ARV

CLIMATE POSITIVE CIRCULAR COMMUNITIES

D4.1 DESIGN GUIDELINES FOR A CLIMATE POSITIVE CIRCULAR COMMUNITY IN OSLO

WP4 SUSTAINABLE BUILDING (RE) DESIGN

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[1] *ARV is a Norwegian word meaning "heritage" or "legacy". It reflects the emphasis on circularity, a key aspect in reaching the project's main goal of boosting the building renovation rate in Europe.*

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	V.01	Nicola Lolli (SINTEF)	First Draft	10.12.2023
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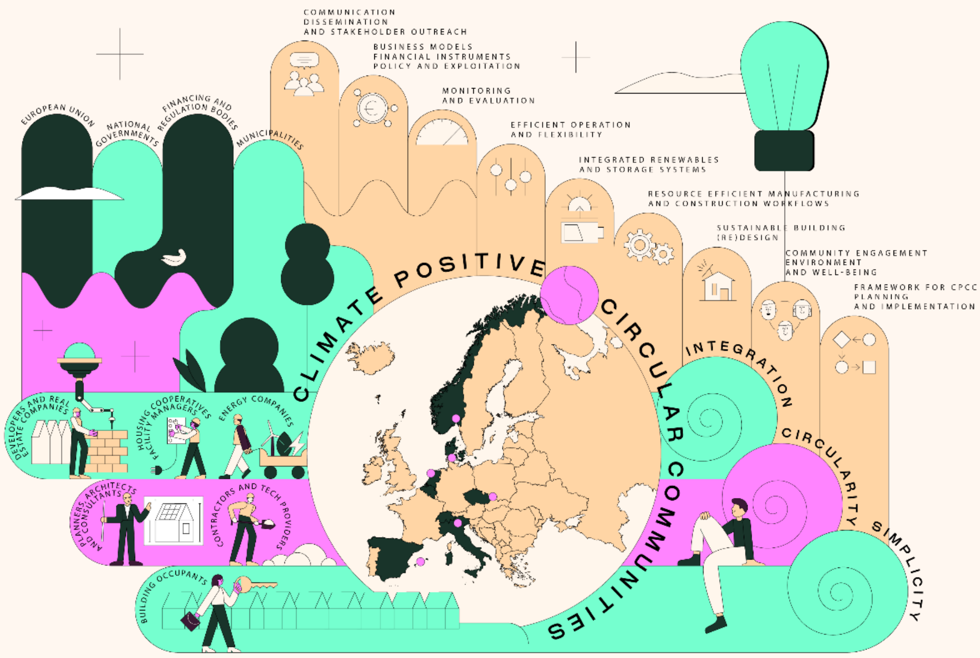
ABOUT THE ARV PROJECT

The vision of the ARV project is to contribute to speedy and wide scale implementation of Climate Positive Circular Communities (CPCC) where people can thrive and prosper for generations to come. The overall aim is to demonstrate and validate attractive, resilient, and affordable solutions for CPCC that will significantly speed up the deep energy renovations and the deployment of energy and climate measures in the construction and energy industries. To achieve this, the ARV project will employ a novel concept relying on a combination of 3 conceptual pillars, 6 demonstration projects, and 9 thematic focus areas.

The 3 conceptual pillars are integration, circularity, and simplicity. **Integration** in ARV means the coupling of people, buildings, and energy systems, through multi-stakeholder co-creation and use of innovative digital tools. **Circularity** in ARV means a systematic way of addressing circular economy through integrated use of Life Cycle Assessment, digital logbooks, and material banks. **Simplicity** in ARV means to make the solutions easy to understand and use for all stakeholders, from manufacturers to end-users.

The 6 demonstration projects are urban regeneration projects in 6 locations around Europe. They have been carefully selected to represent the different European climates and contexts, and due to their high ambitions in environmental, social, and economic sustainability. Renovation of social housing and public buildings are specifically focused. Together, they will demonstrate more than 50 innovations in more than 150,000 m^2 of buildings.

The 9 thematic focus areas are 1) Effective planning and implementation of CPCCs, 2) Enhancing citizen engagement, environment, and well-being, 3) Sustainable building re(design) 4) Resource efficient manufacturing and construction workflows, 5) Smart integration of renewables and storage systems, 6) Effective management of energy and flexibility, 7) Continuous monitoring and evaluation, 8) New business models and financial mechanisms, policy instruments and exploitation, and 9) Effective communication, dissemination, and stakeholder outreach.



The ARV project is an Innovation Action that has received funding under the Green Deal Call LC-GD-4-1-2020 - Building and renovating in an energy and resource efficient way. The project started in January 2022 and has a project period of 4 years, until December 2025. The project is coordinated by the Norwegian University of Science and Technology and involves 35 partners from 8 different European Countries.

EXECUTIVE SUMMARY

This is the second edition of the design guidelines of a climate positive circular community in Oslo. The Norwegian demo project is the Voldsløkka School and Cultural area.

The main objective of this report is to describe the design process from the early urban planning stages to the detailed design and construction of the Voldsløkka project. The project includes the construction of new buildings and the renovation of an existing listed building. The area has high environmental ambitions and is Oslo's first plus energy school, with a surplus of energy generated, covering all energy needs.

The report involves the main stakeholders and describes the decision-making process in the design phases by analysing qualitatively and quantitatively the most relevant aspects taking into account the spatial, technical, environmental, regulatory and social context of the district.

The fundamental goal is the integrated circular design, evaluation and implementation of Climate Positive Circular Communities (CPCCs). The CPCCs design includes concepts of flexibility, multi-use, quality of use, inclusive design, plus-energy and low emissions, as well as innovative storm water management and, moreover, renovation and adaptive reuse of a historical building. Chosen technical solutions aim to be robust, simple, environmentally friendly, and reasonably standardized. They should ensure cost-effective management, operation, and maintenance of the school facility.

This second edition of the report covers the history of the development of the Voldsløkka project, from the regulatory process to the detailed design and its implementation, describing the technologies behind the innovations implemented in Voldsløkka and the challenges faced by the design team in this work. Secondly, a scenario analysis on design alternatives for the school and the cultural centre is presented to show the potential savings in greenhouse gas emissions and architectural qualities deriving from an extensive reuse of the existing constructions on the site. Thirdly, a detailed analysis of GHG emissions of the Voldsløkka project and its performance against the ARV benchmark of 50% reduction in life cycle embodied GHG emissions compared to current practice is implemented. Fourthly, an energy and cost analysis of different energy target scenarios of the Voldsløkka project is given to assess the potential cost-benefits resulting from changing the energy efficiency performance of the school and cultural centre buildings. Finally, a description of the early design choices made for the sports hall which is going to be built on the adjacent site of the Voldsløkka project is included.

The Design Guidelines report will be revised and supplemented annually to present the design practices and advancements of the climate positive circular community in Oslo.

TABLE OF CONTENTS

1. INTRODUCTION

The overarching aim of ARV WP4 is to address the design of new and retrofitting of existing buildings as zero-emission positive energy-buildings in sustainable climate positive circular communities (CPCC) to (i) reduce their embodied energy and emissions, (ii) increase their energy efficiency, and (iii) match sustainability with aesthetics and quality of life (in line with New European Bauhaus strategy). Each of the six ARV demonstration projects addresses these goals differently, due to the different demos' sizes, geographical locations and local climates, and buildings use.

The strategies adapted in the different demonstration projects include, among others: adaptation to local climate conditions, deep renovation with minimum disruption for buildings occupants, high energy efficiency with active & passive solutions, reuse and recycling of building materials, elements, and modules, and integration of renewables.

Task 4.2 addresses the goals specifically for the Norwegian ARV demonstration project, Voldsløkka project. Different scenarios of combinations of state-of-the-art materials, components, technologies, and smart control systems are analysed and tested against the ARV KPIs. The following design strategies will be analysed:

- BIM and Virtual scenarios will be used to document the performance of the design process.
- Climate adapted design using an innovative open surface water solution and green solutions for the outdoor area of the Voldsløkka project.
- The environmental benefit of implementing a circular renovation strategy, where most of the walls and windows in the old factory are reused and upgraded to new energy performance standards.
- Facade integrated BIPV system using novel, angular and coloured modules with high degree of standardized module sizes and fastening solutions.

The design and construction process of the Voldsløkka project is well ahead and as per July 2022 the planning and design stages have been already completed, and the construction and renovation activities are more than half-way to being completed.

Given the advanced stage of the Norwegian demo project, the current report has been adjusted to provide a thorough insight of the planning, designing, and construction activities of Voldsløkka project by focusing on the followings:

a. Which were the decisions taken in the critical steps of the urban planning and design processes.
b. Why these decisions and design choices were made.
c. Which was the decision-making process and who was involved.

The first issue of this report is dedicated to the documentation of the planning, designing, and construction activities of Voldsløkka project. Further revisions (December 2023 and December 2024) will describe and report the results of the scenarios analyses.

To proceed with the first issue of this report, documentation of the design processes of the Voldsløkka project needed to be obtained. To do so, information is retrieved from several sources, namely:

- Reporting of the urban planning and design processes produced by the Office of Urban Planning of Oslo Municipality, Oslobygg KF, and the Education Department of Oslo Municipality
- Interviews with key persons who were involved in the decision-making processes of the urban planning, design, and construction activities. These have been identified and summarized in Table 1.
- Results from the benchmarking of Voldsløkka project performance against the parameters described in the core ARV Key Performance Indicators (KPIs). The core ARV KPIs are described in Table 2.

An interview guide has been developed to be used for the different key persons. Interviews are based on a semi-structured framework, where a list of arguments is shared beforehand with the interviewees. The interviews cover the three main stages of the design process (early concept design, design development, detailed design). For each of these, three sets of arguments are discussed between the interviewer and the interviewees:

- Description of the procedure, by highlighting the vision, ambitions, and goals of the projects, key persons/authorities leading the process, limitations imposed from external authorities.
- Description of the used KPIs or Minimum Performance Requirements (MPRs) in the project, their quantification/calculation, compromises made in the design that did not meet the set KPI/MPR.
- Description of the occurred process, why and how decisions and compromises were made, what could have been done differently, and limitations.

Table 1*. List of the stakeholders interviewed.*

Stakeholder	Interviewees
Project developer: Oslobygg KF (OBF)	Bodil Motzke Øystein Johansen Marianne Vikene Eivind Bryne Retterstøl
Landscape design: Østengen & Kari Bergo	Marit Myklestad Kari Bergo
Architectural design: Kontur Arkitekter AS	Erik Brett Jacobsen
Architectural design: Spinn Arkitekter AS	Miriam Sivertsen

The information obtained during the interviews was used to detail the information given from reports and official documents of the regulatory plan, and the design development. Moreover, insights on the challenges given by this project were given during the interviews and these are reported in chapter 7. Follow-up interviews were conducted in October 2023.

Benchmarking against the ARV KPIs and description of the analysis factors:

- Design and architectural qualities
- Social qualities
- Environmental sustainability (energy use, emissions, recyclability, circularity, etc)
- Economy (Life cycle costing and investment cost)

Table 2. *Overview of target values for new and renovated building in ARV CPCCs.*

Assessment criteria	New construction	Renovated buildings
Energy	**At least 50% reduction in energy needs** compared to current country building code. **Positive energy** level based on primary energy	**At least 50% reduction in energy needs** compared to pre-renovation levels. At least **nZEB** standard.
IEQ	High levels of indoor environment quality according to EU norms.	**At least 30% improvement** compared to pre-retrofitting levels according to EN 16798-1:2019
Noise and dust levels	According to the EU health, safety, and environment standards.	**At least 30 % reduction** in occupant disruption during retrofitting compared to local current practice
Embodied emissions	**At least 50% reduction** compared to local current practice	
Construction/retrofitting time	**At least 30% reduction** compared to local current practice	
Life Cycle Costs	**At least 20% reduction** for the community compared to local current practice	
Construction/retrofitting costs	**At least 30% reduction** compared to local current practice	

2. EXECUTIVE SUMMARY OF THE PROJECT– VOLDSLØKKA, OSLO, NORWAY

The Norwegian demo case is the Voldsløkka School and Cultural area. The project includes the construction of a secondary school for 810 students, a new culture hall, a dance hall, and rehearsal space. This involves the construction of new buildings and the renovation of an existing listed building, in total about 14000 m² floor area. The area has high environmental ambitions and will be built as Oslo's first plus energy school, with a surplus of energy generated, covering all energy needs included appliances/plug-loads. The total area of the PV-installation is 1556 m² and a yearly estimated production of 192 MWh. The new school facility will be integrated as part of the surrounding local area, which complements the area with new functions and activities and strengthens the area's green structure. The set of actions that will be undertaken by the ARV project will encompass resource efficient renovation processes, district energy analysis and operation, and highlighting social, educational, and digital aspects to enhance citizens involvement and generating Citizen Energy Communities.

Table 3. *Summary of the main characteristics of the Voldsløkka project.*

Name and Address	
Project type and ambition level	Plus-energy (S-building) + Class B (H-building)
Building types	School (S-building) and cultural centre (H-building)
Location	Voldsløkka, Oslo
Building owner	Oslobygg KF (OBF)
Design team	Østengen & Kari Bergo (Landscape design), Kontur Arkitekter AS and Spinn Arkitekter AS (Architectural design), Oslobygg KF (Project developer), Veidekke (Main contractor)
Number of occupants	810 pupils, teaching staff, 1 750 weekly users in the cultural centre
Mean average annual temperature	5.7 °C
Degree-days HDD/CDD	3587 (HDD)
Total annual horizontal solar radiation	876 kWh/m²
Design phase/construction phase/completion date	Design phase: 01.2018-03.2023 Construction phase: 04.2020 – 10.2023 Completion date: 08.08.2023
Plot area (m²)	12578
Conditioned/heated floor area (m²)	2331 (H-building) + 8888 (S-building) = 11219
Gross area (m²)	14000
Gross volume (m³)	11606 (H-building) + 38837 (S-building) = 50443

3. VISION AND GOALS

3.1. VISION

The project of Voldsløkka project envisioned the construction of a new school building and the energy retrofitting of an existing cement factory (the Heidenreich building) to host 8 parallel secondary school classes for 810 pupils. In addition to the school program, the project features in the above-mentioned buildings a cultural centre and a cultural hall. The cultural hall is used as a sport facility until the completion of the multi-purpose sport hall in the nearby plot of land. The school and cultural activities will cover an area of 11100 m² in the new construction and 2900 m² in the Heidenreich building. The school becomes operative in August 2023.

3.2. GOALS

The project's architectural goal, as set by the Oslo Education Department, is to provide a good school facility where the students should experience an inclusive learning environment adaptable to their specific needs. This implies the school to be planned and developed according to good functionality and quality of use. Chosen technical solutions, therefore, have to be robust, simple, environmentally friendly, and as much as possible based on the Oslo Municipality specified requirements for standardized solutions. Solutions adopted in the planning and designing should ensure cost-effective management, operation, and maintenance of the school facility. Part of the school premises should be shared with activities outside of the core school program, to be dedicated to different user groups and be used at different times of the day.

4. URBAN PLANNING

In this chapter, the Norwegian planning hierarchy is briefly explained. The following chapters give an overview of the various steps of the urban planning procedures followed for the Voldsløkka demo.

The Norwegian planning hierarchy is built upon three overarching master plan levels[2]:

- National plans
- Regional plans
- Municipal plans

The role and purpose of the National, Regional, and Municipal plans are mainly regulated by the Planning and Building Act chapter 3-5, chapter 3-4, and chapter 3-3, respectively[3].The National plans define the guidelines for the Regional plans, and the Regional plans provide guidance to the development and application of the Municipal plans. The National and Regional plans are not as legally binding as the Municipal plans, and provide only guidelines for which measures should be prioritised by the municipalities.

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[2] Det norske planhierarkiet. Https://9pdf.net/article/d-et-norske-planhierarkiet-brukermedvirkning-i-sosial-boligutvikling.zpnvxm8o Det norske planhierarkiet.
[3] https://www.regjeringen.no/en/dokumenter/planning-building-act/id570450/

MUNICIPAL PLANNING

At least one Municipal planning strategy must be adopted by the municipal council from the time of its election. As shown in Figure 1, the Municipal plan consists of a *Community part* which describes the needs of the local community, an *Action part* that details the development strategies, and an *Area part*, which details the areas of pertinence of the actions. The municipality must also prepare Municipal sub-plans (Regulatory Plans) for various areas, themes, and business areas. The A*ction part* in the Municipal plan must describe how the Regulatory Plans are to be followed up during their development (Regulatory process).

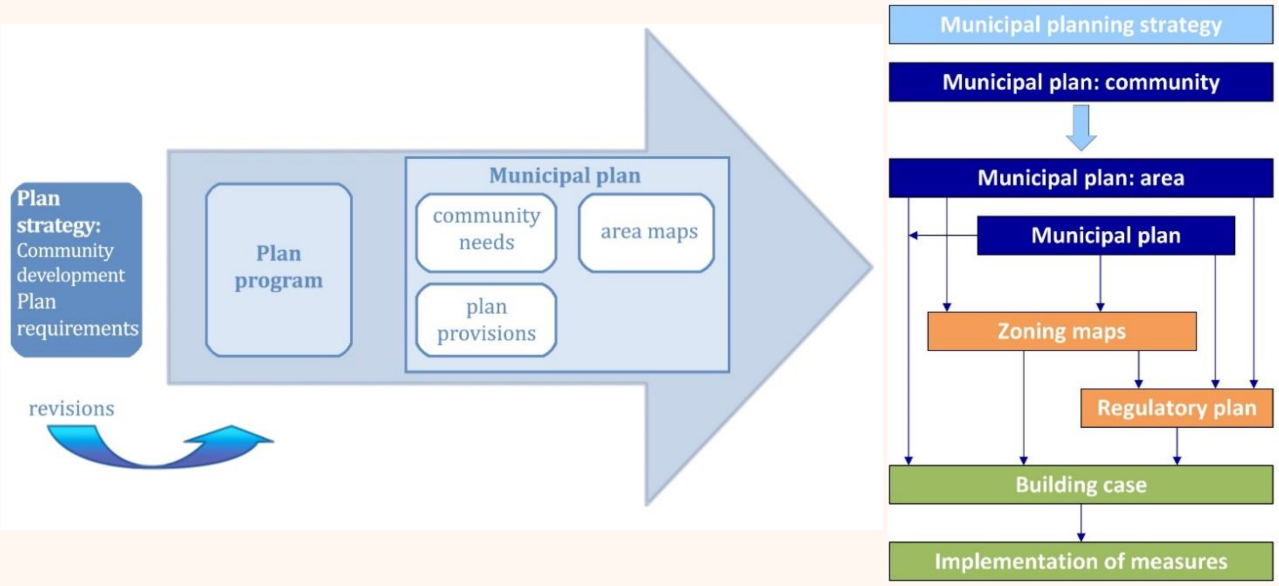


Figure 1. *Municipal planning strategy. Original image from https://distriktssenteret.no/artikkel/kommunal-plan-gjennomforing, edited by Nicola Lolli (SINTEF).*

The *Community part* of the municipal plan describes and details the overall municipal planning strategies through a holistic approach to community planning and business development. The *Community part* documents the conditions of the municipality and provides the common framework for a coherent development and adoption of all the sub-sequent municipal sub-plans, projects, and planning measures.

The *Area part* defines the area-related prerequisites for achieving the goals for the community development defined in the *Community part*, and these are implemented in the form of infrastructural development (e.g., roads, residential, commercial, recreational, and natural areas). More detailed description of land use is given in the *Regulatory* Plans (Områderegulering and Detaljeregulering)[4]. A Regulatory Plan consists of a detailed map with detailed land provisions and limitations to determine how the municipal areas are to be used and developed. The Regulatory Plan determines, among other things, the degree of utilization and building limits, land purpose and specifications of their use, and areas of protection. It is adopted by the municipal council as a single decision and it is legally binding, but it can be waived in certain cases by way of a dispensation. According to the Planning and Building Act, private actors are authorized to promote private planning initiatives. Before a private actor notifies

[4] *Saksgang ved kommunedelplan. Https://www.ha.no/_f/p1/id0d82c5c-2c3c-4a8d-af50-6cc503dc5de0/saksgang-ved-kommunedelplan_bogo-edit.pdf*

the start of a Regulatory Plan development, it must submit proposals through a start-up meeting, to allow the municipality to give advice and assist in the planning process.

The procedure for the development of a Regulatory Plan (regulatory process) initiated by a private landowner/operator is as follows[5]:

- First, a kick-off meeting is held between the municipality and the initiative owner/proposer.
- Second, the start of planning work is publicly notified to allow the local community to be informed and participate in the process. The local community and affected parties have to right to give their remarks and feedback to the proposed plan.
- Third, a completed planning proposal is then submitted to the municipality, which proceeds to initial consideration by the planning committee. The planning proposal is evaluated for six weeks before it is taken forward for a second consideration. After the second round of consideration has been carried out, the proposal is adopted as a single administrative decision by the municipal council, and it is eventually announced with the right to appeal.

The procedural steps to be followed from the development of a Municipal plan to a Regulatory Plan are summarized below[6]:

- **Draft of the plan program**. The administration prepares a draft planning programme, which is presented to the municipal planning committee for consideration.
- **Amendment of the planning program and notification of commencement of work on the municipal sub-plan**. After the draft planning program has been approved and published for consultation by the municipal planning committee, the planning program is made available to the public to notify the start of planning work. The notification is sent to public bodies and interest organizations in the area. The work is also notified on the municipality's website and in local newspapers, with a hearing deadline of usually 6 weeks.
- **Approval of the planning program in the municipal council**. The municipal planning committee processes the input received, makes changes, and sends the matter to the municipal council for final processing.
- **Preparation of draft plans**. Based on the planning programme, the administration prepares working notes and explanations, and submits these to the municipal planning committee for consideration. Based on the individual notes and the treatment of these in the municipal planning committee, the administration draws up a draft municipal sub-plan with text/plan description and map. Drafts are presented to the municipal planning committee for consideration.
- **Public inspection**. The municipal planning committee publish a draft of the municipal sub-plan for public inspection and sends it to the relevant bodies for a statement. Notice period at least 6 weeks.
- **The municipal board**. The plan is adopted, or else the municipal council can decide to send the draft plan back to the administration to make changes. If the plan is adopted without any objections, the draft plan must be sent to the Ministry of Local Government and Modernization for final decision/clarification following a more detailed procedure.
- **Appeal against decisions**. The municipal board's decision on the municipal plan cannot be appealed.

