B5) was given.

2.2 LIFE CYCLE ANALYSIS (LCA)

To accomplish the scope of the research, a Life Cycle Analysis was next used to determine the overall building GHG emissions of the case studies and which elements of the building envelope contributed the most. Through standardization, LCA has gained global support as the most important tool for furthering more environmentally friendly choices in the sector. The functional unit for this analysis, in reference to the school buildings, was defined as one square meter of floor area for a period of the lifecycle (1 m2); The life cycle of the school buildings was set to 60 years as this enables comparisons with similar studies. The system boundary for a building's life cycle consists of material manufacturing, transportation, construction, operation(A1-A3), and maintenance phases (B4-B5). The LCA methodology software that was used for all 4 case studies is the OneClickLCA. The specific software was chosen as it follows the requirements of NS 3720 Norwegian standard which is based on EN 15978:2011 and ISO international standard [19].

After the overall GHG emissions of the buildings were calculated, the required environmental impact ratio was established by dividing the CO_2 emissions by the area and the life cycle of the building. The final ratio of $kgCO_2/m^2/year$ is compared with the ZEN 2020 median ratio and the ZEN 2050 prognosis.

2.3 THE CASE STUDIES

The criteria of choosing the case studies include the same material choice (a combination of CLT, steel and concrete) as well as the addition of multifunctional spaces (sports and cultural halls). Furthermore, all 4 buildings follow the Norwegian TEK 17 building legislation [20], hence the same regulations on technical requirements. In addition, all school buildings have been designed with high sustainability standards in mind and received sustainability certifications after their completion.

Case A - Flesberg school (2017-2019)

Flesberg is a school building built according to Passive house sustainability standards. It consists of 4 individual building 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, and the sports hall are isolated from the last two volumes which are used for teaching spaces. The connecting area between the building volumes serves as a common area for students between the library, the amphitheatre and the administrative space. The building is placed partly under the terrain because of the topography of the chosen site. The parts of the building that are under the terrain, are constructed in concrete. Above ground level, massive timber is used in various parts of the building frame, including the walls of the sports hall and the swimming hall.

Case B - Bamble school (2018-2021)

Bamble is a BREEAM -very good accredited school that consists of 3 building volumes; the first two that inhabit the teaching spaces are connected through a common area, while the third one that accommodates the sports, swimming hall and the gym, is independent. The concept has separated the building volumes to protect the main teaching spaces (classrooms) from the more acoustically challenging volumes (sports hall, swimming hall, gym). The building volumes that host teaching facilities are constructed in massive timber, while for the swimming hall, concrete was used. Although the site was flat, a volume was placed under the terrain to host sports facilities.

Case C - Huseby school (2017-2021)

The school received a BREEAM-Very good certification and consists of 2 different building volumes that connect through a concert hall and a sports hall. The school's concept was to separate the different age groups (each age group has a different entrance) but at the same time unite them under the cultural and activity spaces. The main teaching spaces (classrooms) are constructed in massive timber, while the common spaces (sports hall, concert hall) are constructed out of steel and placed under the terrain.

Case D - Nordre Ål school (2017-2019)

Nordre Ål school is built according to Passive house standards and consists of 4 different building volumes. All volumes are connected through an amphitheatre which represents the heart of the school. The foundations, elevator shafts and ground floor slabs are made of concrete, while the remaining structural elements are predominantly made of massive timber.

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Table 1. *The table shows an overview of the characteristic parameters for the different cases.*

	Case A	Case B	Case C	Case D
Facilities	Teaching spaces Sports hall Swimming hall Library Cultural space	Teaching spaces Sports hall Swimming hall Gym Cultural space	Teaching spaces Sports hall Cultural space	Teaching spaces Sports hall Cultural space
Building data received	IFC model	IFC model	IFC model	Solibri model
Material data received	EPD massive timber EPD steel	EPD massive timber EPD steel	EPD massive timber EPD steel	EPD massive timber EPD steel EPD plasterboard
Gross Area (m^2)	8884	14565	12933	8109
Sustainability Certificate	Passive house	BREEAM very good	BREEAM very good	Passivhaus
Sub. volumes	yes	yes	yes	no

3 FINDINGS

In this section, the outcomes of the life cycle GHG emissions were analyzed and compared with the given ZEN benchmarks. Additionally, the volume of material per square meter of heated floor area is highlighted.

3.1 BUILDING ENVELOPE FINDINGS

In all four buildings due to the requirement of sustainability certifications, an effort was made for good environmental performance. When embodied energy is concerned, that effort was reflected in the addiction of massive timber in the building envelope.