[5] *Reguleringsplanveileder. Https://www.regjeringen.no/no/dokumenter/reguleringsplanveileder/id2609532/?ch=4*
[6] *Saksgang ved kommunedelplan. Https://www.ha.no/_f/p1/id0d82c5c-2c3c-4a8d-af50-6cc503dc5de0/saksgang-ved-kommunedelplan_bogo-edit.pdf*

4.1 VOLDSLØKKA SITE HISTORY

The Heidenreich building (H-building) is registered by the Office of Historical Preservation of the City of Oslo in the list of historical buildings worth being protected for its industrial and architectural value. Together with the worthy-of-conservation in Margarinfabrikken building, the Heidenreich gives historical legibility and identity to the area. The H-building was built and formerly used as a cement factory in 1918 and owned by Christiania Monier og Cementvarefabrikk AS. The company was specialized in producing reinforced concrete elements to be used especially for the building of energy production facilities and water sewage infrastructures[7]. At the time of construction, the factory building at Voldsløkka was one of the largest of its kind in Scandinavia and was an early example of the use of load-bearing structures in reinforced concrete. The building was located south of a planned railway route from Bestum to Grefsen. The track never came, but the plan prevented other development on Voldsløkka. The water pipe wholesaler Heidenreich took over the building in 1935 and operated there for over 70 years.

At the time of the project, two buildings were present on the plot, in addition to the Heidenreich building, named Building A and Building C. Both buildings, with a total area of 6 600 m^2 were rented out to two different companies as office use and storage. These two buildings, visible in the bottom right picture in Figure 2, were demolished to make place for the school building and the playground of the Voldsløkka project.

[7] *http://industrimuseum.no/bedrifter/oslomonier__cementvarefabrika_s*

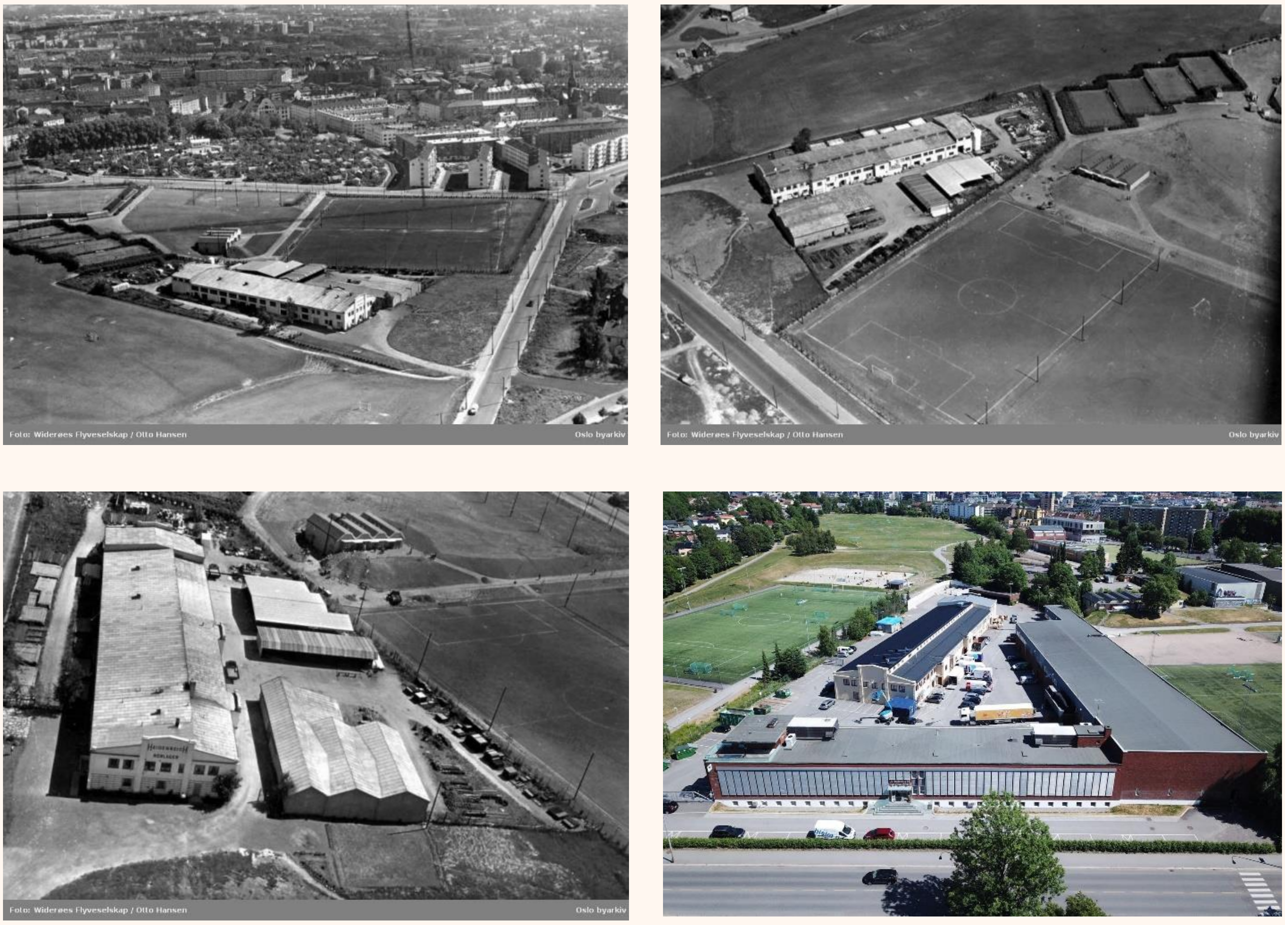


Figure 2. *Historical images of the Heidenreich Building taken in 1951 by Widerøes Flyveselskap / Otto Hansen. Source Oslo Byarkiv. Bottom right: image of the site taken in 2018, source Spinn/Kontur Arkitekter.*

4.2 REGULATORY PLAN OF VOLDSLØKKA

In this chapter the main steps of the urban planning process of the Voldsløkka area are described.

STAKEHOLDERS IN THE REGULATORY PROCESS OF VOLDSLØKKA

The stakeholders involved in the Regulatory process of Voldsløkka are summarized in Table 4. Description of their function and role in the Regulatory process of Voldsløkka is given in Appendix A.

Table 4. *List of the stakeholders involved in the Regulatory process of the Voldsløkka project.*

Stakeholder type	Stakeholder name	Abbreviation
Stakeholders directly involved in the Regulatory process of Voldsløkka		
Landowner (private company)	Uelands gate 85 AS	UG85AS
Process initiator	Uelands gate 85 AS	UG85AS
Administrative authority	Oslo City Planning and Building Agency	PBE
Administrative authority	Oslo City Council for Urban Development	BYU
Administrative authority	Oslo City Education Agency	UDE
Administrative authority	Oslo City Urban Environment Agency	BYM
Administrative authority	Oslo City Water and Sewerage Agency	VAV
Administrative authority	Oslobygg KF	OBF
External consultant	Dark Arkitekter AS	DAAS
External consultant	Asplan Viak AS	ASVAS
External consultant	COWI AS	COAS
External stakeholders who gave remarks during the public consultation		
Administrative authority	Sagene city district	BYSA
Administrative authority	Nordre Aker city district	BYNA
Administrative authority	Oslo City Property and Urban Renewal Agency	EBY
Administrative authority	Oslo City Fire and Rescue Service	BRE
Administrative authority	Oslo City Renovation and Recycling Agency	REG
Administrative authority	Oslo City Office for Building Preservation	BYA
Administrative authority	Oslo City Education Agency	UDE
Administrative authority	Oslo City Urban Environment Agency	BYM
Administrative authority	Oslo City Water and Sewerage Agency	VAV
Administrative authority	County Governor of Oslo and Akershus	FMOA
Administrative authority	Norwegian Water Resources and Energy Directorate	NVE

Public association	The Nature Conservation Association in Oslo and Akershus	NOA
Public association	Oslo Sports Circle	OIK
Public association	Skeid football club	SK
Public association	Sagene Sport Association	SAIF
Public association	Oslo and Akershus Corporate Sports Associations	OBIK
Private company	Ruter AS	RAS
Private company	Hafslund Nett AS	HNAS
Other	Private citizens	

THE REGULATORY PROCESS OF VOLDSLØKKA STEP-BY-STEP

The Regulatory process of Voldsløkka[8] (the area defined in Figure 3) was originally initiated by a private actor, the new-formed company Uelands gate 85 AS (UG85AS), which submitted a regulatory planning initiative to the Oslo City Planning and Building Agency (PBE) in November 2012. The planning proposal was to develop the area for residential purposes.

A meeting between UG85AS and PBE was held in February 2013, where PBE recommended UG85AS to wait for further planning work within Oslo municipality for receiving more clarifications on the intended use of the area to be developed. This was because PBE recommended to clarify within the Oslo Municipality whether the plot was to be used for public purposes or private residential. Furthermore, should the land to be developed for housing, further design and planning guidelines were needed. PBE stated that if these guidelines had been not followed up, PBE would commence an alternative Regulatory proposal for housing.

In a meeting between with the Oslo City Council for Urban Development (BYU) and UG85AS, the municipal interests in placing a school in the Voldsløkka area (Figure 3), and specifically in the land occupied by the Heidenreich building, was expressed.

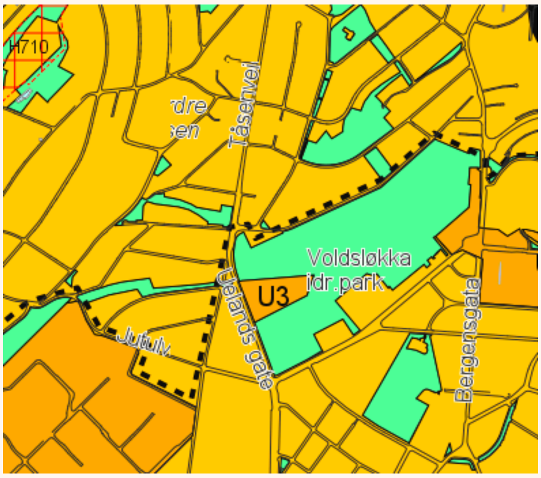


Figure 3. *Oslo Municipal plan 2015-2030 with identified the Voldsløkka area for school development (U3).*

[8] *https://innsyn.pbe.oslo.kommune.no/saksinnsyn/showregbest.asp?planid=201214524*

Figure 4. *Left: Alternative 1development of Voldsløkka with* the apartment buildings proposed by UG85AS. Right: Alternative 2 development of Voldsløkka with the school proposed by UDE. The Heidenreich building is coloured in yellow. Original image by PBE, edited by Nicola Lolli (SINTEF).

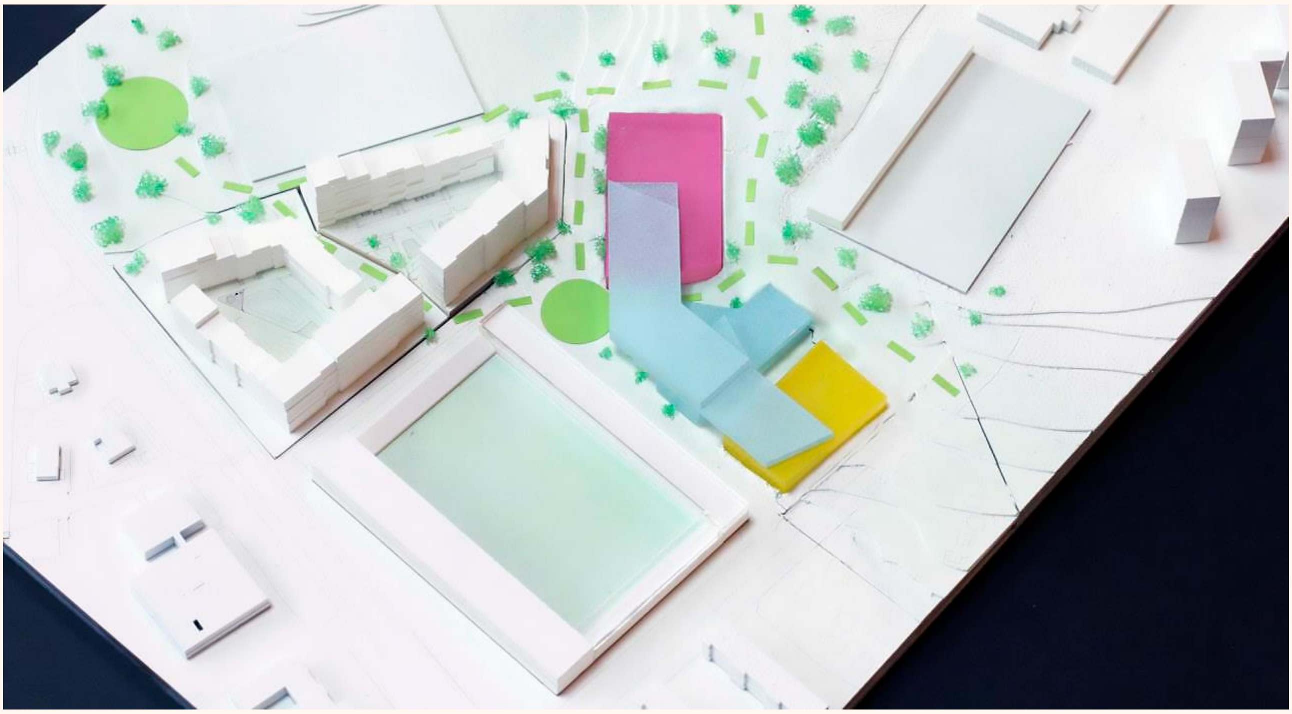


Figure 5. *Alternative solutions with the school (right in the figure) and the sports facilities (bottom in the figure) developed on the municipal land, and the apartment buildings (top in the figure) developed on UG85AS property. Image by PBE.*

In June 2013, the Oslo City Education Agency (UDE) was commissioned to propose an alternative Regulatory Plan for school purposes on the property of Uelands gate 85 AS (UG85AS). With this regard, UG85AS with the assistance of Dark Arkitekter AS prepared a feasibility study to show a future comprehensive study as input to the Regulatory Plan for Voldsløkka. This was proposed to include in the proposed Regulatory Plan for residential development the adjacent plot of land (Figure 5), which was regulated by the Oslo Municipality Urban Environment Agency (BYM) to be used for sports purposes. The feasibility study proposed an overall assessment of the area, where school, sports and housing uses were integrated.

The feasibility study resulted in August 2013 in the proposal of a Concept Selection Study (KVU) for Voldsløkka, to evaluate the possibility of adapting the area for different purposes and to assess the realism of placing the school among the sports facilities at Voldsløkka. The KVU was expected to be commenced by PBE in autumn 2013 and concluded by the end of 2013. However, by February 2014 there was no clarification weather the KVU had been started or not. UG85AS consequently decided to start in February 2014 a Regulatory Plan proposal for developing the Voldsløkka area for residential purposes and submitted their proposal in June 2014.

Between May and July 2014, the BYU requested PBE in collaboration with the BYM and UDE to investigate in more detail and outline a possible solution for the joint use of housing, multi-purpose hall, football field and school. The results of this investigation showed that placing the school above a buried triple sports hall would have been expensive and poorly functional. Since it was clear that it was difficult to satisfy the desire to place many building programs in the same area, BYU asked PBE to collaborated with UG85AS, UDE, and BYM, to find a third alternative that could satisfy the most important requests, including the housing development. In September 2014, UG85AS agreed to collaborate for finding a third alternative and in to have the regulatory process for housing development to be put on hold.

In autumn 2014 several workshops and meetings were carried out between UG85AS, BYM, PBE, and UDE, to find a third alternative that included housing, school, and sports facilities. PBE notified BYU the result of this process in February 2015, with a third development alternative for Voldsløkka. However, UG85AS withdrew from the cooperation on the basis that this alternative design implied a large reduction of the allocated volume for housing development and a replacement area was needed to be found for the remaining volumes to be developed.

In August 2015, PBE resumed the processing of the Regulatory Plan for Voldsløkka and decided to submit plans for both the school and the residential developments. Both the proposals were advertised for public feedback. Both Regulatory Plan proposals were subsequently (March 2016) merged in one case, as requested by BYU. Figures 6-9 show conceptual images of the two alternative developments.

Figure 6. *Alternative 1: apartment building development. View from Uelandsgate. Image by Dark Arkitekter.*

Figure 7. *Alternative 1: apartment building development. View from the football field. Image by Dark Arkitekter.*

Figure 8. *Alternative 2: school development. View from Uelandsgate. The Heidenreich building is coloured in yellow. Original image by Asplan Viak, edited by Nicola Lolli (SINTEF).*

Figure 9. *Alternative 2: school development. View from the football field. The Heidenreich building is coloured in yellow. Original image by Asplan Viak, edited by Nicola Lolli (SINTEF).*

Between April and June 2016 several meetings were held between PBE, Oslo City Water and Sewerage Agency (VAV), BYM, UDE, and Dark Arkitekter regarding different aspects of the two alternatives in the Regulatory Plan proposal, and revised planning proposals were submitted for a 2nd round of processing by PBE.

PBE in November 2016 recommended to develop a school on the Voldsløkka area and dismissed the residential development alternative. The school alternative was chosen because this proposal helped to ensure the needed school capacity in Voldsløkka and developed the area as a publicly accessible, green park by ensuring a coherent and large area for living, recreation, play and sports. The residential development alternative was not recommended because it would have added additional private residential volumes with a too-high density factor, and it was, therefore, considered to conflict with the Municipal Plan 2015 - Oslo towards 2030 (Figure 3). Moreover, most of the Heidenreich building was planned to be demolished in the residential development plan, whereas the preservation of its integrity was ensured in the school development. The Heidenreich building was considered an important part of the area's identity and by its demolition, the building's industrial history would have disappeared. Additional remarks on the residential development concerned the splitting of the existing landscape given by the new volumes, which would have hindered the plan of connecting the various parts of the sports park in Voldsløkka.

The Planning and Building Agency, therefore recommended to develop the Voldsløkka area by building a school with a possible multi-purpose hall is in line with the desired further development as a public area with a park, sports, kindergarten, and school. The school would strengthen Voldsløkka as a meeting place for children and young people. PBE also emphasized that population forecasts for the area showed a large and growing need for new school places in the school district and a lack of suitable areas for schools. Uelands gate 85 was therefore considered to be well suited for school purposes and recommended in a long-term urban development perspective.

Since Uelands gate 85 was owned and managed by Uelandsgate 85 AS, an agreement on the purchase of the property was needed to be found. The costs that followed due to the implementation and securing of the development of the infrastructural facilities and green structural elements outside the planning area, was decided in municipal agreements between the Oslo City Urban Environment Agency (BYM) and Undervisningsbygg Oslo KF (OBF) as project developer. The Regulatory Plan was adopted in December 2017.

PROJECT SPECIFICATIONS BASED ON THE REGULATORY PLAN OF VOLDSLØKKA

In this chapter the critical design and planning specifications that defined the regulatory process of the school alternative are described. These specifications were the result of the various meetings between PBE and the involved authorities and stakeholders (see list of stakeholders and their roles in previous chapters). The specifications defined for the housing development alternative are not discussed here since this alternative was not eventually chosen for the Voldsløkka area.

The overall development of the Voldsløkka area, as suggested by PBE, is summarized in Figure 10. PBE suggested a plan which aimed at developing a sustainable local community, where the residents had access to clean air, clean water and adequate recreational areas to pursue these goals the following areas were prioritized:

- Reduction of noise, air pollution and greenhouse gas emissions
- Development of a sustainable urban environment and environmentally friendly urban spaces.
- Preservation and strengthening of the blue-green structures.

The PBE plan defined the strategies and measures for reducing the inhabitants' noise load, facilitating non-motorized transportation routes, avoiding densification at the expense of green structure, prioritizing cultural heritage, and preserving older buildings, preserving and further developing the green structure with focus on coherence and quality, and reopening rivers and streams.

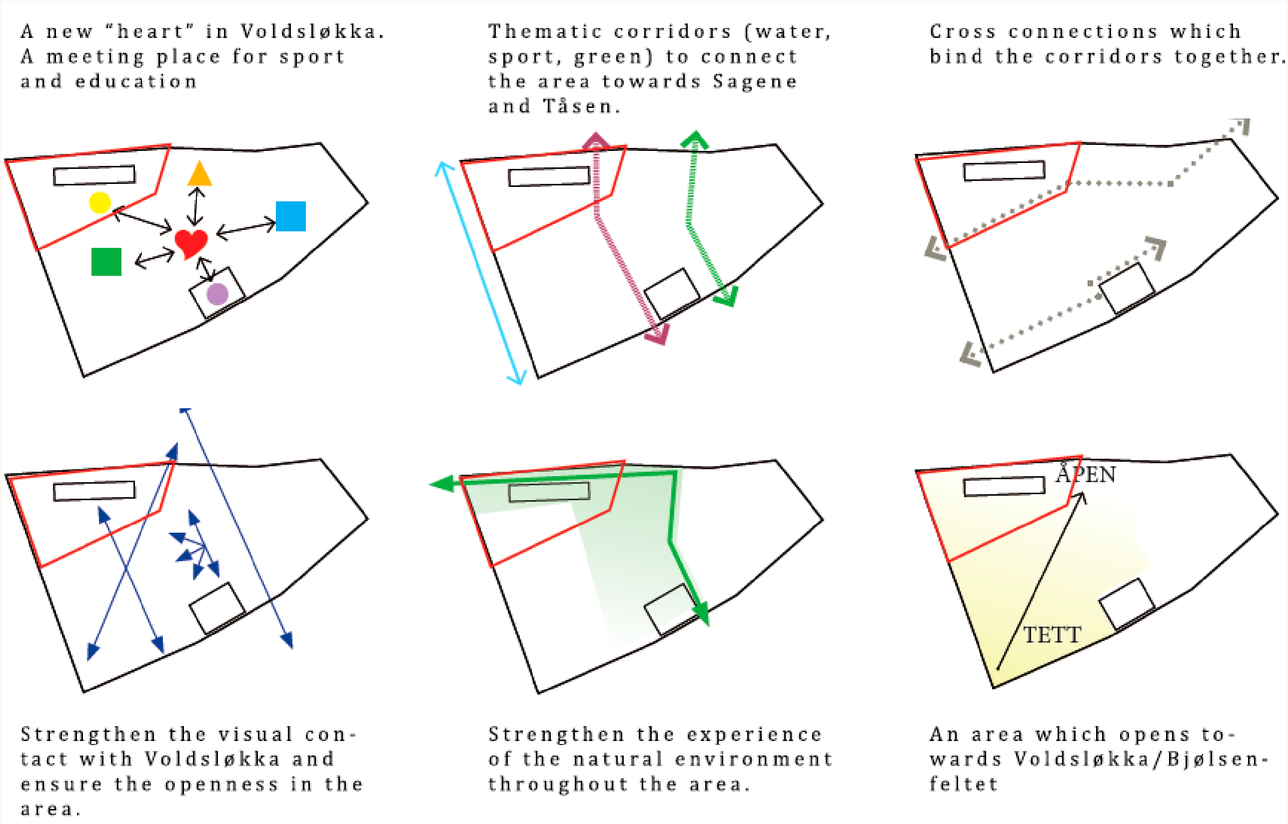


Figure 10. *PBE's site analysis. Edited by Nicola Lolli (SINTEF).*

From such a perspective, the choice of using the Voldsløkka area for school development aimed at making this area a gathering point for the local community by integrating educational, sport, and cultural activities in the local natural landscape. The initial concept envisaged the development of a multi-use hall (sport and cultural activities) by the school area to be used outside the school opening time. The Heidenreich building was proposed to be preserved while the other buildings on the site were to be demolished (Figures 11 and 12), as the Heidenreich building helped to define an identity of the area, by continuing the narration of the area's previous industrial history. To ensure high qualities of the school outdoor area, PBE included provisions regarding the prohibition of using artificial grass and ensuring the use of permeable and natural land cover. This was integrated in the local open surface water management plan, which followed the Oslo Municipality's environmental policy. Oslo Municipality promotes the use of open, local surface water management to contrast the damage to buildings and infrastructure produced by poor rainwater management. Such a problem is exacerbated by climate change, which in the Nordic will lead to more rain and sudden heavy rainfall. By opening closed streams and rivers and using green roofs and draining surfaces instead of asphalt, rainwater flows are slowed down and the risk of flooding reduced.

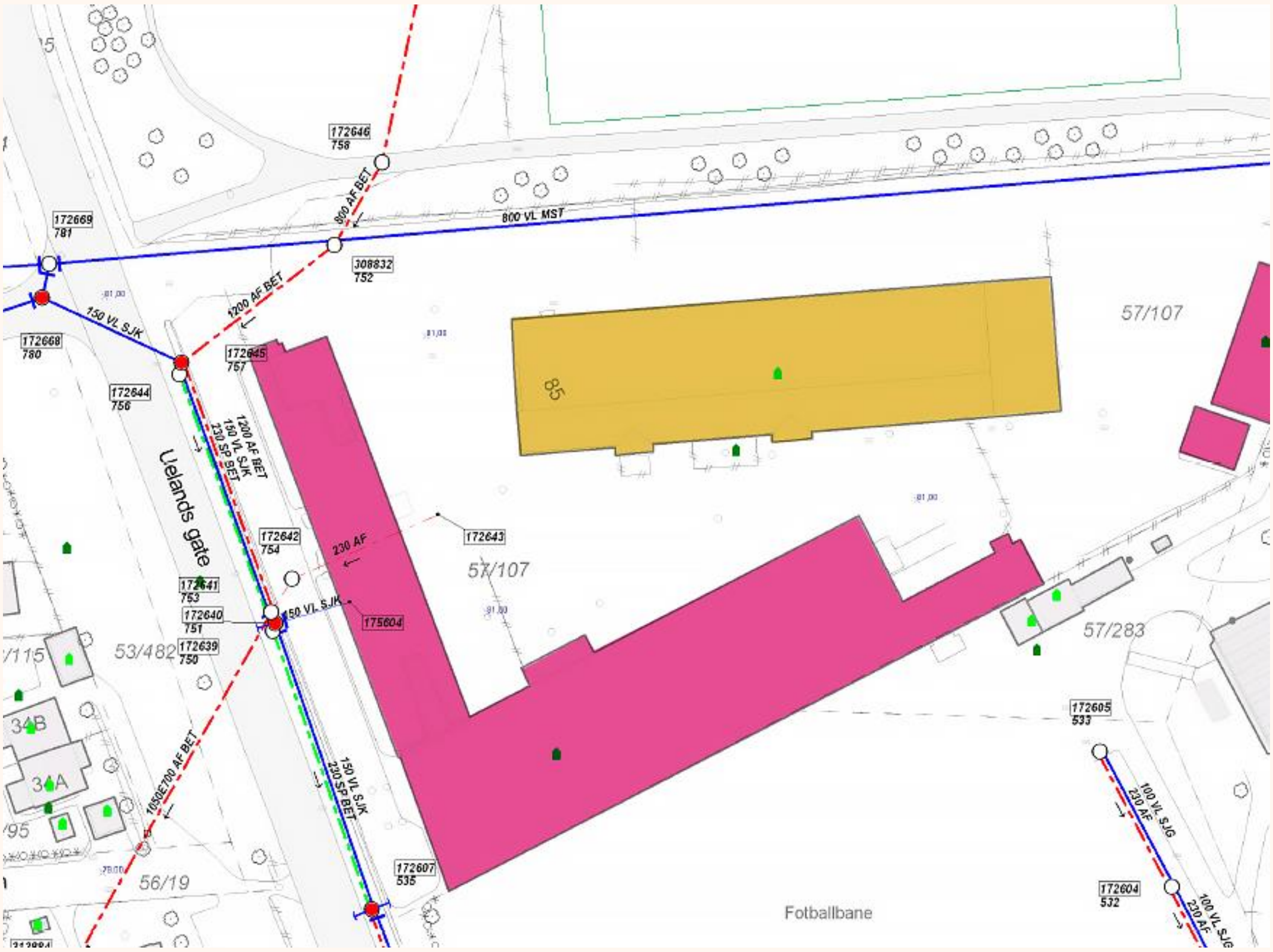


Figure 11. *Map of the main waste-water infrastructure near the Voldsløkka project. The Heidenreich building is coloured in yellow, the office-industrial buildings (Building A and C) which were demolished are coloured in pink. Original image by VAV, edited by Nicola Lolli (SINTEF).*

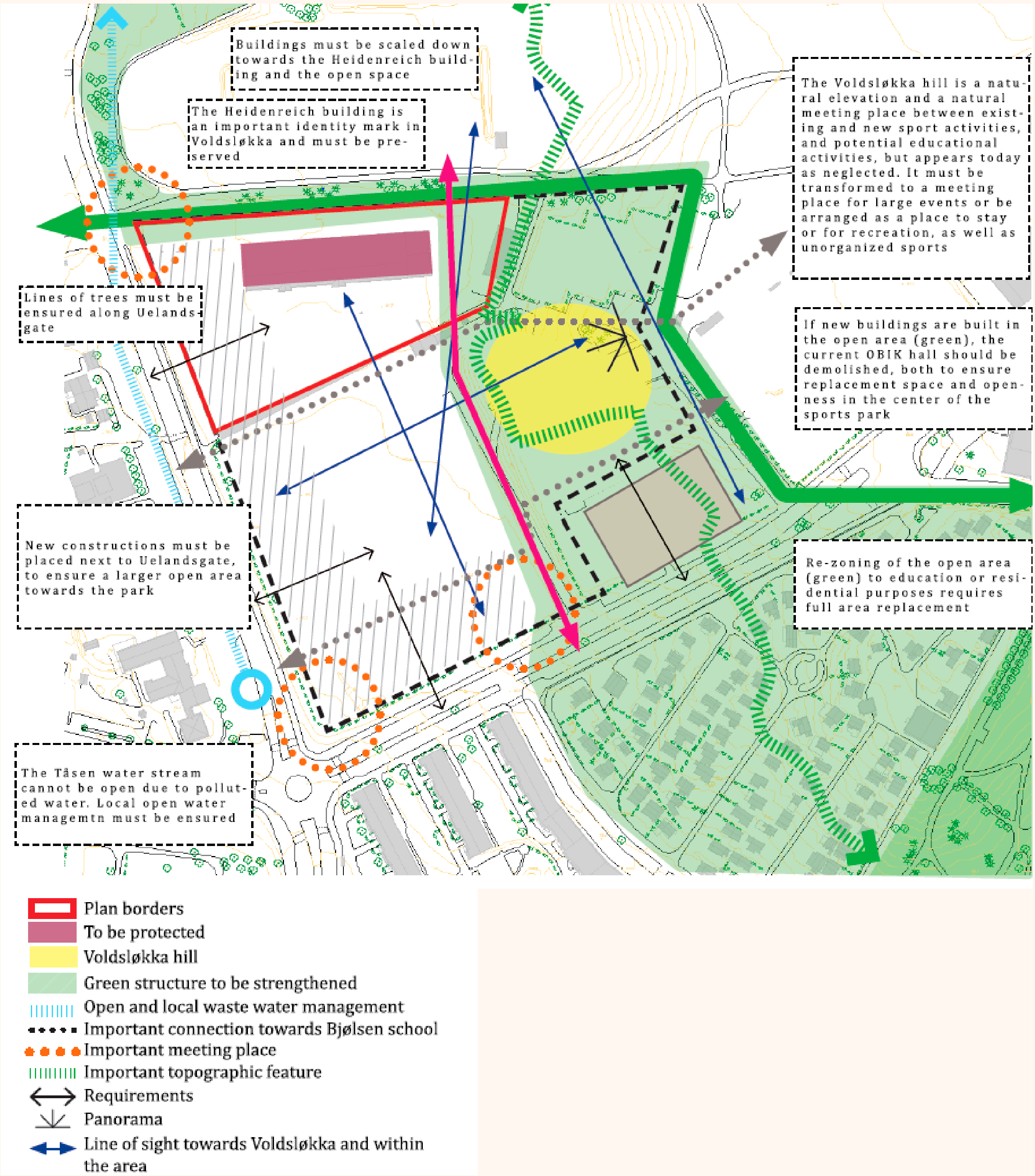


Figure 12. *Suggested plan development from PBE's site analysis. Original image by PBE, edited by N. Lolli (SINTEF)*

In the Regulatory Plan, PBE proposed the width of the new school building to be set to 22 m. this would have provided room for development of for various floor plan layouts, as shown in Figure 13. Such a building dimensioning provides well-proportioned classrooms with daylight on the long side, and a central zone with studio rooms and open student workspaces, or, with a double corridor layout, it provides teaching rooms combined with office workplaces and core functions. The 22-m-width dimensioning allows for the placement of the multi-purpose all within the building footprint, as shown in Figure 13. With this regard, two alternative placements of the multi-purpose hall were studied, and its placement was proposed to be either partially underground, or on the 3rd-4th floor of the building. By placing the multi-purpose hall within the new construction footprint, circa 1500 m² of floor area for education activities are to be moved in the Heidenreich building, as shown by the blue volume in Figure 14.

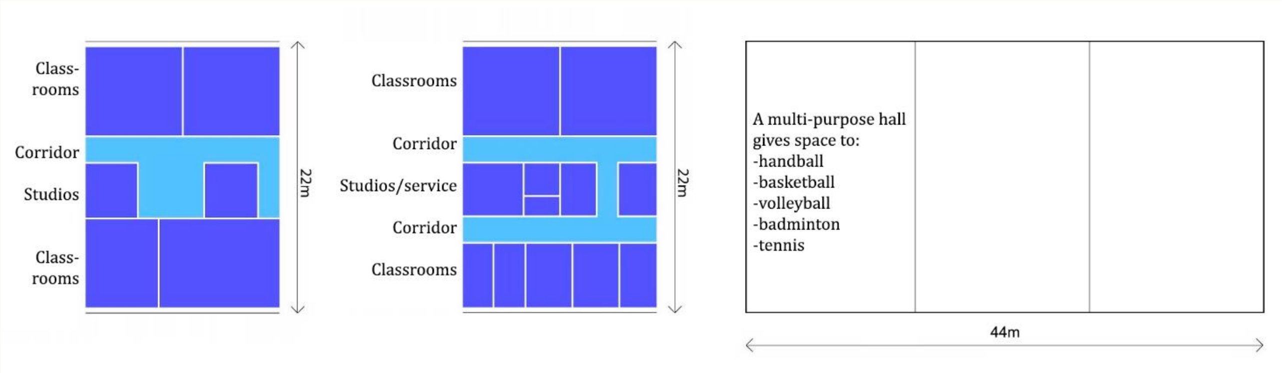


Figure 13. *Conceptual layouts given by defining the building width to 22 m. Original image by PBE, edited by Nicola Lolli (SINTEF)*

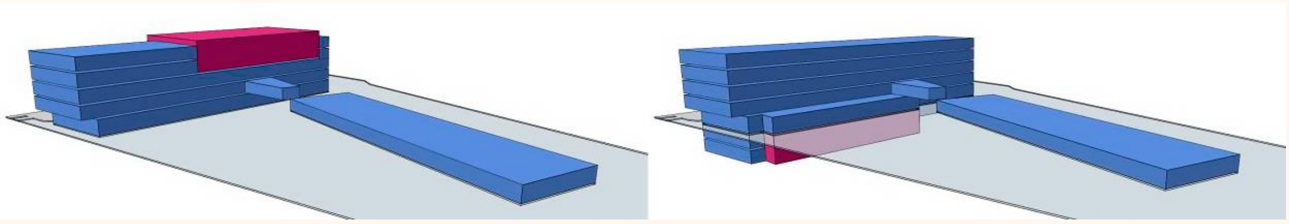


Figure 14. *Alternative A (left) and alternative B (right) placements of the multi-purpose hall. Source PBE.*

Upon request of BYA, PBE required the Heidenreich building to be preserved. The following requirements were defined in the Regulatory Plan:

- The building could not be demolished.
- The building could be improved, provided that the building's exterior with regard to scale, shape, detailing, use of materials and colours was maintained.

Therefore, the original exterior building parts had to be preserved to the greatest extent possible and reused in their proper context. The interior of the Heidenreich building was allowed to be changed in order to allocate the new education and cultural activities. Moreover, a connection (bridge) between the Heidenreich building and the new school construction was allowed, given that this connection was as transparent as possible and made in such a way to retain the original identity of the historical building. The transparency of the bridge ensured line of sight between the school courtyard and the open field north of the Heidenreich building, as shown in Figure 15.

Figure 15. *Concept of the bridge connecting the Heidenreich building (right in the image) to the new construction (left in the image). Source PBE.*

PBE proposed that the overall project of the outdoor area to have a green feeling and to be integrated in the Voldsløkka existing natural environment. This had to be ensured by implementing a smooth transition of the vegetation and type of ground cover between the surrounding park and the school area. Moreover, the use of fences had to be avoided to ensure the users experienced a continuous and park-like environment. Different types and heights of vegetations were to be used and a minimum of 30% of the outdoor areas had to be made of permeable and natural coverings (grass, gravel, sand, bark, paving stones, wooden coverings, etc). The use of artificial grass was not allowed. In such a perspective, local and open surface water management strategies were implemented in the area. This was to avoid the rainwater runoff damaging buildings, properties, and infrastructures and creating inconveniences to the local residents. The placement of the new construction was set in the area to ensure the surface water run-off was to be redirected to the existing waste-water infrastructure (shown in Figures 11 and 12). More specifically, VAV suggested PBE to place the new construction at enough distance from Uelandsgate to make room for local surface water management, given the wastewater main line was on the East side of Uelandsgate. VAV suggested to use infiltration and diversion strategies, the use of open waterways, and the use of local water recipients for handling the local surface water run-off.

A detailed strategy for ensuring an effective local water management was set by using the recommendations in the guide for the calculation of the Blue-Green Factor (BGF)[9] developed by PBE and Bærum Municipality, under the Framtidens Byer cooperation program.

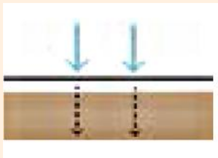
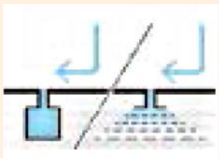
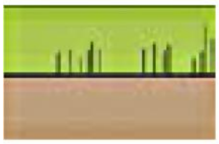
The guide recommends minimum BGFs based on the urban density of the area the project is placed on:

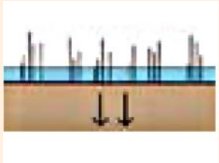
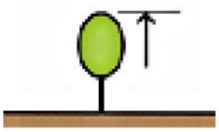
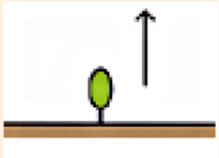
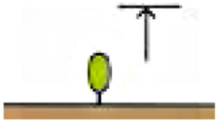
- Project in dense city/centre areas (incl. dense block housing): 0.7
- Project in outer city/small house development/terrace house/open block development: 0.8
- Public streets and squares: 0.3

[9] *Blågrønn Faktor, Veileder byggesak. Framtidens Byer. 2014. https://www.regjeringen.no/no/tema/kommuner-og-regioner/by_stedsutvikling/Framtidens-byer-2008---2014/id752427/*

The BGF is calculated by dividing the areas of "green-dedicated" surfaces by the total area of the project plot of land, and by adding eventual additional points for connection to existing blue-green infrastructures, as shown in Table 5. Education buildings and kindergartens were not specifically mentioned in the guideline, and there were no examples of such facilities in the sample collection. A school building with outdoor areas where requirements cannot compete on the BGF against a housing project. This is because the outdoor areas for a school building usually have a greater need for the placement of activity zones and a more intensive use. This leads to the use of more robust surfaces which, by being less permeable to water, give lower points in the BGF calculation. The BFG was therefore calculated in the Voldsløkka project by making sure the surface of the existing green areas was increased, to plant large new trees, to make sure the presence of large and continuous green areas, to plan a fairly high proportion of permeable surfaces, and plan the opening of a new open water stream for storm water management. Given the limitations due to use of outdoor areas for school activities, the proposed plan gives a BGF of 0.4, as shown in Table 5.

Table 5. *Calculation of the Blue-Green Factor (BGF) for the Voldsløkka project. Source PBE.*

BGF value	image	Description	Area m²	BGF
		total plot area	12578	
1		Permanently open water table to absorb rainwater	131	131
0.3		partially permeable surfaces such as gravel, shingles and grassy cover	2390	717
0.2		impermeable surfaces with runoff to vegetation areas or open drainage	635	127
0.1		impermeable surfaces with runoff to a local underground drainage system	4780	478
1		surfaces with vegetation associated with soil or natural rocks	1275	1275

0.3		rain bed or equivalent	160	48
0.6		existing small/medium-sized trees (5-10 m)	2	1.2
0.7		new planted trees which will grow more than 10 m tall	25	17.5
0.5		new planted trees which will grow between 5 m and 10 m tall.	35	17.5
0.4		hedges, shrubs and multi-stemmed trees	300	120
0.3		perennials and ground covers	425	127.5
0.1		connected green areas larger than 75 m2	1275	127.5
		total equivalent blue-green area		3888
		calculated BGF (total equivalent blue-green area/plot area)		**0.3**
0.05		connections to existing blue-green structures		0.05
		Final BGF		**0.4**

5. DESIGN

STAKEHOLDERS IN THE DESIGN PHASE OF VOLDSLØKKA PROJECT

The stakeholders involved in the design phase of Voldsløkka are summarized in Table 6. Description of their function and role in the design phase of Voldsløkka is given in Appendix B.

Table 6. *List of stakeholders involved in the design phase of the Voldsløkka project.*

Stakeholder type	Stakeholder name	Abbreviation
Project developer	Oslobygg KF	OBF
Project developer	Undervisningbygg	UBF
Client	Oslo City Education Agency	UDE
Client	Norwegian Education Union	UF
Client	Norwegian Student Organization	EO
External consultant	Spinn Arkitekter AS	SPAS
External consultant	Kontur AS	KOAS
External consultant	Østengen & Bergo AS	ØBAS
Builder	Veidekke AS	VEAS
Builder	Øyvind Moen AS	ØMAS
Technical consultant	Various	
External auditor	Various	
Subcontractor	Various	
Administrative authority	Norwegian Labour Inspection Authority	ARTY
Administrative authority	Sagene city district	BYSA
Administrative authority	Oslo City Urban Environment Agency	BYM
Administrative authority	Oslo City Office for Building Preservation	BYA
Administrative authority	Oslo City Water and Sewerage Agency	VAV
Administrative authority	Oslo City Planning and Building Agency	PBE

5.1 DESIGN DEVELOPMENT

THE DESIGN DEVELOPMENT PHASE OF VOLDSLØKKA STEP-BY-STEP

Summary of the Interviews

Several interviews were conducted to understand the design development procedure and stakeholders involved in Voldsløkka and the different goals in architectural, environmental, social, and economic areas. The list of interviewees is shown in Table 1.