In the two case studies (Case A and Case C) that we have inclined site topography, the building volumes that are below the earth are made in concrete while the timber is used mainly above terrain levels. That has resulted in a higher concrete volume than massive timber per square meter of HFA. (Table 2). In Case B, even though there wasn't any inclined site topography, a requirement of a basement was made, making the concrete volume almost equal to the massive timber used (Table 2).In Case D, as being the only school without the need for a basement, a great differentiation is shown between the massive timber and concrete volume used per square meter, with massive timber volume being more than double. (Table 2)

Table 2. *The table shows the summary of the environmental data of 4 massive timber school buildings.*

	Case A	Case B	Case C	Case D
$kgCO_2$ (A1-A3)	1,9 million	2,1 million	2,9 million	1,3 million
$kgCO_2$ (B4-B5)	128 407	945 510	195 277	41 448
$kgCO_2/m^2/year$	3,8	3,5	4,1	2,9
Timber ($\frac{m^3}{m^2}$ HFA)	0,18	0,18	0,29	0,43
Concrete ($\frac{m^3}{m^2}$ HFA)	0,32	0,19	0,9	0,17

3.2 LCA FINDINGS

The LCA data showed that all case studies have achieved lower emissions than the median 2020 benchmark of 4.5 $kgCO_2/m^2/year$.

Nordre Ål school (Case D), with the highest percentage of massive timber compared to concrete, and without underground volumes seems to perform the best with a 2,9 $kgCO_2/m^2/year$ while Huseby (Case C) seems to perform the worst with 4,1 $kgCO_2/m^2/year$. When placed in the 2030 and 2050 GHG emission scenario, Huseby's (Case C)ratio depicts the 2025 target, while Flesberg's (Case A) 3,8 $kgCO_2/m^2/year$ ratio is the 2027 target. Bamble school (Case B) , with a ratio of 3,5 $kgCO_2/m^2/year$ represents the 2029 target, while Nordre Ål (Case D) 2,9 $kgCO_2/m^2/year$ ratio for the 2032 GHG reduction, exceeding the 2030 commitment. (Fig 1)

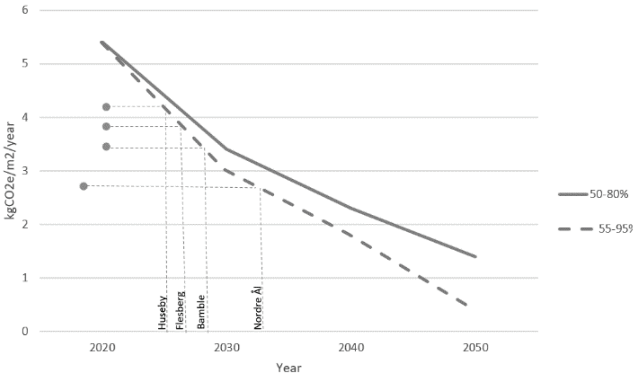

Figure 1. *The Figure shows the comparison of kgCO_2/m²/year ratio of the case studies to the 2030 and 2050 GHG reduction scenarios. The scenario benchmark values were calculated by ZEN (M. Kjendseth Wiik, 2020)*

4 DISCUSSION

As Norway is in the process of lowering its GHG emissions, all four case studies represent newly built sustainable schools. It is greatly understood that massive timber when used as a building material bears environmental benefits [21, 22] hence seems to be promoted for usage in all case studies. The initial results of the research confirm that indeed the percentage of low carbon materials such as CLT that are used in building modules, play the biggest role in the reduction of total emissions, making all case studies perform better than the median set by ZEN.

It is also understood that the overarching goal of these case studies is to achieve the best environmental performance according to the 2020 benchmark standards with great success. But still, fail to reach the 2050 goal. Massive timber, a material with a low carbon footprint, was used mostly in less acoustically challenging areas with smaller span such as classrooms and meeting rooms. Subsequently, if the use of massive timber was greater, the case studies might have shown better lower-emission performance.

Added to this, the preliminary results show that buildings that require subterrain volumes due to the formation of the terrain or due to other circumstances, perform worse emission wise. Concrete, as a building material, is currently regarded as the only option when building volumes under the earth level. Even though great research has been put into reducing its carbon footprint [23], still concrete is concerned a high emission material when compared to massive timber. Although it is difficult to draw definite conclusions, to be able to tackle the 2050 targets, the usage of concrete needs to be further reduced in the building envelope. This may be done by either reducing the number of subterrain volumes or changing the way those volumes are constructed.

5 CONCLUSIONS AND FURTHER RESEARCH

To play a role in restricting the global temperature increase to a safe level of 1.5°C and hence follow the Paris agreement targets, a greater effort in the use of low carbon materials such as massive timber is required. This research revealed that to design a school with high environmental standards, a great percentage of massive timber should be used. But even though those buildings broadcast lower GHG emissions than the average benchmark, they need more improvement to reach the 2050 targets.

For the next step, it would be interesting to address more case studies to examine deeply the connection between the emissions related to material use and the overall GHG emissions in school buildings.

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