Project initiation

The design development started in 2018 after the regulation was adopted in 2017. The regulatory procedures by the education authorities were based on the typical school's needs. There was not a complete start-up process apart from internal selection of roles, as the objectives related to the programme, functions, and use with a focus on cultural offers were clear. Moreover, there was an insight into limitations and considerations, under the condition of preservation of some existing facilities in combination with new developments.

Project development

Voldsløkka is a pilot project where several strategies were tested as a new plus-energy school facility and a cultural centre, that made it very special along the process. The project development and the different phases supported the objectives set by the Norwegian Education Agency Authority, with guidelines[10] that shaped the order of the development phases and framed the existing goals in something buildable that ensured user participation in the leadership of OBF.

During the **pre-project phase,** the FutureBuilt definition (2014)[11] of positive energy buildings and the technicalities necessary to achieve it, was discussed. However, the definition changed in 2018.

The **preliminary project** was divided into different themes: Energy and environment, Function, Building and outdoor spaces, with assigned responsibilities to experts in each area, as shown in Figure 16. In the preliminary phase, the BIM software was used to navigate between the design and the requirements, which later complemented the integrated energy design process.

During the **concept phase** the needs and requirements for user participation in the final solution, were facilitated through workshops based on cross-mapping their insights and technical design for consequences and solutions.

Guidelines and frameworks

Requirements were taken as a base for the further Concept Selection Study (KVU), with demands on all aspects of sustainability. OBF has framework agreements with different groups for working during the preliminary project where requirements about the experience, contributions to the positive energy building and the landscape were settled, for example. However, for the design of the framework, Norconsult was the main actor.

[10] SKOK 2015. https://skok.no/skok-2015

[11] https://www.futurebuilt.no/content/download/28126/157914

Functionality

Given the defined placement and footprint of the school building, the architects and OBF had to work on flexible room placements and functions within the school building. The design solutions sought for space flexibility by enabling the classrooms' floor area to be increased or decreased by using movable partitions. The room scheme shows desired connections, which have to be prioritized when rooms are rearranged due to space limitations. The sharing of same spaces at different times of the day was an additional strategy employed by the design team to "increase" the usable floor area. This strategy was implemented in the flexible use of the school and cultural centre throughout the day. In such a way, the complex, school and cultural centre, serves the needs of both the students and the local community. In order to achieve a good sharing concept, facilities are used longer time, which affects the school operating hours. This approach could seem to contradict the aim to reduce energy use, while at the same time the buildings are used for a larger share of the time. There are different areas in the project. The Culture Axis goes into much of the cultural building, so there are different functions for the students who are out in the schoolyard. The outdoors was specially focused on, creating islands for recreation and collecting water and decreasing pressure on the water drainage. More details on the design solutions are given in chapters 5.1 and 5.2.

Positive energy-building ambitions

The main goal set by OBF that influenced different aspects of the design, was Voldsløkka to be Oslo's first plus-energy building school with a 50% reduction of greenhouse gas (GHG) emissions. This goal was coupled to the ambition to adhere to passive house standards and to achieve an emission-free construction site. However, in a project that involved a combination of an existing culturally protected building and a new construction, it would have been extremely difficult to achieve this goal. Therefore, the focus was shifted to optimising the positive energy building concept for the new school building only, through the installation of large PV surfaces, very efficient thermal system, and very high energy performance of the building shell. The energy target was retrieved from the FutureBuilt 2014 plus-energy definition. During the process, it became clear that PV energy production was needed on the facades, as the production from roof PV would have not been sufficient. This was initially rejected by the contractor, but then changed because of the higher energy production on the facade all year round.

Several challenges were given to the design team and OBF in achieving the plus-energy target. Notably, the north-south orientation was not optimal for PV production, given that the shortest façade is facing south. The aesthetic requirements set in the Regulatory Plan did not envision large monotonous surfaces of black-coloured (and most efficient) PV panels. The PV technology in relation to their performance advanced more rapidly than the decisions on the design team, which is typical for any project of this type and magnitude. The existing building (Heidenreich building) was excluded from the plus-energy concept because, due to its conservation status, the energy retrofitting intervention allowed for reaching just a class B, and no PV systems could be installed on either its roof or facades. The school building was designed to rely mostly on a very efficient ground-source heath pump (GSHP) coupled with a low-temperature floor heating system, despite the available the connection to the local district heating. This was done to ensure that the energy use (PV+GSHP) was cleaner than the district heating, to reach the GHG emissions goal. On the other hand, the Heidenreich building was designed to be connected to the district heating only.

Therefore, to answer the challenges given by this project, the team had to find technical and design solutions that ensured both the plus-energy target and the development of an aesthetically appealing school building. These are detailed in chapter 5.1, 5.2, and 7.

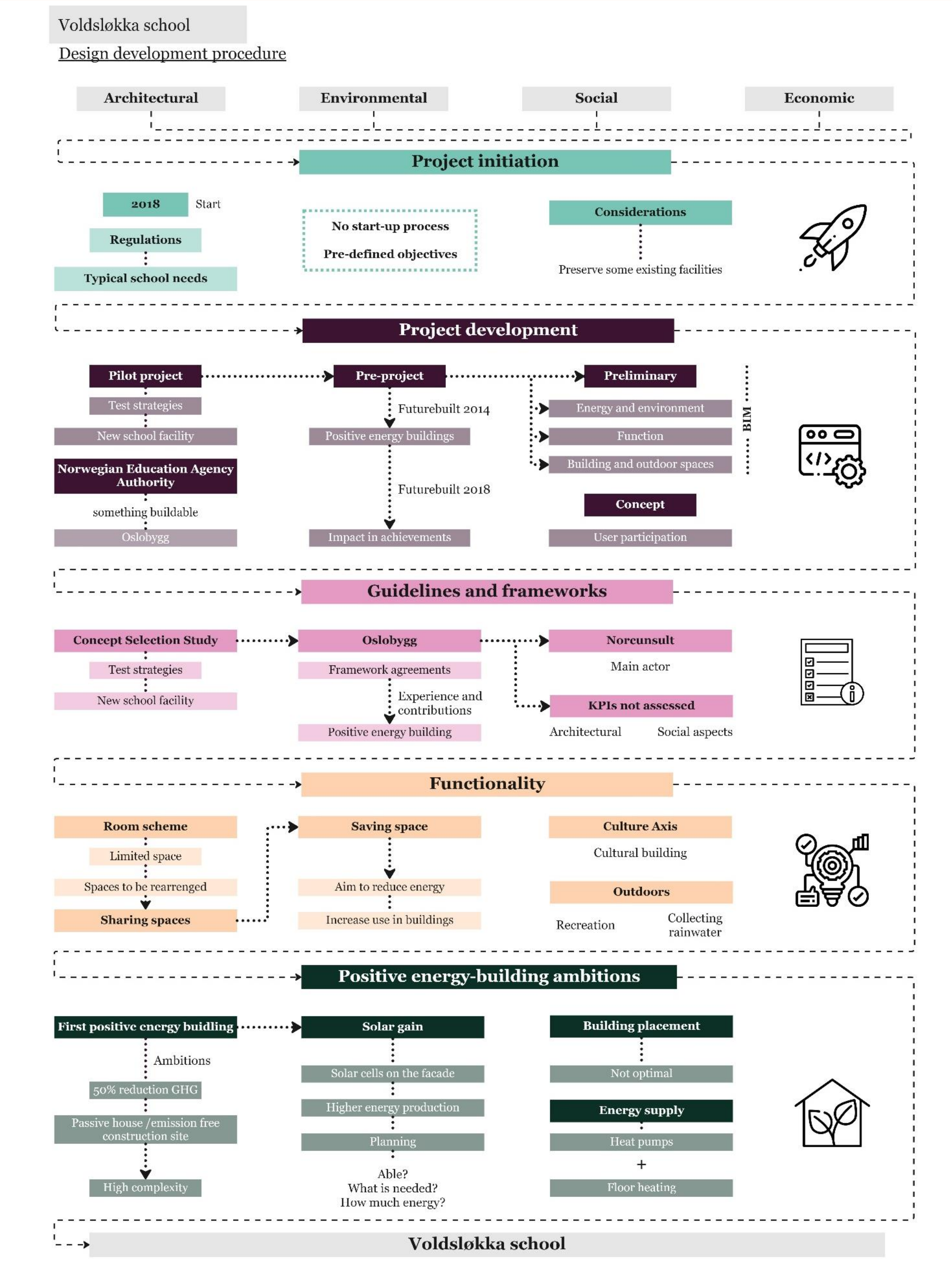


Figure 16. Design development procedure in the Voldsløkka project, by Jesus Daniel Garcia Melo (NTNU).

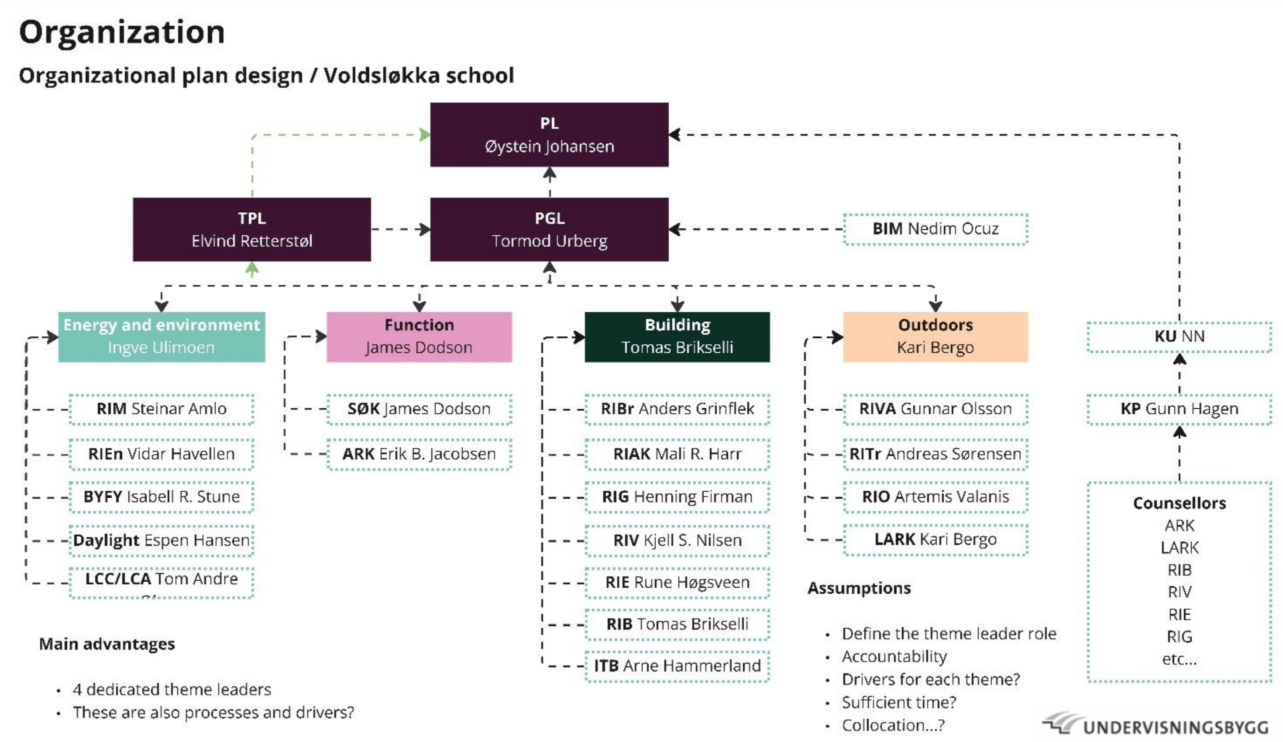


Figure 17. *Original organizational scheme by OBF. Edited by Jesus Daniel Garcia Melo (NTNU).*

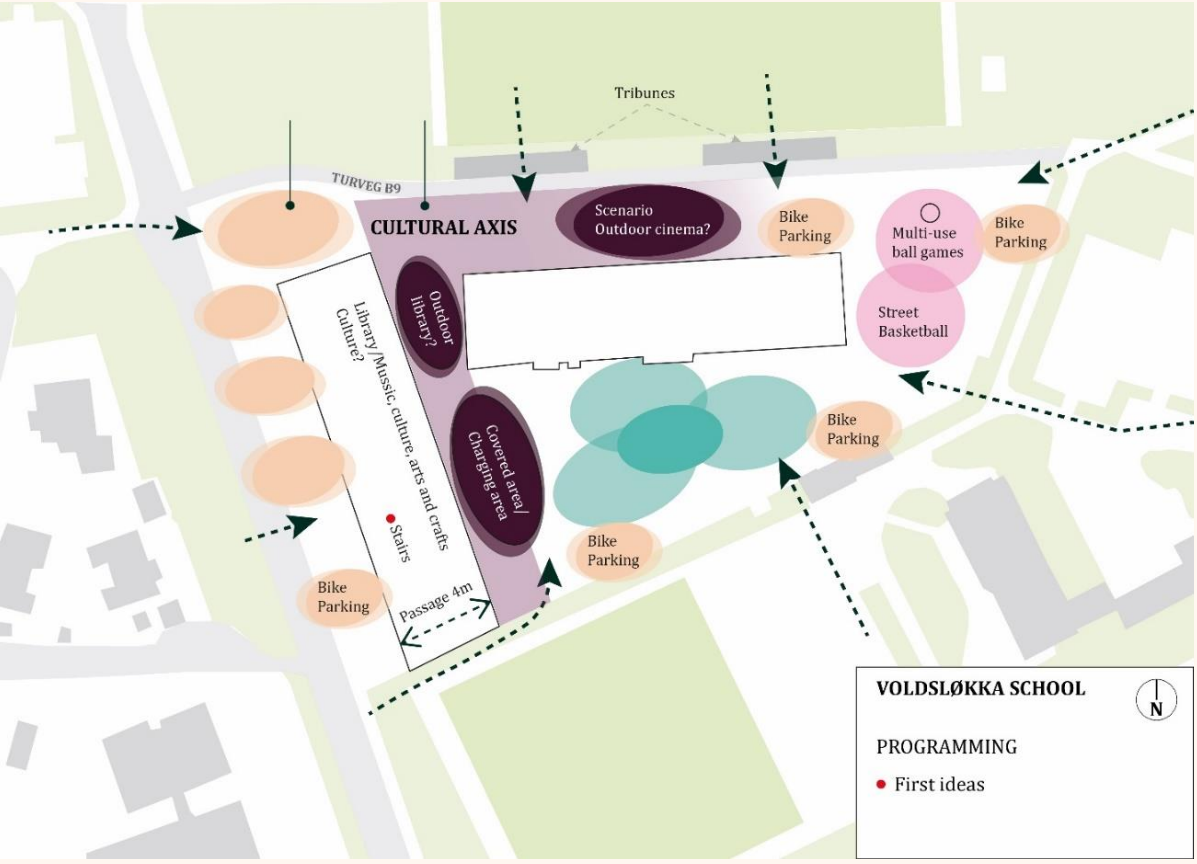


Figure 18. *Initial sketch of the Voldsløkka School outdoor program. Original image by ØSTENGEN & BERGO AS. Edited by Jesus Daniel Garcia Melo (NTNU).*

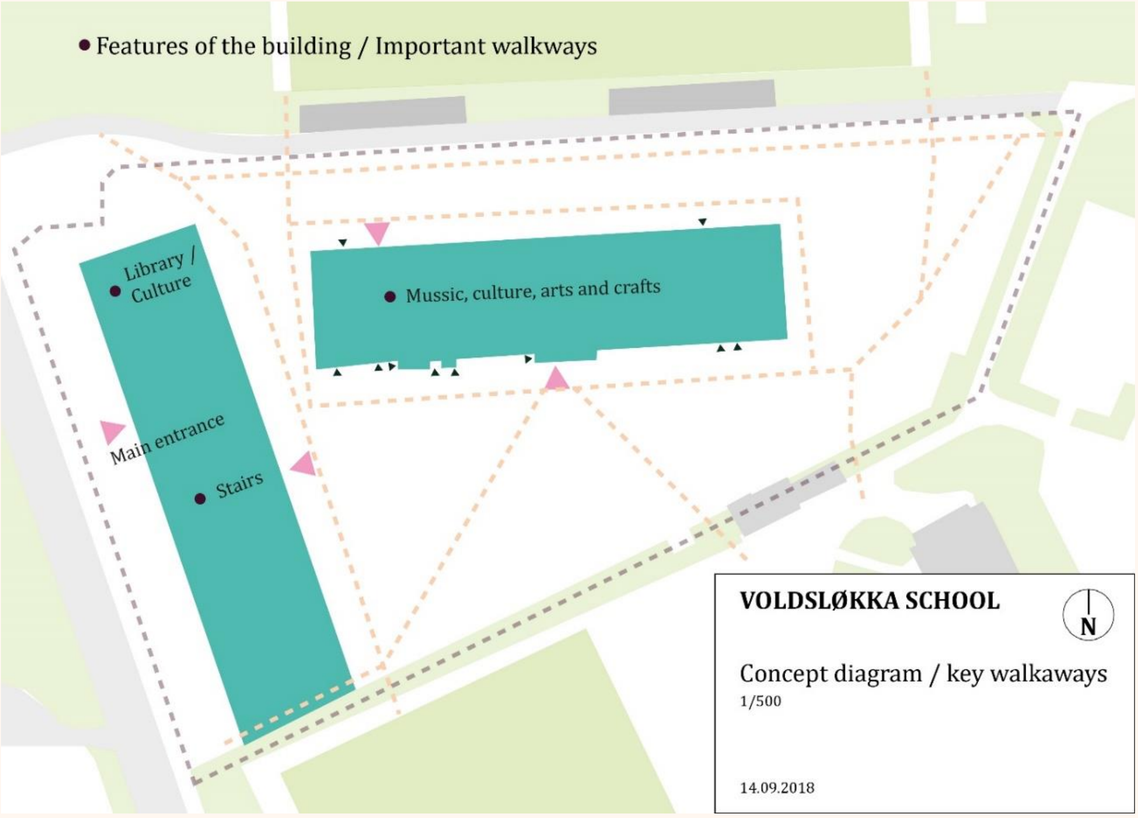


Figure 19. *Initial sketch of the Voldsløkka School indoor program. Original image by ØSTENGEN & BERGO AS. Edited by Jesus Daniel Garcia Melo (NTNU).*

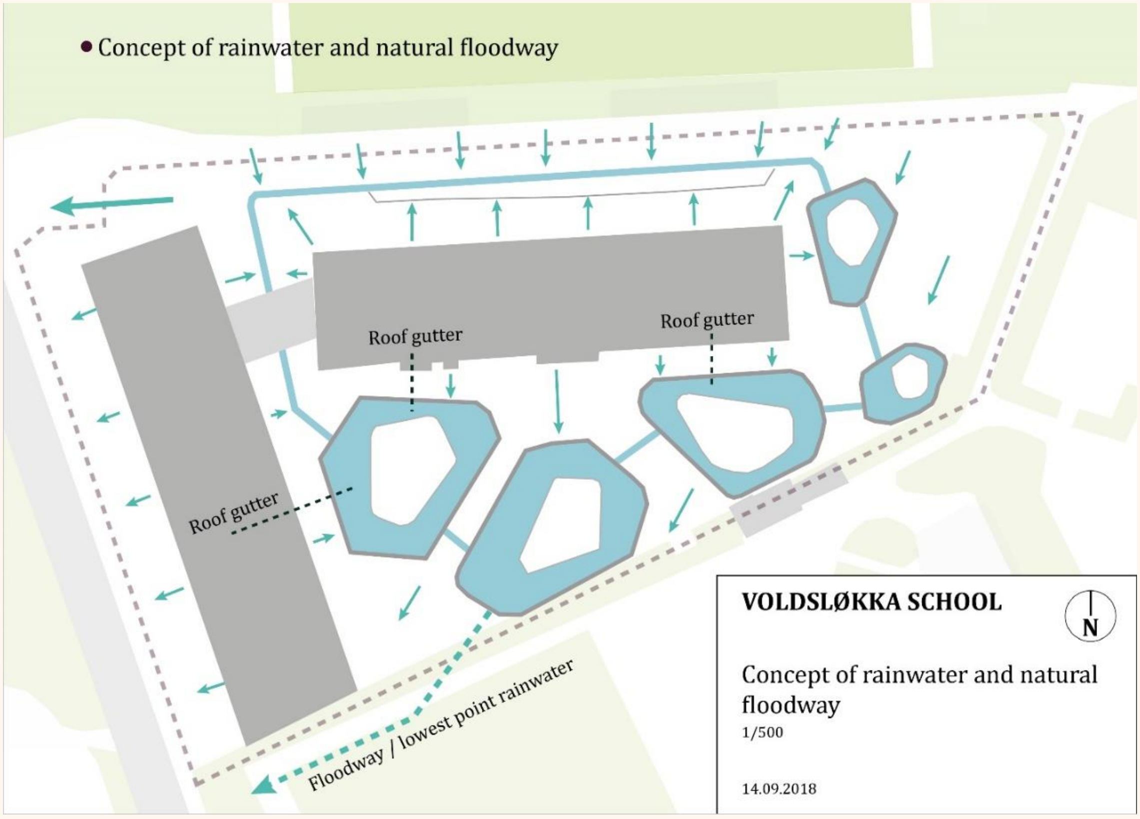


Figure 20. *Initial sketch of the Voldsløkka School stormwater management. Original image by ØSTENGEN & BERGO AS. Edited by Jesus Daniel Garcia Melo (NTNU).*

PROJECT SPECIFICATIONS OF THE DESIGN DEVELOPMENT PHASE

The Voldsløkka project consists of a Secondary School with a cultural hall and spaces for cultural activities. The collaboration between the education and the cultural activities is ensured by the mixed use of the building during and outside the normal school opening time. This is achieved by using the school building (S-building) and the Heidenreich building (H-building) either at the same or at different times of the day for various activities, as shown in Figure 21. The functional areas for education and culture are therefore distributed in the school building and the Heidenreich building, and the passage between these two is provided by a glazed bridge located at the floor 2, where the canteen, the kitchen, and the Food & Health department are located. Most of the education activities are located in the S-building, which is built over 5 floors, with the main access from Uelands gate. The distribution of the internal areas in both the buildings is planned so that those programs that require joint use and/or accessibility after regular school hours are located close to each other. The buildings' closing system is arranged so that the various user groups only have access to those rooms that can be reserved outside the school opening time.

The shared use and zoning of functions is planned so that the building can be easily divided into areas belonging to the school, those shared between the school and the cultural space, and those reserved to the cultural space. Such a zoning is the basis for defining the location of the rooms in the H-building and the S-building, as shown in Figure 21. The final arrangement of the building program and rooms placement is the result of a user participation process that has involved OBF, UDE, UF, and EO.

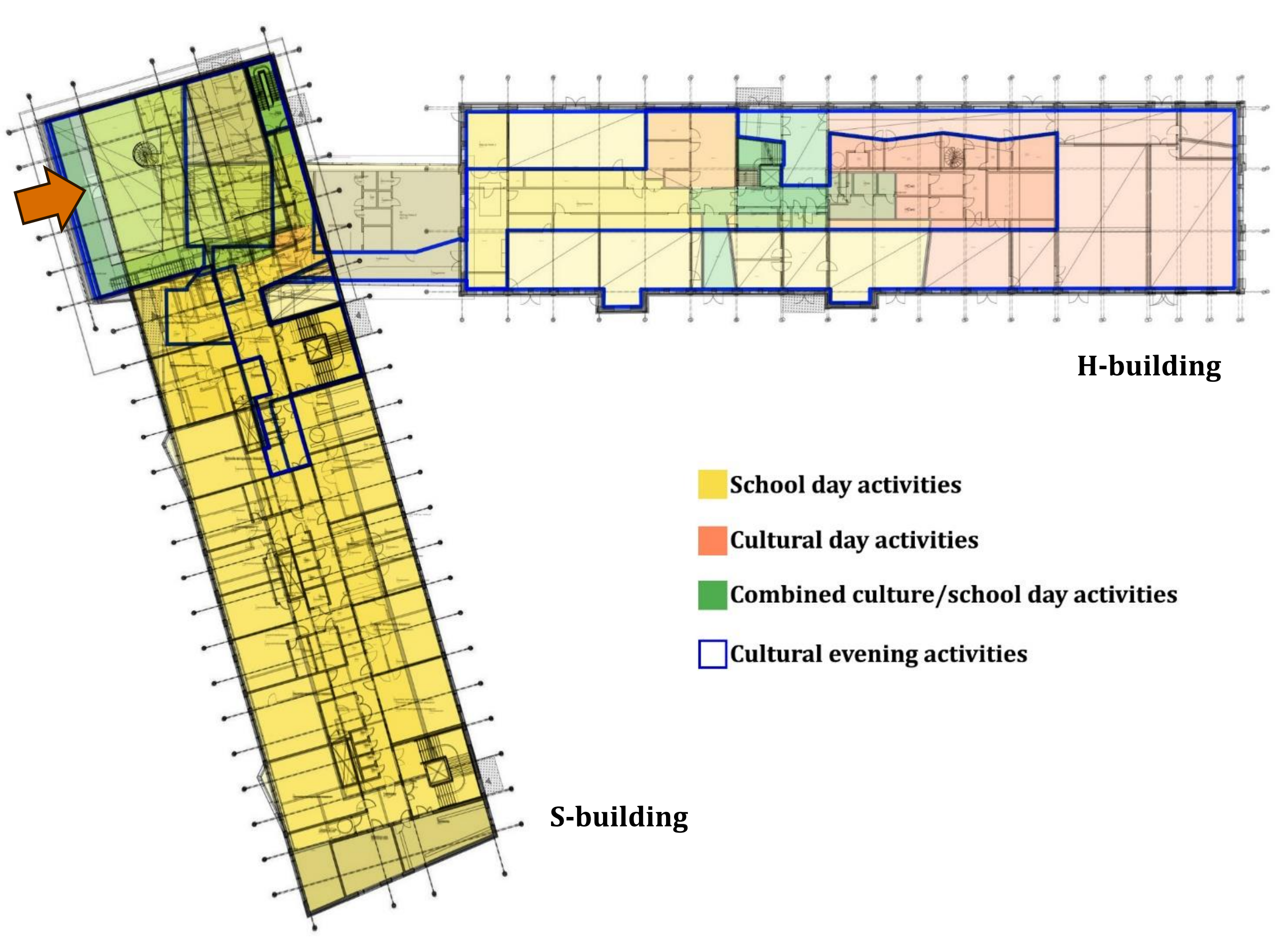


Figure 21. *Map of the different time-related uses of the Voldsløkka project. Original image by KONTUR and SPINN Arkitekter, edited by Nicola Lolli (SINTEF).*

The school building

The S-building is built over 5 floors and accommodates all the school activities. The northernmost part of the S-building is used for the auditorium, the main entrance, and the areas where the combined cultural/educational activities take place. This planning was made to ensure that those areas that are used jointly are placed next to each other. For this reason, the bridge connecting the S-building to the H-building is placed next to the auditorium, as shown in Figure 21. The distribution of the different rooms' programs in the S-building and in the H-building is done as such:

- The general learning areas (classrooms, teachers' and students' workspaces, reception rooms, teachers' meeting rooms) are placed together from level 2 to level 4.
- Some of the classrooms and administration are placed in the basement, level 1, and level 5 of the S-building, and in the bridge and in the H-building.
- The canteen and specialized learning areas are located in the part of the H-building closest to the S-building.
- The cultural area is located in the part of the H-building farther from the S-building.

The areas dedicated to cultural activities consist of various music and teaching rooms (rehearsal rooms), auditorium/black box, dance hall and associated warehouse. The auditorium/black box are located in the north of the S-building, closely linked to the building's main entrance (Figure 22).

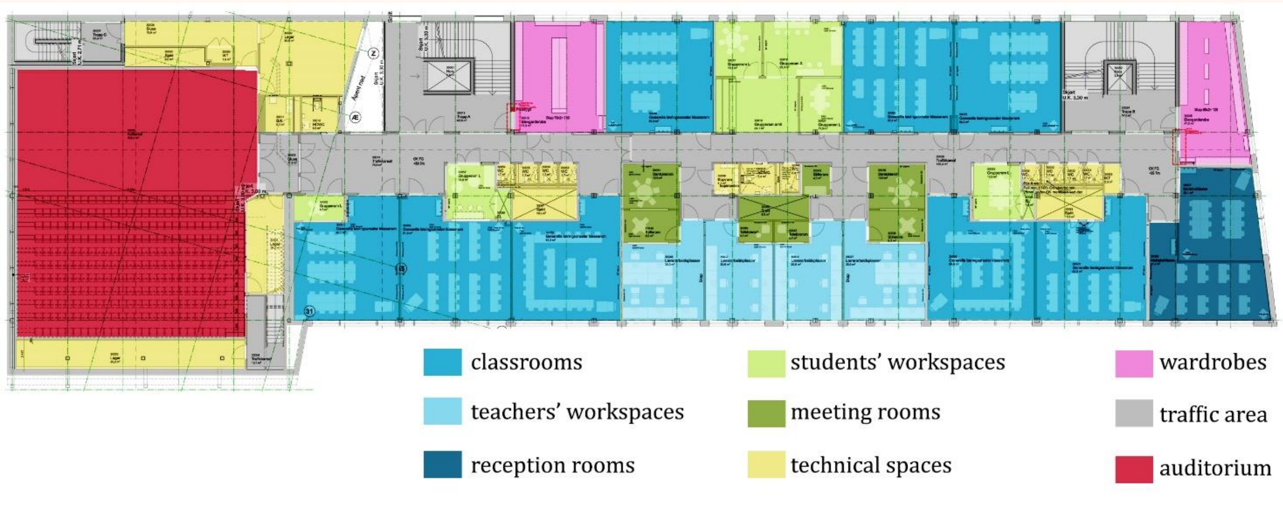


Figure 22. *Plan of the school building rooms program. Original image by KONTUR and SPINN Arkitekter, edited by Nicola Lolli (SINTEF).*

The general learning areas in the S-building are distributed over 3 floors, so that each learning grade is accommodated in each floor. Each area for general learning consists of rooms of different sizes and uses for the students:

- Classrooms and students' workspaces of different sizes
- Toilets and two separate areas for wardrobes directly connected to stairwells with direct access to the school yard.
- Teacher workplaces
- Flexible learning areas arranged for reception classes.
- Teachers/students meetings rooms

Each learning grade hosts 120 students, which are divided in two groups. Each group of students is associated to the learning areas placed on one of the two sides of the building, by the respective responsible teachers' workplaces. The students of each of the two group can access their own respective learning areas by a ramp of stairs and have their own wardrobe. This floor layout ensures the student flow to be controlled and the students can get directly to their own zone and avoid too much crossing traffic. Each group of 60 students is allocated in two classrooms of 30 students each. These classrooms are designed in such a way that they can be combined to form larger rooms. One of the classrooms of each group can, instead, be further divided to form two smaller classes of 15 students each. Finally, all classrooms belonging to each learning grade can be further arranged to form 4 classes of 20 students each, of which one classroom accommodates two separate groups of 10 students each, and, finally, one classroom which accommodates 40 students (Figure 22).

External facades cladding and PV modules

The school building at Voldsløkka school is built as a “plusshus” (plus-energy building) in accordance with FutureBuilt's definition from 20.08.2014[12]. This means that parts of the facades generate electricity which exceeds the total yearly energy use by 2 kWh/m^2 year. The plus-energy building goal also defines the guidelines for the building shell, which is built according to the minimum requirements set in NS3701 for low-energy buildings. The school building's shell is an insulated post and stud timber frame construction, finished with a non-ventilated system facade with photovoltaic panels and glass panels. The decisions for the cladding materials decided in the design development were based on the specifications given in the Regulatory Plan:

"The building's facade material must be glass, a plastered surface, wood, brick, concrete, natural stone or facade panels. The facade panels must be of high aesthetic quality and the facade cladding between the new school building and the existing listed building must be made of glass so that the visual contact between the schoolyard in the south and park in the north is ensured".

The facade cladding of the S-building consists of a curtain wall system outside the climate shell in the parts of the building where PV and glass panels are installed. A sufficient number of PV panels are installed on the curtain wall so to meet the requirements for a plus-energy building. The installation of a technical layer (PV panels) on top of a traditional insulated post-and-stud timber frame is planned to ensure a simple maintenance of the façade and simple operations for future replacement and inspection, without this conflicting with the school building's climate envelope. Two shades of green are chosen for the glass panels and PV panels, of which a part consist of standard black panels, as shown in Figure 23. Windows' installation is designed so they are installed and replaced from inside the building without the need to remove the outermost technical layer.

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[12] *Kriterier for Futurebuilt Plusshus.* https://www.futurebuilt.no/content/download/5861/55365

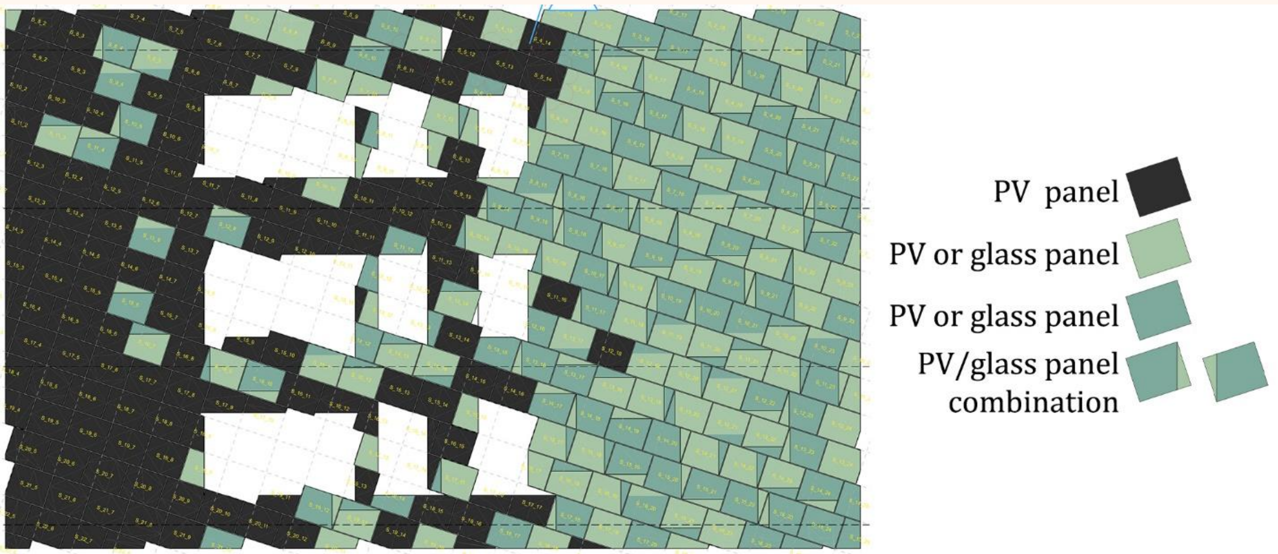


Figure 23. *Plan of PV panels installation on the south façade of the school building. Original image by KONTUR and SPINN Arkitekter, edited by Nicola Lolli (SINTEF).*

The Heidenreich building

During the project development phase several meetings with the Oslo City Office for Building Preservation (BYA) have been organised to discuss the guidelines for the renovation of the H-building. The following decisions were taken after BYA's recommendations. Given the specific requirement of preserving the architectural expression of the H-building decided in the Regulatory Plan, the facade appearance and design of the H-building from 1935 was used as a general guideline for the restoration, as the current window division originates from this period. In addition, the doorways on the ground floor shown in the original facade drawings from 1919 are re-established.

To meet today's TEK 17 U-values requirements, the building facades were insulated from the inside to preserve as much as possible the outside appearance of the building. The roof of the H building is replaced in its entirety, but the original cornice details are preserved, so that the appearance of the facade is not changed. Four skylights are installed for the students' workplaces on the mezzanine. The skylights do not protrude over the roof surface to be visible as little as possible from the courtyard. The existing roofing made of corrugated steel sheets is preserved. In the meetings with Oslo City Office for Building Preservation (BYA), the prerequisite to maintain the same roof height after the post-insulation and technical upgrading was clearly expressed to make sure the roof surface meets the cornice. Other internal roof structures in the H building were demolished.

Wood and concrete columns are preserved as visible non-load-bearing elements. In addition, the original water radiators are retrofitted and re-installed in the building as aesthetic elements. The façades are finished with plaster with the original colour and materiality.

Figure 24. *Demolition plan of the north façade of Heidenreich building. Original image by KONTUR and SPINN Arkitekter, edited by Nicola Lolli (SINTEF).*

Windows's retrofitting

As a general rule, the old windows were to be replaced with new windows which are made with the same material use, detailing, and dimensions as the existing original windows. However, some exceptions were applied. Four original inner windows were reused as outer windows and installed in the North façade, by following the 1935 façade appearance. The door openings in the South facade were re-established according to the 1919 drawings. The original windows in the South façade were retrofitted and the wooden windows replaced with new ones to match the 1935 appearance. Today's openings in the East façade are preserved since the original windows were lost and no information regarding their origin could be found. The opening sizes and positions were preserved but the windows were replaced with new ones. The windows opening in the West façade were maintained since they are shown in the 1935 drawings. However, a larger recess was planned in the bridge connection, to ensure accessibility between the S-Building and the H-building. Figures 24 and 25 show the changes on the H-building facades.

Roof construction

The existing roof was demolished and a new ventilated roof that satisfies TEK 17 U-value requirements was installed with the same external appearance. The details of roof cornice were preserved and restored to maintain the original façade expression.

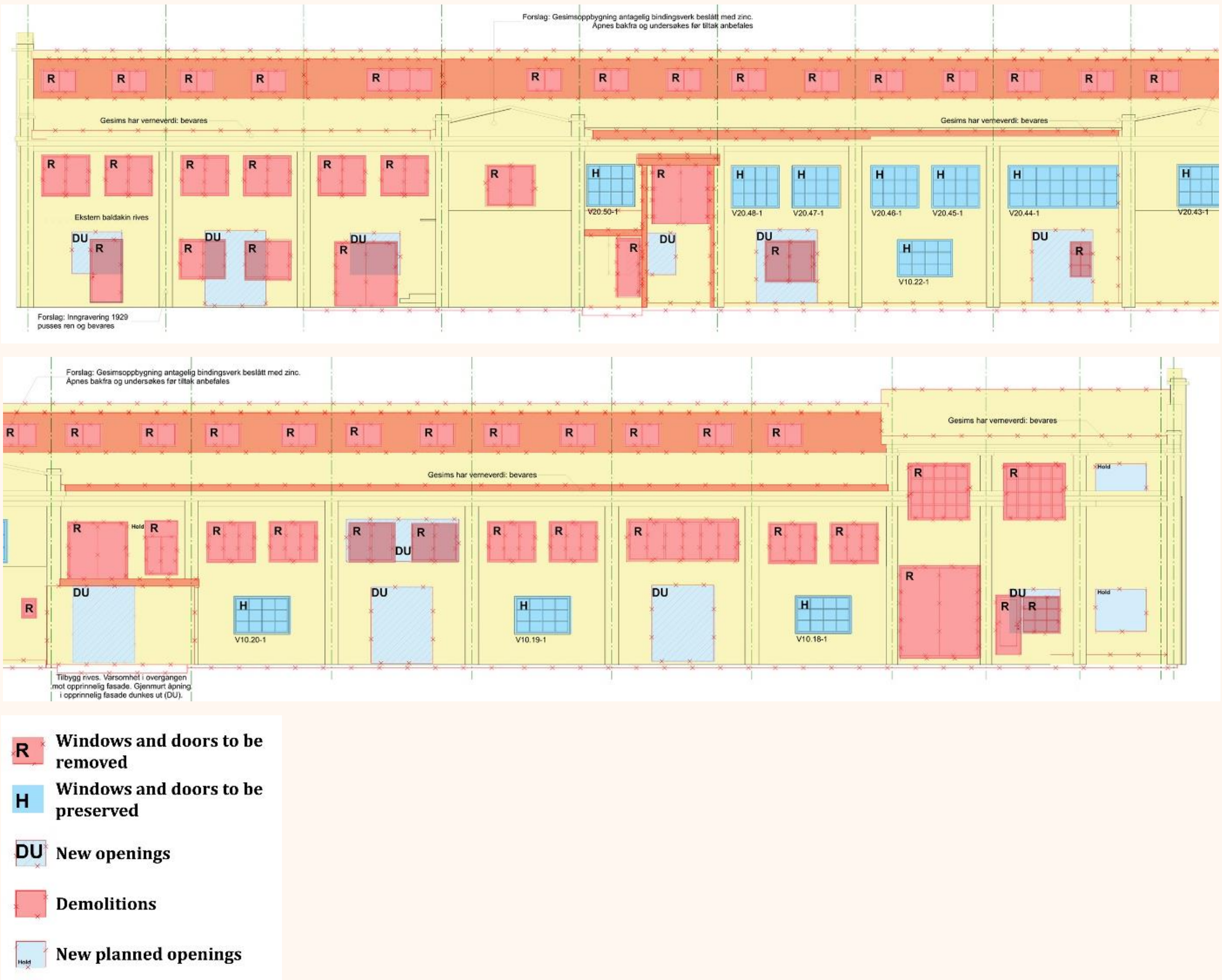


Figure 25. *Demolition plan of the south façade of Heidenreich building. Original image by KONTUR and SPINN Arkitekter, edited by Nicola Lolli (SINTEF).*

The bridge between the H-building and the S-building

The bridge connecting the H-building and the S-building is designed according to the requirements defined in the Regulatory Plan, where a low and transparent volume was suggested, to ensure continuity of the line of sight between the school courtyard and the park on the north side of the H-building. UDE asked for this space to be used as a functional space, given its proximity to both the H-building and the S-building, the adopted joint use of both the buildings for educational and cultural activities, and the imposed limitations to its volume. The bridge allocates the kitchen of the school canteen and Food & Health Department, whereas the canteen dining and living area is placed in the mezzanine of the H-building. Given the large number of users, 810 secondary school students and 1 750 weekly external users of the cultural purposes, the canteen kitchen and its eating and living area are placed between the H-building and the S-building to provide a natural meeting point that integrates the functions of the two buildings together. In such a way, the canteen kitchen and the dining and living area can be accessible from both the students or the external users during the school daily activities and the cultural activities in the evenings.

BYA recommended to use cladding materials for the bridge roof and walls that matched both the H-building and the S-building. In such a way, the bridge should appear as part of the whole complex expression and not as a single independent element.

School courtyard and playground

The pathways and activities of the outdoor space were thought to work together with the surrounding area. Because the plot is rather small, the landscape architects in agreement with the municipality designed the school courtyard in such a way that it functions as a part of the greater area of Voldsløkka. In the area, there are a sports park and other fields for training and motion which supplements the school's direct outdoor spaces. The design of the school courtyard itself took as a starting point the water management solution the landscape architect designed. The Regulatory Plan requires that the school courtyard is to be developed as a park with a variety of vegetation at different heights and with permeable surfaces and natural surfaces covering at least 30% of the outdoor flooring. The school's green areas are organized and planned in two main groups with different designs, to facilitate natural protection of the vegetation, green areas at the plot edges, and green island in the middle, as shown in Figure 26.

Figure 26. Landscape design of the Voldsløkka project. Original image by ØSTENGEN & BERGO AS, edited by Nicola Lolli (SINTEF).

Green areas in the edge zones. The green areas are used to accommodate the difference in terrain height to surrounding areas. The marginal zones are established as sloping flower meadows with a varied density of trees and shrubs, as shown in Figure 26.

The green areas in the centre zones. The central green areas are developed as islands surrounded by "channels". These "channels" are the features that ensure an efficient stormwater management on the school grounds. The terrain around the channels is planned so that rainwater flows towards the islands, as shown in Figure 27. The channels are covered by metal grates below of which rain beds are placed. On the rain beds, a flower meadow with Norwegian, wild, perennial meadow plants is placed. When the plants get tall enough, they will stick up through the grates and will then be worn down by passers-by. The stormwater is collected by the channels and redirected to the islands, where it is absorbed and led deeper down towards the crushed stone reservoir below, as shown in Figure 28. In the islands, native bushes and multi-low-stemmed trees are planted densely, to achieve a nature-like feel, by using plant species that can withstand standing in water for shorter periods. The islands are surrounded with fences, edges, and benches, to make it difficult to walk in the islands and ruin the vegetation. Safe flood roads are ensured on the surface, out into Uelands gate, so that flood damage is avoided. The system islands-channels are designed in such a way to clearly show the water flows and the mechanism of storm water management employed in the school site.

Figure 27. *Scheme of storm water management in one of the project's "islands". Original image by ØSTENGEN & BERGO AS, edited by Nicola Lolli (SINTEF).*

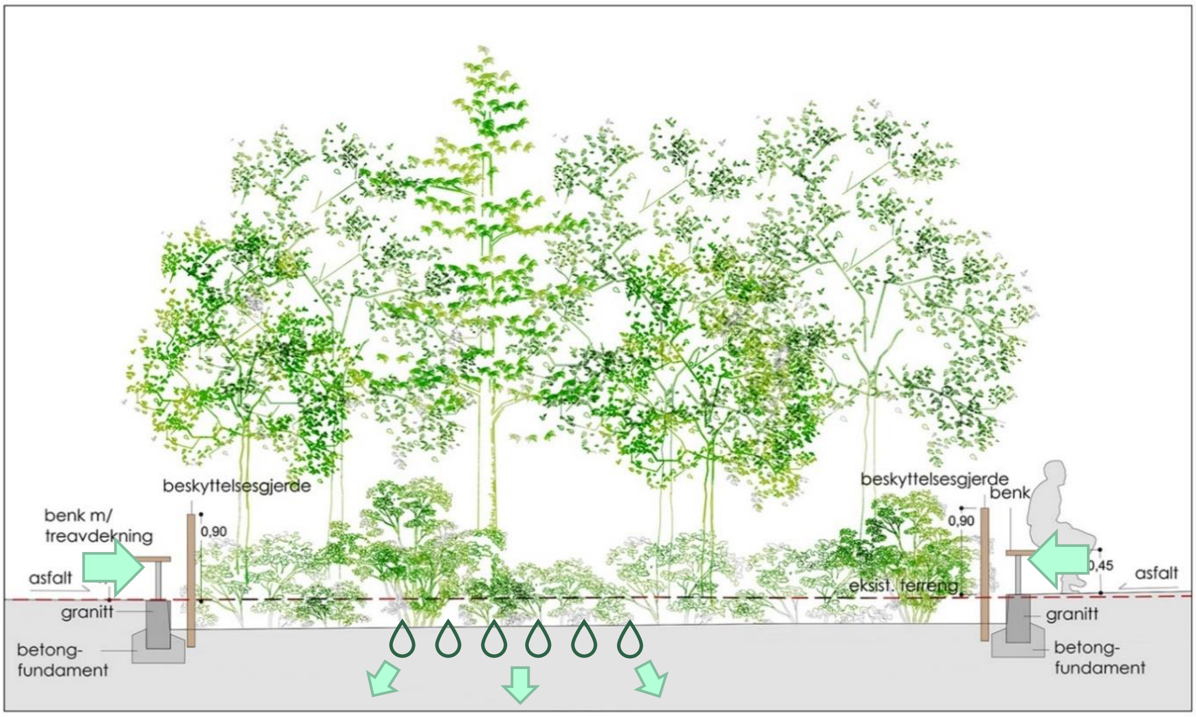


Figure 28. *Scheme of storm water management in one of the project's "islands". Original image by ØSTENGEN & BERGO AS, edited by Nicola Lolli (SINTEF).*

DESIGN DEVELOPMENT OF THE ADJACENT SPORTS HALL

The sports building continues the established urban design concept at Voldsløkka consisting of an urban front along Uelandsgate which frames a large green urban park behind. The sports hall follows Uelandsgate as an extension of the school building, and its location is then at the intersection of Uelandsgate and Stavangergata in Sagene, Oslo, as shown in Figure 29. The site on which the building will be erected has an area of 29 500 m^2 and the building has a gross area of 12 359 m^2. The site is part of the large Voldsløkka park, which also has a large artificial turf pitch, sand volleyball courts, playground, ball binge, tennis courts, field hockey pitch with associated clubhouse, and the old sports hall that will be demolished. The design phase is expected to take place throughout 2024 and partially 2025. The construction phase is expected to begin in summer 2025.

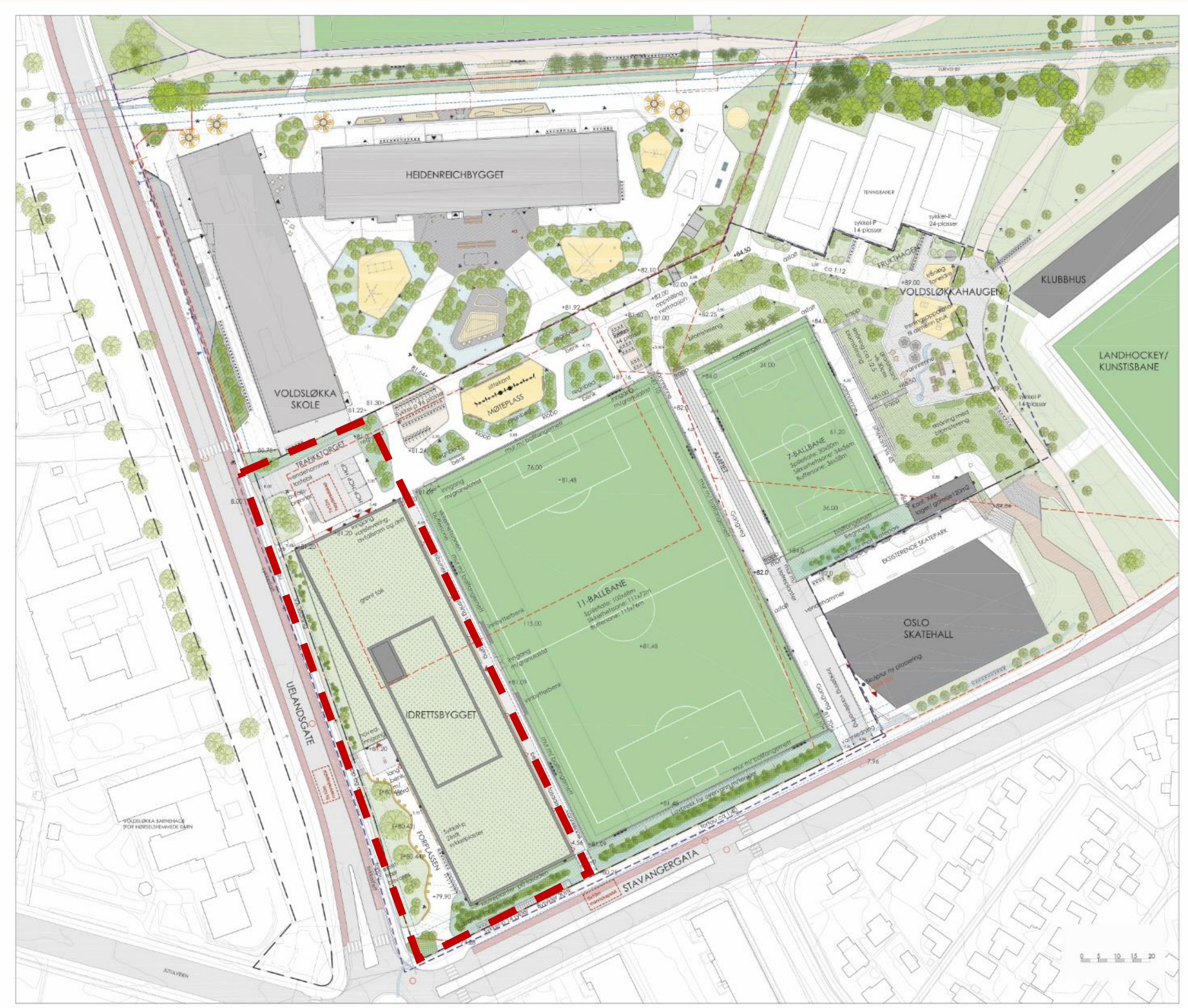


Figure 29. Plan of the Voldsløkka area with the S-building and H-building (top) and the sports hall (bottom left, highlighter in red). Source: Østengen & Bergo.

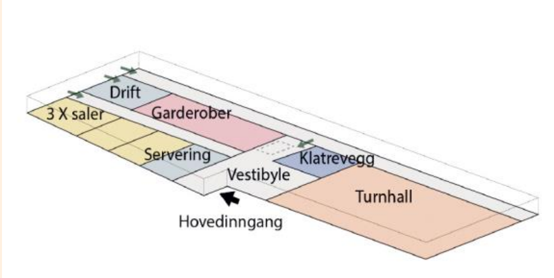
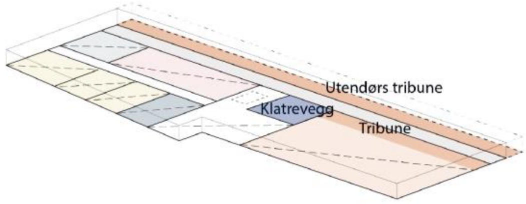
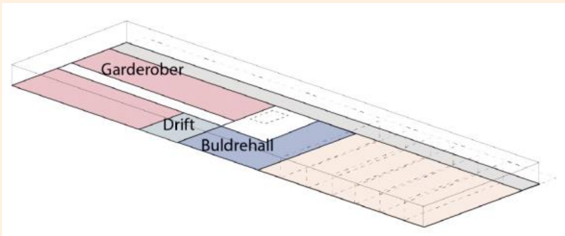
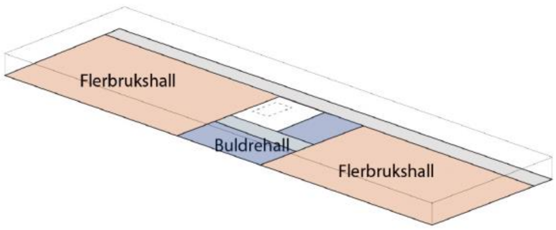
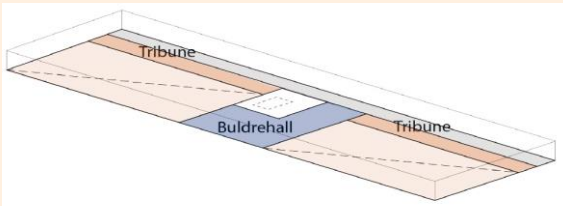
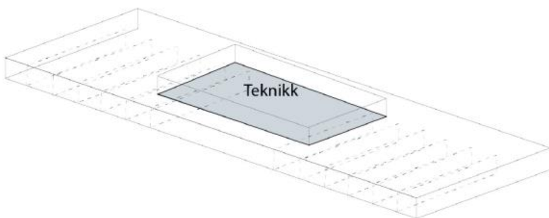
The zoning regulations and zoning plan defined clear expectations for the building to be perceived as accessible, open, and inviting from the street front. The building will be designed to clearly make visible its main functions behind transparent façade surfaces (Figure 30 and Figure 31). The indoor areas for sports activities will be made visible from the building entrance and adjacent street front, and this solution also provides enough daylight in the activity rooms. Transparency is also emphasized in the interior, by ensuring visual contact between the foyer and gymnasium, and potentially between the corridors and the large activity hall.

Given the small site and footprint, the resulting building shape is tall and long. This inevitably produces longer than usual horizontal and vertical distances between changing rooms and halls. The East-facing glass facade is designed to make this connection a positive experience, in such a way the corridors become galleries with a view on the outdoor courts and Voldsløkka park (Table 7).

Figure 30. *West view of the sports hall from Uelandsgate. Source: Asplan Viak.*

Figure 31. *Conceptual section of the building. Source: Asplan Viak.*

Table 7. *List of activities for each floor of the sports hall. Source: Asplan Viak.*

Floor	Function	
Ground floor	Gymnastics hall Climbing wall Cloakrooms gymnastics Gymnastics and climbing storage Technical room with central heating system	
Mezzanine	Service point with security guard, catering and kiosk. Offices and meeting rooms Public toilets Activity halls Grandstand gymnasium and tribunes Locker rooms and dressing rooms Storage for outdoor sports Bicycle parking Technical rooms Electrical and ICT	
1st floor	Student and team locker rooms Bouldering hall Public toilets	
2nd floor	School hall (multi-purpose hall with SKOK requirements for layout and furnishings). Multi-purpose hall Storage Bouldering hall Public toilets	
3rd floor	Tribunes for school hall and multi-purpose hall Bouldering hall Public toilets	
Roof	Technical room Green roof and photovoltaic system	

The project is designed to meet the criteria of a nearly zero energy building (NZEB) according to "Criteria for NZEB for Futurebuilt projects"[13] and possibly become a plus energy building, under the category of Sports building. Under such a category, the weighted delivered energy of a plus energy sports hall has to be 10% lower than that given in the NZEB requirement, which is set to a maximum weighted delivered energy 25 kWh/(m^2 year)[14]. For the building to reach a plus energy goal, the required annual energy production from the photovoltaic system must be at least of 220 000 kWh/year. Solar cell systems is designed to be placed on the entire roof of the building, both on the main roof and on the roof of the technical room, and on the south and west-facing walls of the technical room (Figure 32).

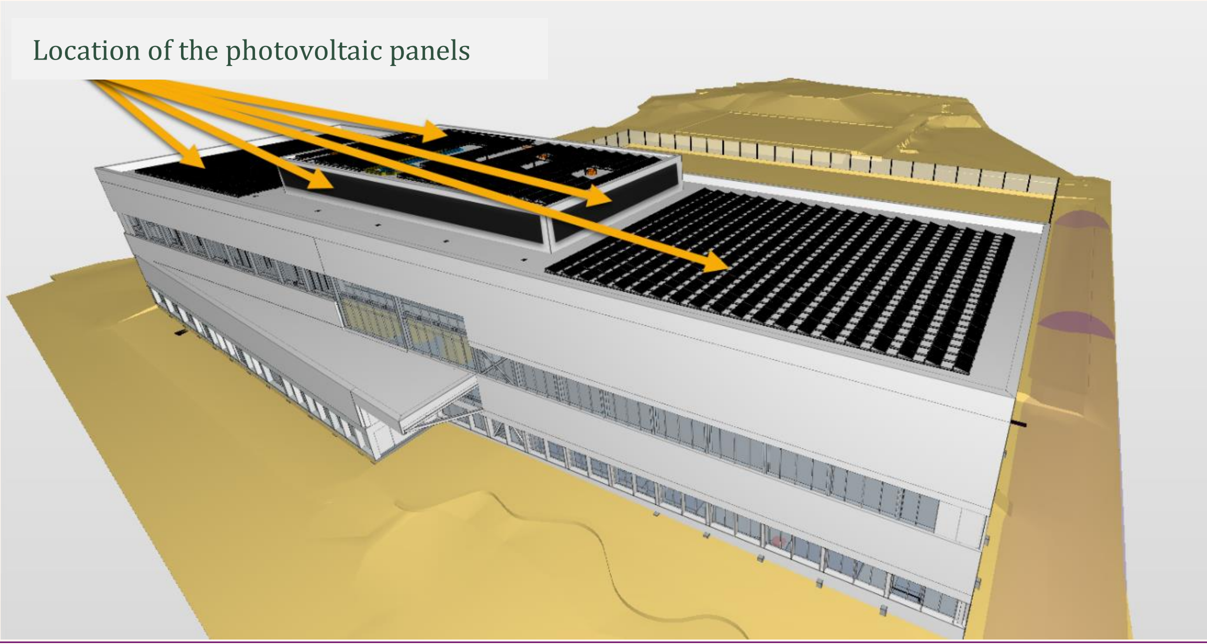


Figure 32. *Scheme of the location of the photovoltaic panels on the sports hall. Source: Asplan Viak.*

The thermal energy system of the building will consist of a large heat pump with R744 (CO_2) as the fluid medium, connected to energy wells. Energy wells will be excavated under the outdoor artificial turf pitch. The heat pump will supply the sports building with thermal energy (cooling and heating) and will produce heating for the large artificial turf pitch in winter. A system for recovering heat from grey water will be installed to preheat the tap water. The heat pump will also preheat tap water via an accumulator tank with electric coils. District heating will be used as a peak load for both space heating and tap water production. District heating in combination with an electric boiler will also be used as a backup solution to reduce the need for high demand of district heating. The energy wells will be used to produce free cooling for the ice water system as long as the temperatures in the ground allow this, when the heat pump is operated in cooling mode.

Oslobygg has defined a set of goals for environmental ambitions of the project to reduce the embodied emissions and environmental impact of the sports hall construction. The greenhouse gas emissions from the production of materials and components are requested to be lower than the values given in Table 8. Moreover, the project aims at using recycled steel from shipyards, dismantled ships, and oil platforms, in the form of plates to be shaped into load-bearing elements for the staircases in the building. This is to

[13] "Kriterier for NZEB for FutureBuiltprosjekter". https://www.futurebuilt.no/content/download/33284/182295
[14] "Kriterier for Futurebuilt Plusshus". https://www.futurebuilt.no/content/download/28113/157869

ensure the project target for greenhouse gas emissions associated with material use is lower than or equal to 420 kg CO2e/m² of gross floor area. Moreover, to follow the City of Oslo's aims of waste reduction from construction sites, the construction will be managed to achieve a 90% of sorting and separation of the different types of waste produced on-site, by allowing a higher amount of waste to be sent to energy recovery or recycling. Waste volumes are expected not to exceed 25 kg of waste per m^2. To achieve this, the detailed design will be developed to reduce the need for cutting, a return scheme for packaging will be established, the use of disposable pallets will be avoided, and the use of temporary wooden structures such as railings and ramps, will be minimized. Finally, by following the City of Oslo minimum requirement for emission-free construction sites (in force from 2025), the use of electric machineries and transportation vehicles will be maximized, and the use of low emission heating sources (district heating, renewables) will be ensured.

Table 8. *Limits of GHG emissions of materials and building parts set for the sportshall. Source: Oslobygg.*

Materials and building parts	Maximum GHG emissions for stages A1-A3
Steel columns, hollow profiles	3.66 kg CO2e/kg
Steel beams, hollow profiles	3.66 kg CO2e/kg
Concrete for decks and basement walls, cast-in-place	Low carbon class A (170-240 kgCO2e/m³)
Steel beams I, H, U, L and T profiles	2.12 kg CO2e/kg
Beams trusses	2.12 kg CO2e/kg
Cast-in-place	Low carbon class A (170-240 kgCO2e/m³)
Insulation in the foundation	4.44 kg CO2e/kg
Concrete in prefab hollow core slabs	Low carbon class A (170-240 kgCO2e/m³)
Windows, glass facades and doors in building envelope	65 kg CO2e/m2

5.2 DETAILED DESIGN

THE DETAILED DESIGN PHASE OF VOLDSLØKKA STEP-BY-STEP

The detailed design phase of the project commenced once the selected architects (Spinn Arkitekter AS, Kontur AS, Østengen & Bergo AS) developed and completed the design concept, described in Chapter 5.1. The detailed design started by the end of March 2021 for a duration of 100 weeks (until March 2023). During this phase the construction permits for the following activities were processed:

- Demolition of the two existing buildings on the project area (Building A and C).
- For the landscape: demolition of existing loading ramps (associated to the existing A-, C-, and H-buildings), digging and ground movements.
- For the H-building: demolition of the existing roof, installation of a new roof, demolition of the indoor partitions and installation of the new wood, concrete, and steel structural systems, opening of new voids in the façade, restoration of existing windows and façade outermost layer
- For the S-building: laying the foundations piles, glulam, concrete, and steel superstructures, weather proofing of the building.

Differently from the usual design development process, the architect team and the fire safety consultant were assigned to work in both the design development and detailed design phases. This was done to ensure that the overall environmental concept of the project (plus-energy building, storm water management, GHG gas reduction, etc) was developed with the same quality and characteristics in both the detailed design and in the design development phase. The normal process in detail designs is to assign the solution of the design concept to the builder, within a total enterprise contract. The builder is, therefore, responsible to develop technical solutions that fit the architectural concept. Since there may be more than one solution possible, is it up to the design team to agree on those that fit best their original ideas. By making the original design team following the detail design phase, it was easier to coordinate the work with the several subcontractors hired by the main contractor (Veidekke) to make sure the implementation of the different part of the design was done in accordance with the original ideas.

Timeline for the design, building, completion, and test phase of the Voldsløkka project

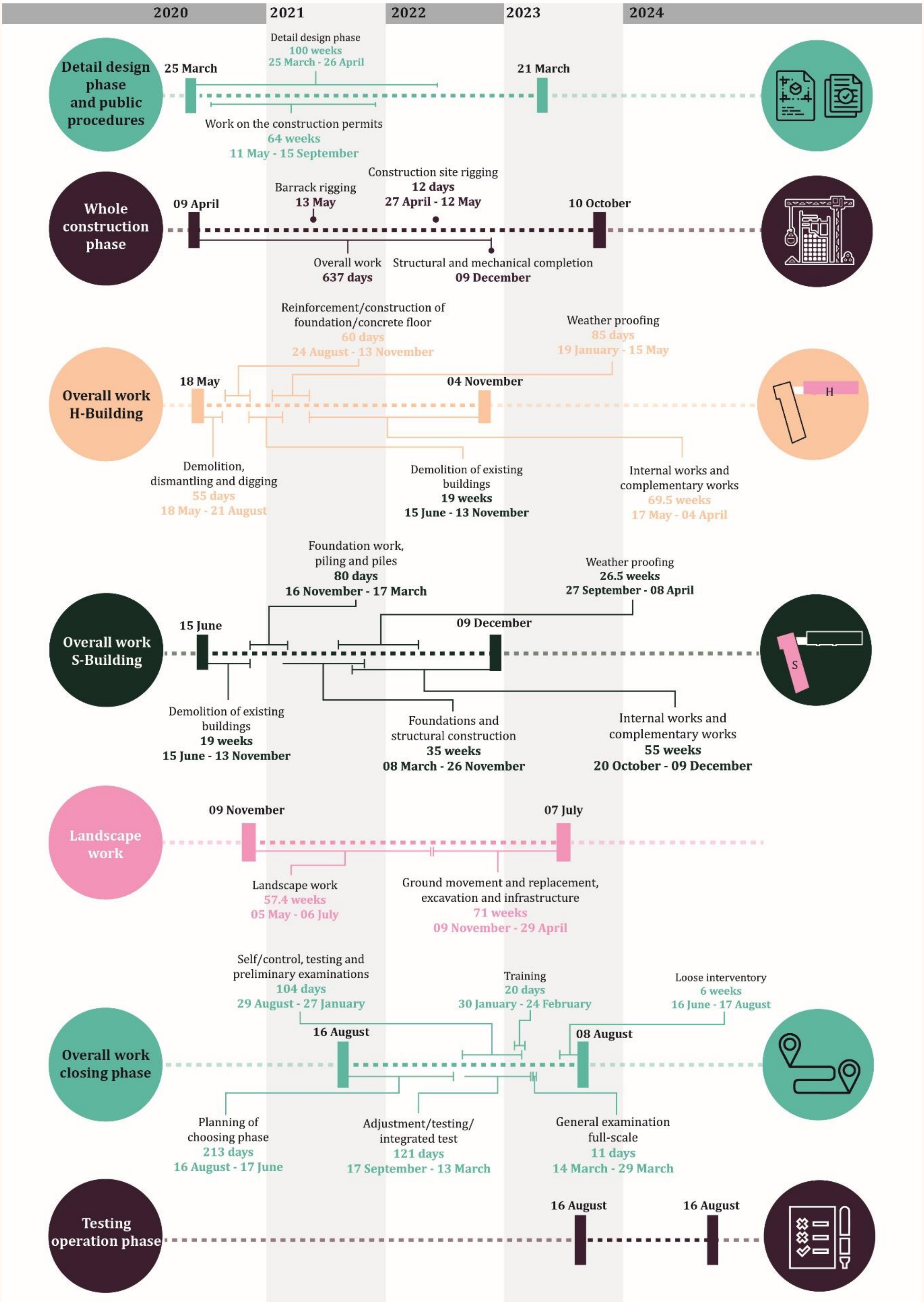


Figure 33. Timeline of the Voldsløkka project, by Jesus Daniel Garcia Melo (NTNU).

PROJECT SPECIFICATIONS OF THE DETAILED DESIGN PHASE

In this chapter the most interesting design solutions for the H-building and the S-building are described. Some of the challenges derived from the design process are described in Chapter 7.

The school building PV facade

The PV system is designed to produce circa 230 000 kWh per year. The design of the PV modules' layouts is defined by the PV modules' orientation in relation to the sky, the orientation of the school building's longest facades, and the regulatory provision regarding the look of the PV façade. For the design of the PV façade, a parametric tool was used to test out different solution for the layout and colouring, simultaneously testing the appearance and the production. The building's N-S orientation is not optimal for PV production, as the longest facades are facing either East or West, thus not taking advantage of the higher insolation on South-facing facades. In addition, the regulatory provision requested the school façade not to resemble that of an office building, meaning that solutions that entail large and monotonous surfaces with PV panels were possibly not accepted. On the other hand, the goal set by OBF for the school building is to produce 2 kWh/m^2 year of excess electricity. The challenge is therefore to combine the limitations given by the not-optimal building orientation, the need for variety of the façade appearance, and the highly ambitious energy goal for the building. The choice of using different shades of green and black for the PV panels, and the rotation of their vertical axis (as shown in Figure 35) is given by the goal of avoiding a uniform and monotonous look of the façade. The overall principle of the façade design is therefore dictated by finding a balance between energy production and aesthetic appearance.

The rotation of the PV panel vertical axis determines the need of cutting the panels in triangular shapes. This reduces the space for allocating modules in each panel, and, depending on the rotation angle, higher or lower numbers of modules can be allocated, thus changing drastically the overall energy production of the façade. Given the plus-energy building target, the decision on the optimal angle for rotating the panels is taken by using a parametric design tool used by an external consultant[15]. The tool that was used in the project used allows the designers to test several panels orientations, calculate the panels cuts, the allowable modules placement, and the overall energy production. The choice of the green coloured PV modules lowers their potential efficiency at producing electricity, given the maximum efficiency is achieved by black modules. Tests of different shades of green are performed on the building site to evaluate which shades of green give the highest electricity outputs, as shown in Figure 35.

The PV panels are hung on an aluminium profile system with a backside minimum air gap depth of 100 mm. The vertical span between the profile system's vertical elements is 600 mm (Figure 34). The profiles are continuous and installed in front of the windows and they will be visible. Therefore, the placement of the vertical profiles and the vertical frames of the windows must match. A secondary profile system with a 20-degree angle is installed in front of the first profiles, to be used for hanging the PV panels at the designed rotation angle. Where the secondary profile system partially overlaps with the windows behind, glass panels are installed instead of PV panels. These glass panels match the colour variations used for the PV panels, as shown in Figure 35. This configuration of glass panels overlapping over the windows opening allows for a more dynamic and varying expression of the windows pattern, without incurring in the technical difficulty of installing non-rectangular windows. The number of total glass panels is circa 15% of the total number of PV panels. The PV panels installed on levels 2, 3 and 4 of the S-building are 850 mm by 1000 mm. The ratio of the green-coloured modules and black modules

[15] Format Engineers Ltd. Https://formatengineers.com/

is as such: about 25% of the modules on the west facade and about 40% on the south façade are black. All other modules come with two different shades of green, in such a way each PV panel consists of two different, green-coloured parts. Two different combinations of the bi-coloured panels are used, as shown in Figure 23. These panels are installed either in an upright position or rotated by 180 degrees. This is to make the impression that 4 different panels are installed on the façade. An equal number of panels of each of these two-colour combinations is installed on the facades on level 5. Standard, black solar panels of 1700mm by 1000mm are installed on the east, west, and south facades.

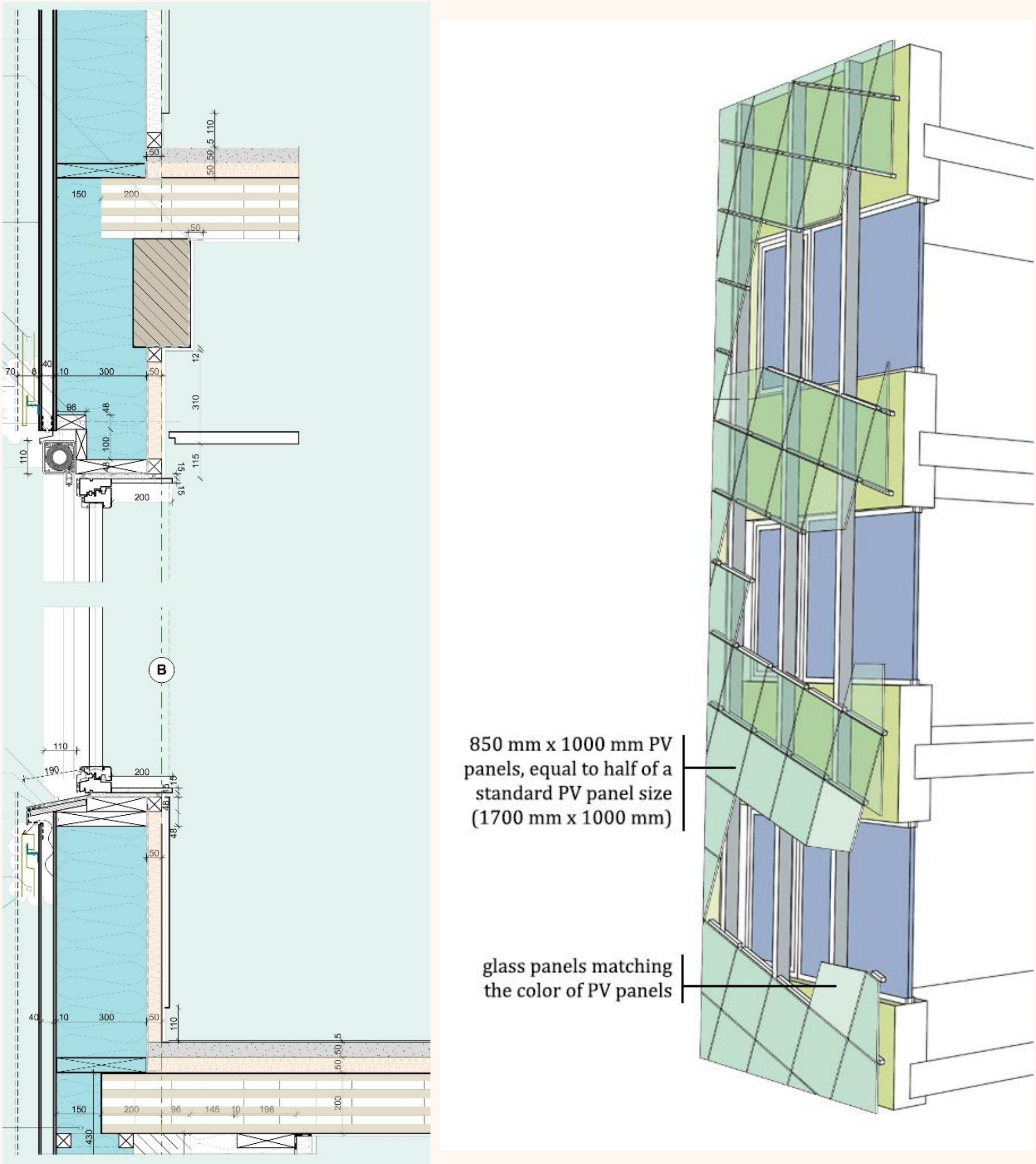


Figure 34. *Left: technical section of the school façade. Original image by KONTUR and SPINN Arkitekter, edited by Jesus Daniel Garcia Melo (NTNU). Right: Scheme of the installation of the PV panels on the school building facades. Original image by KONTUR and SPINN Arkitekter, edited by Nicola Lolli (SINTEF).*

Figure 35. *Left: image of one of the bi-coloured PV panels tested on the building site (photo by Inger Andresen, NTNU). Right: technical section of the school façade. Right: scheme of different installations of the two bi-colour PV panels. Original image by KONTUR and SPINN Arkitekter, edited by Nicola Lolli (SINTEF).*

Technical solutions used in the H-building

The H-building was required to be preserved by BYA. The renovation is therefore focused on minimizing the impact on the parts of the building that are expected to be preserved while ensuring an improvement of its energy efficiency. The design of the energy retrofitting technical solutions covers two main areas of intervention: roof and façade. BYA agreed that the roof could be replaced entirely by a new lightweight ventilated roof construction by ensuring the preservation of the existing cornice height and design. This to preserve the building facades appearance. The roof insulation (210-mm-thick stone wool insulation) is placed between the structural frame to preserve the overall building height. The existing facades are insulated from the inside and the overall wall section consists of (from inside): gypsum boards anchored to a new wood structural system, 50 mm air gap, moisture barrier, 100 mm stone wool insulation with metal studs, 40 mm air gap, existing wall construction (Figures 36, 37, and 38).

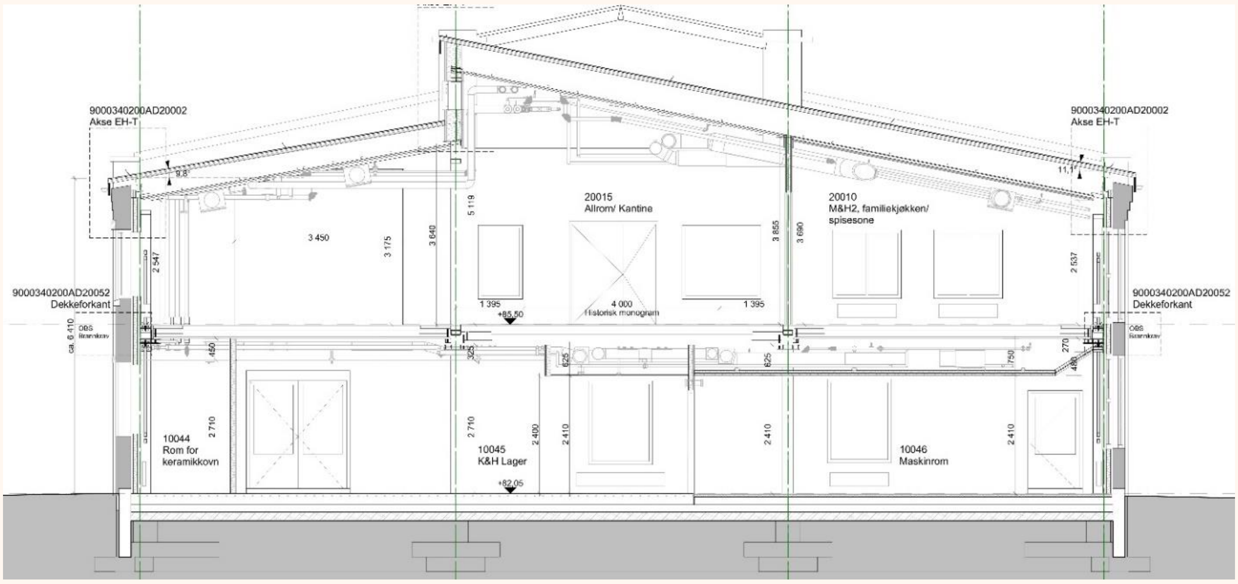


Figure 36. *Technical cross section of the H-building. Original image by KONTUR and SPINN Arkitekter.*

Figure 37. *Image of the internal insulation layer in the H-building. The new wood structural system is shown. The gypsum boards, not installed yet, are to be placed between the vertical and the horizonal wood frame. Photo by Nicola Lolli (SINTEF).*

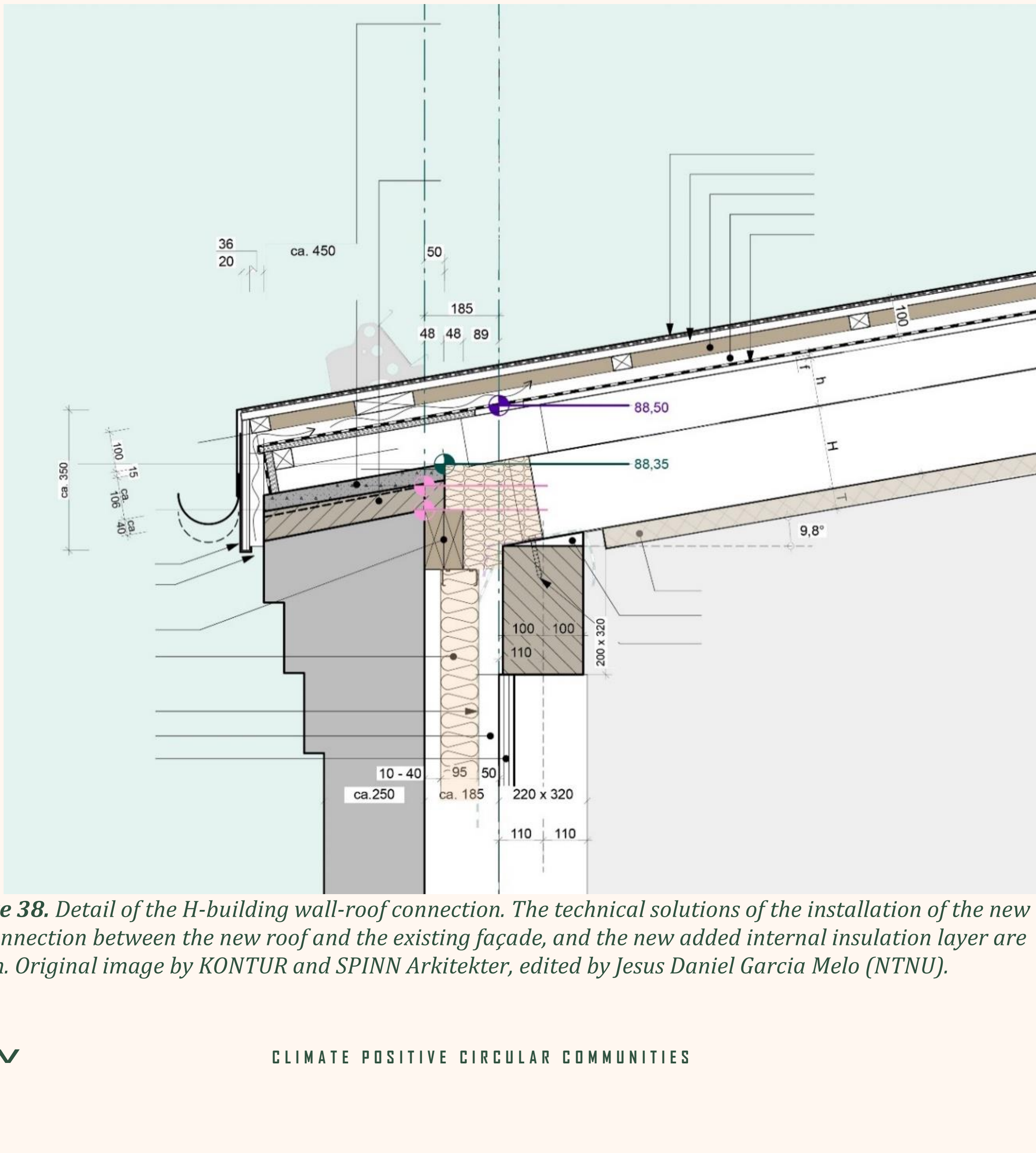


Figure 38. *Detail of the H-building wall-roof connection. The technical solutions of the installation of the new roof, the connection between the new roof and the existing façade, and the new added internal insulation layer are shown. Original image by KONTUR and SPINN Arkitekter, edited by Jesus Daniel Garcia Melo (NTNU).*

Technical solutions used in the school courtyard

The "islands" placed in the central outdoor area house vegetation, stormwater, and outdoor activity between central walkways. The activities allocated in each island are chosen based on being appealing to young people with different skills. The installed equipment is therefore chosen to be used in different ways and at several levels, depending on the student's individual skill. Biological diversity with greenery that is resistant and belongs to the local/regional species diversity is considered in the school landscape plan. To ensure a natural environment that can foster pollinating insects, part of the new vegetation consists of berry bushes and fruit trees.

Stormwater is handled according to the three-step principle: minor rainfall is handled locally, major rainfall events are delayed, and extreme rainfall is diverted into safe floodways. The rain bed facing Uelandsgate is planned without the steel grates (which are used in the central islands), as shown in Figure 39. This is because no student outdoor activities are planned in the plot facing the main road, due to traffic noise. Green lawns are planted on the outer edges of the east side of the plot, whereas the open areas in the north and south consist largely of gravel, and lawn areas with trees. Rainwater from the S-building roof is directed into underground drains and to a sump at the closest island in the school yard, where the water is distributed and later drained. Roof water from the H-building and the bridge is directed to the closest islands and there to the ground via external drainage. As shown in Figure 40, a stone draining mass is planned under the rain bed, in the islands. Between the draining masses, drainage lines are installed (between 110 mm and 200 mm diameter) to distribute storm water between the islands. In each island, a sand bed is installed for the distribution of stormwater to the draining mass.

The paving materials for the outdoor area varies depending on the intended use of each outdoor area. Permeable materials and greenery are used to ensure stormwater management, and rubber asphalt and concrete is used under the playground areas. Alternatives to rubber asphalt have been looked for (e.g., cork), however, their lifespan is not comparable due to their lower durability.

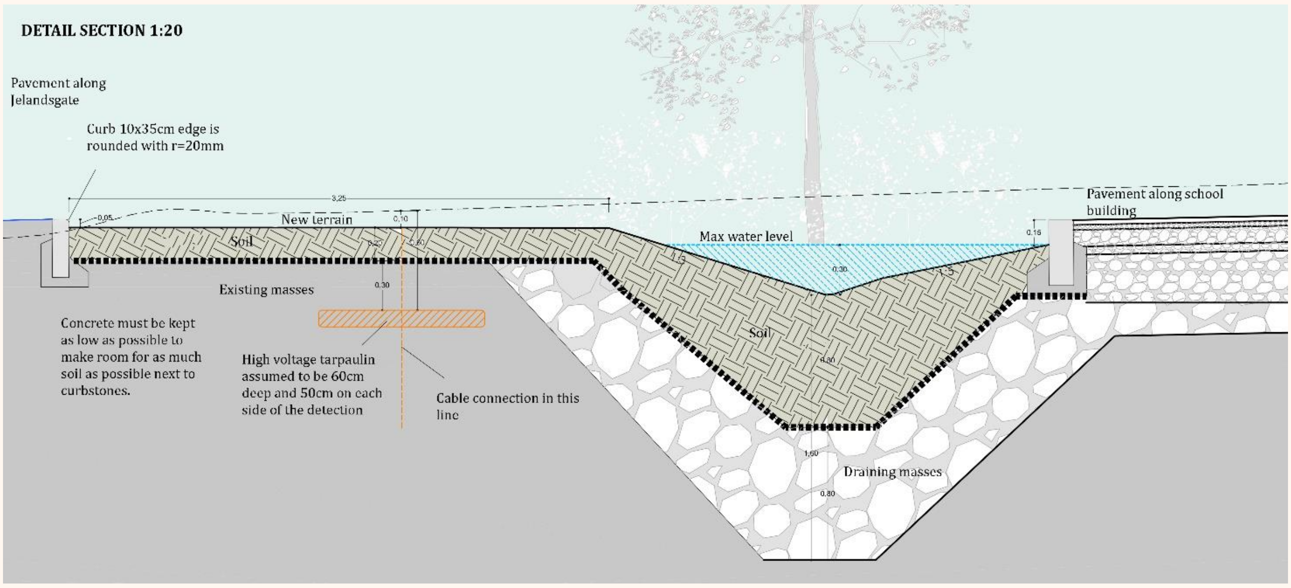


Figure 39. *Detail of the stormwater drainage system along Uelandsgate. Original image by ØSTENGEN & BERGO AS, edited by Jesus Daniel Garcia Melo (NTNU).*

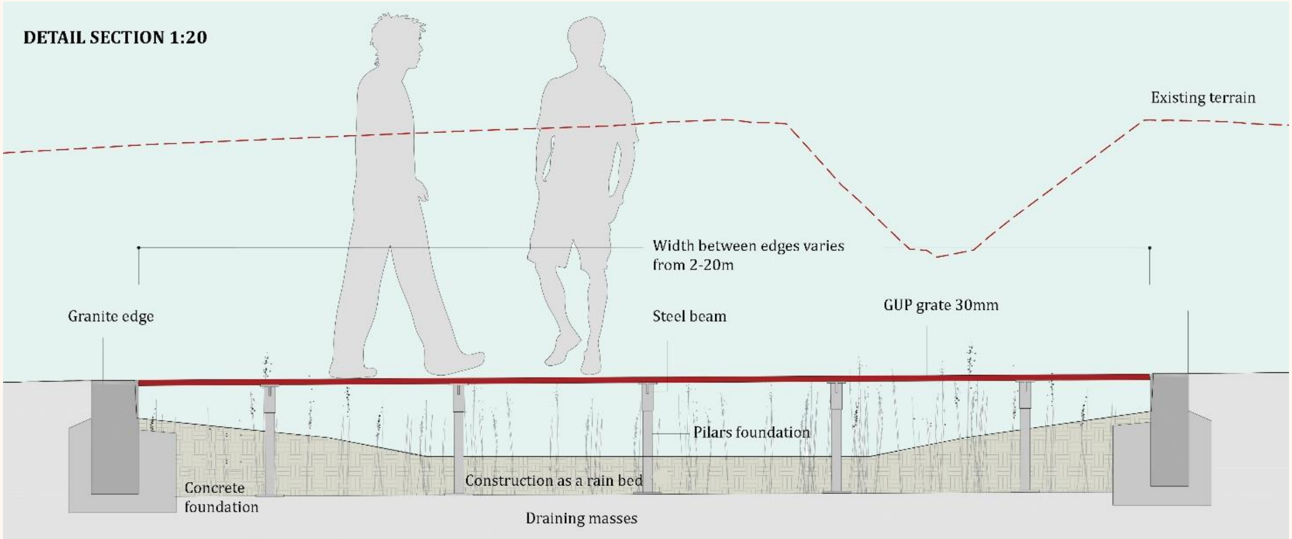


Figure 40. *Detail of the stormwater drainage system in one of the "islands" in the central part of the school courtyard. The rain bed and construction system of one of the channels is shown. Original image by ØSTENGEN & BERGO AS, edited by Jesus Daniel Garcia Melo (NTNU).*

5.3 ALTERNATIVE DESIGNS

DESIGN BRIEF

In the interdisciplinary design studio "Emissions as Design Driver", part of the international master's programme in Sustainable Architecture[16] at NTNU, students were given the task to design alternative solutions for Voldsløkka project. In this chapter, you find the results from three of the student groups, who worked on their proposals from March until June 2023. The course focuses on project work in interdisciplinary groups. The goal is to apply the knowledge and skills, about the life cycle of buildings and greenhouse gas emissions calculations, acquired in the corresponding theory course to a design project. In an emissions-driven design process students work with existing buildings, gather a set of requirements, and develop design proposals for a given program. Various alternatives and scenarios were considered, such as a combination of demolition and new building(s), reuse of materials from on-site or elsewhere, and / or adaptive reuse and supplementary buildings. LCA calculations accompany the design process, and the results support decision making. The overall goal was a design project of high architectural quality in relation to the existing built environment while minimizing or, ideally, eliminating embedded emissions and achieving a positive impact for communities.

The main design task was defined in the design brief: Develop alternative design scenarios for Voldsløkka school in Oslo. The brief required an identical program to the school as it is built today. The difference to the built project was the challenge to keep as much of the existing buildings as possible while keeping ambitions for high quality spaces, both indoors and in the school yard. Participants were also given slightly more freedom with regards to the Heidenreich building. It was to be kept and its heritage value was to be respected. However, placement of PV panels and reasonable changes to the facades were allowed to be considered.

The ensemble of existing buildings on site, two of which had been demolished (A and C), was well documented (Figure 41). Before the Voldsløkka project started, both buildings, with a total area of 6 600 m^2, were rented out to two different companies as office use and storage.

The design should focus on functionality and quality of use by employing robust, simple, environmentally friendly solutions.
Other goals included:

- Integration of school and cultural functions
- Strengthen the area's green structure
- Showcase renovation and reuse: Circular renovation design strategies
- Minimize life-cycle emissions
- Maximize (environmental) benefits
- Strengthen Voldsløkka as a meeting place for children and young people

The students' design project was to specifically focus on the following two priorities:

- Reduction of greenhouse gas emissions over the life cycle of the school
- Use of existing buildings or building materials

[16] https://www.ntnu.edu/studies/mssusarc

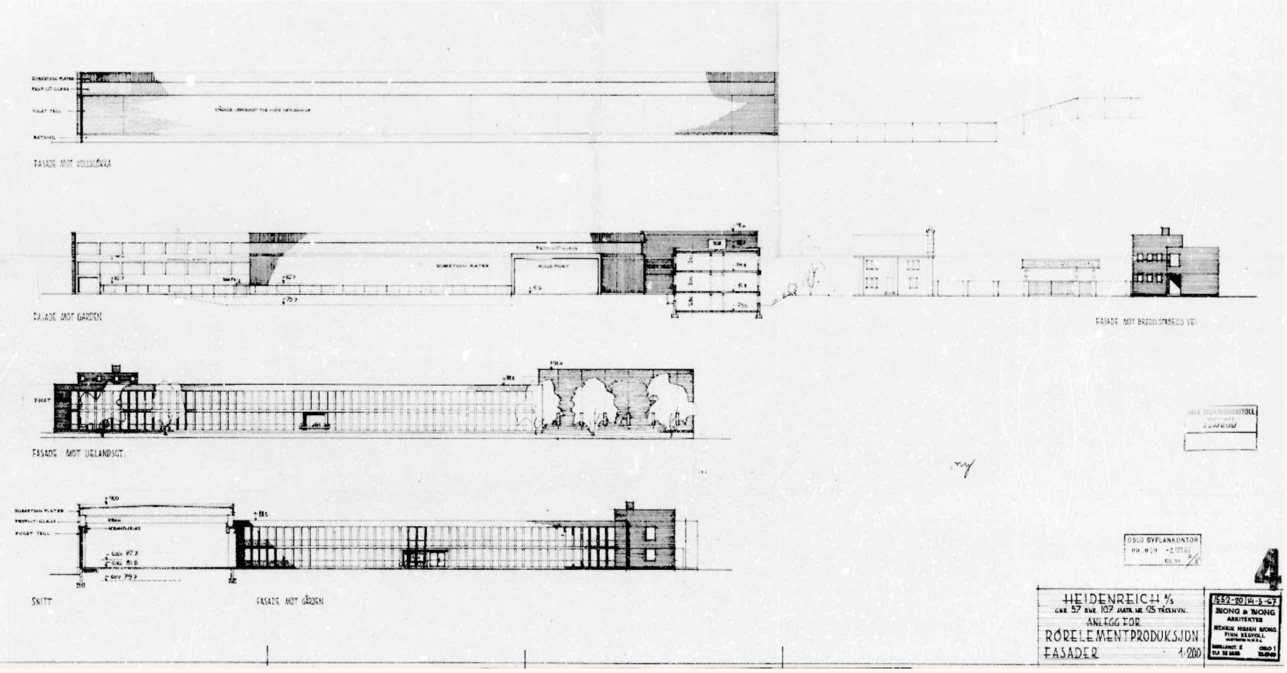


Figure 41*. Historical drawings of the facades of building A (lower part of the drawing) and building C (upper part of the drawing). Source: Oslobygg.*

For the GHG accounting, we used a zero-burden approach (Figure 42), treating the emissions of the existing building as emissions that occurred in the past which are therefore not allocated to the renovation project. The software Reduzer[17] was used to calculate emissions based on Norwegian Environmental Product Declarations (EPDs). The mandatory benchmark to be achieved was in line with the ARV benchmark, the Norwegian Government Agency for Financial Management (Direktoratet for forvaltning og økonomistyring, DFØ) benchmark[18]: Emissions for buildings per GFA must not be more than 50% of the benchmark for schools (life cycle phases A1-A4; B4-B5, no EoL), i.e., 50% of 382 kg CO_2-eq/m^2 GFA (without basements).

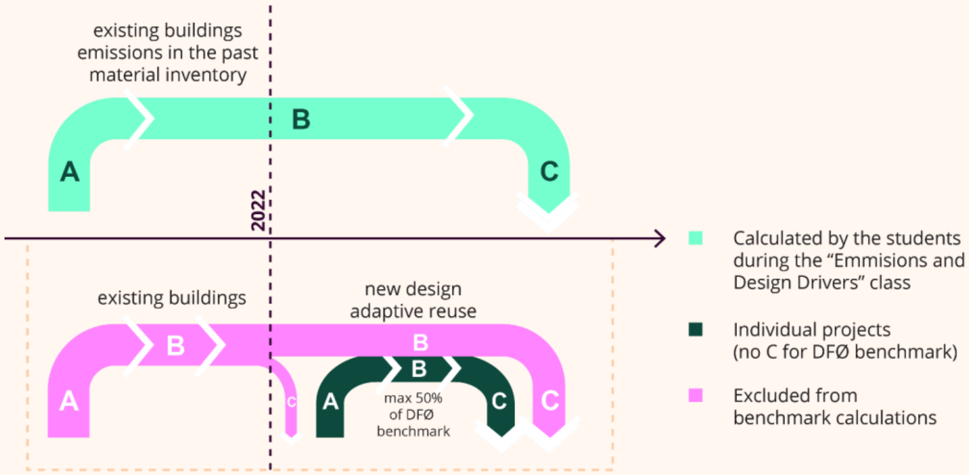


Figure 42. *Zero-burden approach to GHG accounting of renovation projects.*
Graphic by Patricia Schneider-Marin and Jesus Daniel Garcia Melo (NTNU), according to Hasik et al. 2019[19]

[17] https://reduzer.com/home
[18] https://anskaffelser.no/verktoy/analyseverktoy/klimagassutslepp-bygg
[19] Hasik, Vaclav; Escott, Elizabeth; Bates, Roderick; Carlisle, Stephanie; Faircloth, Billie; Bilec, Melissa M. (2019): Comparative whole-building life cycle assessment of renovation and new construction. In: Building and Environment 161, S. 106218. DOI: 10.1016/j.buildenv.2019.106218.

Reuse of building materials on site was encouraged to arrive at circular solutions. This required an analysis of the existing buildings, which was based on the extensive documentation available. As building A and C had been demolished already at the time, no on-site documentation was possible. A BIM model was built of all the existing buildings based on the historical drawings, from which the bill of materials was drawn. This enabled the future professionals to do a greenhouse gas accounting of the existing materials, in other words determining the GHGs that would have to be emitted if the same buildings were built today.

The student group visited the Voldsløkka construction site in March 2023 and worked in groups of 4 or 5 during the semester, with weekly guidance and a kick-off, intermediate and final presentation.

***Figure 43**. Students and teachers from the design course during the site visit to Voldsløkka skole 8.3.2023 (photo: Patricia Schneider-Marin, NTNU)*

Voldsløkka 80³

Authors: Catharina Hansen - Eloïse Veronique Marie Redon - Hennie Hildre Skare - Marta Anna Szabelewska - Maren Lovise Øby

Figure 44. *Proposal illustration of Building A renovation and connection with Building H.*

VISION

The site of the new Voldsløkka Skole is an old industrial plot that once housed a concrete and porcelain factory and has been rented out as office space and storage for the last couple of decades. Three very different buildings are already located on-site, providing a variation of indoor spaces and architectural expressions. The vision for this project is to design a middle school with high architectural quality and a low environmental impact, on a plot with three existing buildings.

The project aims to achieve high architectural quality in relation to the existing built environment, providing good quality spaces for students, staff, and community, as well as being adaptable to new educational forms. That is why we used our initial analysis of the neighbourhood and buildings to identify which community functions in addition to the cultural centre could be added to the school to improve the local community. After completing our initial analysis, we chose to expand the library to function as a public space, further enhancing the school's functions as a cultural centre. By doing this, we also expand the time spent in the building, an important step in reducing the built mass necessary to support the area's activities.

The A-, C- and H-Building on the site are all built in different architectural styles that reflect both the period when they were built and their purpose. The H-building, which is the oldest, showcased new technology and was designed to look beautiful. The A- and C buildings, both built in the 1960s, are more pragmatic and practical. The H-building is today protected due to its cultural heritage, and we want to give new life and function to it while keeping its historical integrity. Through the final design, we also aim to connect the fragments that are the three different buildings to one whole and help create a visual cohesion or feeling of unity between the different buildings, as well as provide a well-functioning school facility.

In terms of our environmental goals, we keep as much of the existing structures on site as possible while achieving good quality spaces that suit the needs of the new functions. We focus on conscious material choices, with reuse of the materials on-site and environmental requirements for new materials introduced in the project. Designing for flexibility is also a part of the sustainability strategies, as we want our buildings to adapt to the needs of the community without requiring deep interventions and the inferred emissions. This is a strategy to not only keep the emissions low for the refurbishment today but also in the future.

We aimed:

- for an 80% reduction of GHG emissions compared to the benchmark,
- to keep 80% of the existing buildings' volume and
- an 80% reduction of GHG emissions compared to the existing buildings' emissions.

Hence the project's name 80^3.

DESCRIPTION

The distribution of the school's functions is strongly based on two principles. The first one is the aim to contribute to the community and extend the use of the buildings, and the second is the existing building structures. To work with the buildings in a conscious, gentle, and compassionate way, we have thoroughly analysed the existing constructions and volumes. The same has been done on a bigger scale to gain an understanding of the area and how to add to it in a beneficial way beyond the function of a school.

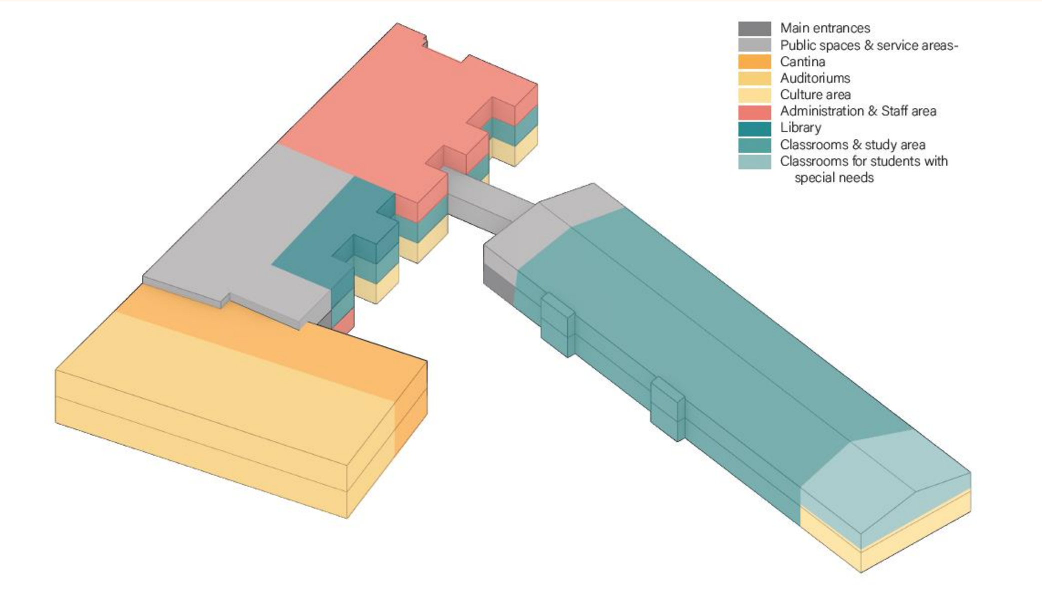


Figure 45. *Distribution of functions in the upgraded building ensemble.*

In this project, the school expanded to a cultural centre, incorporating a cultural school in the afternoon, a space for happenings and performances, as well as a public library, all accessible beyond the school's opening hours. We have achieved this by keeping a strict hierarchy of functions surrounding the main circulation core placed in building A such that it functions as a joint to building C (Figure 45). This allows for the learning areas to be separated from the public functions, without disturbing the natural movement of the students or the visitors and maintaining functionality within all the different spaces.

The creative spaces have been placed on the ground floor of building A, making the floor with the most extroverted activities visible and connected to the street. These spaces are also the ones that will be in use most hours of the day and provide life to the neighbourhood. The more private and calm functions have been organized on the first and second floors, with the library at the top. They are connected to the main entrance with a clear readability and accessibility. The same principle has been applied to the performance-oriented functions placed in the C-building, merging with the core and heart of the school. The main entrance in the new design has a clear visual connection to the H-building with its placement further in on the site. The more introverted functions have found their home in this building, as readability of the neighbourhood was important.

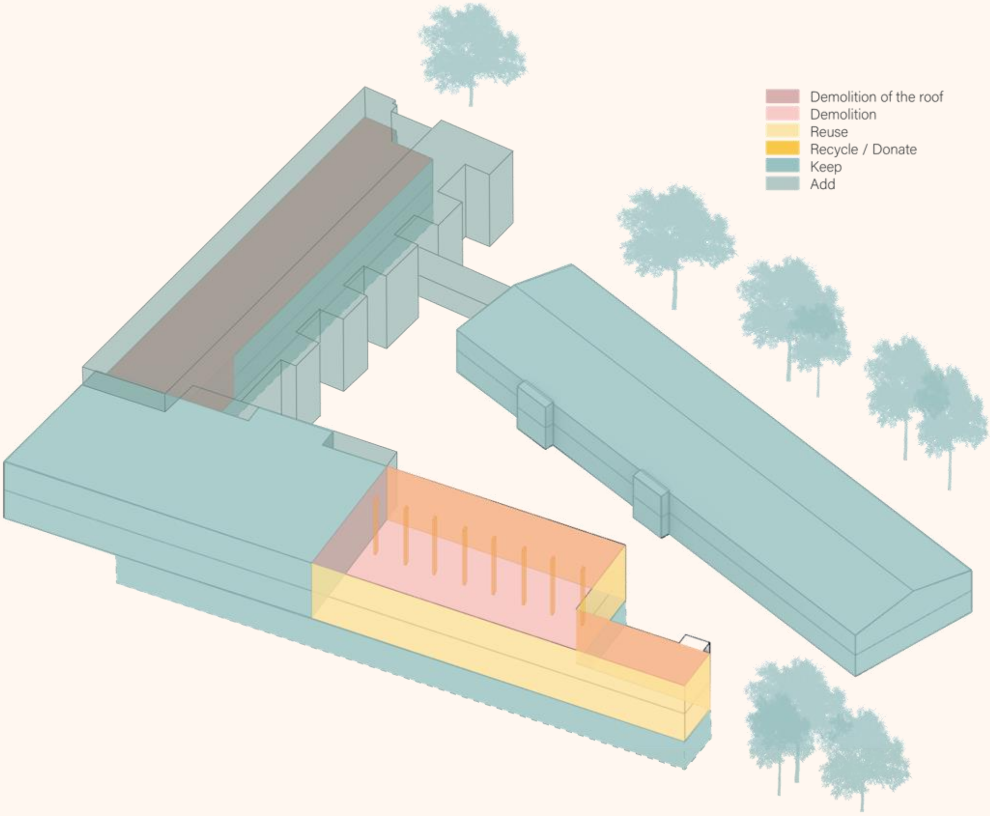


Figure 46. *Levels of intervention in the existing buildings*

One of the focal points in the concept development was to embrace the existing and enhance it. After all, architectural renovation requires balancing today's needs with the existing buildings' premises to find a solution that does not compromise on architectural quality.

The existing buildings, A, C & H, built throughout the 20th century, each have their strengths and weaknesses. A common characteristic is the fact that they all have a load-bearing system based on columns & beams, with next to no interior loadbearing walls, which provides flexibility. The materials are durable, like brick, concrete, and steel, and have potential for reuse. The surrounding area with sports halls and football fields provides the necessary infrastructure for physical education, allowing us to improve daylighting conditions and provide a large, varied schoolyard. Among the problems of the existing buildings, we find a lack of daylighting, low ceiling heights, missing connections between the buildings, and little unity in style and materials.

We have sought to make small improvements to provide a good space for the intended function. As a low ceiling height has been a challenge, this has been leading in the design and provided opportunities suiting our organization of functions. We have also used the existing facades in a constructive way, picking up elements that would benefit our goals with solar energy production and bringing diffuse, comfortable, indirect daylight into the school. This has highly influenced the new structures on site as well, as we have used both materials and visual elements from the original facades to create a coherence between old and new.

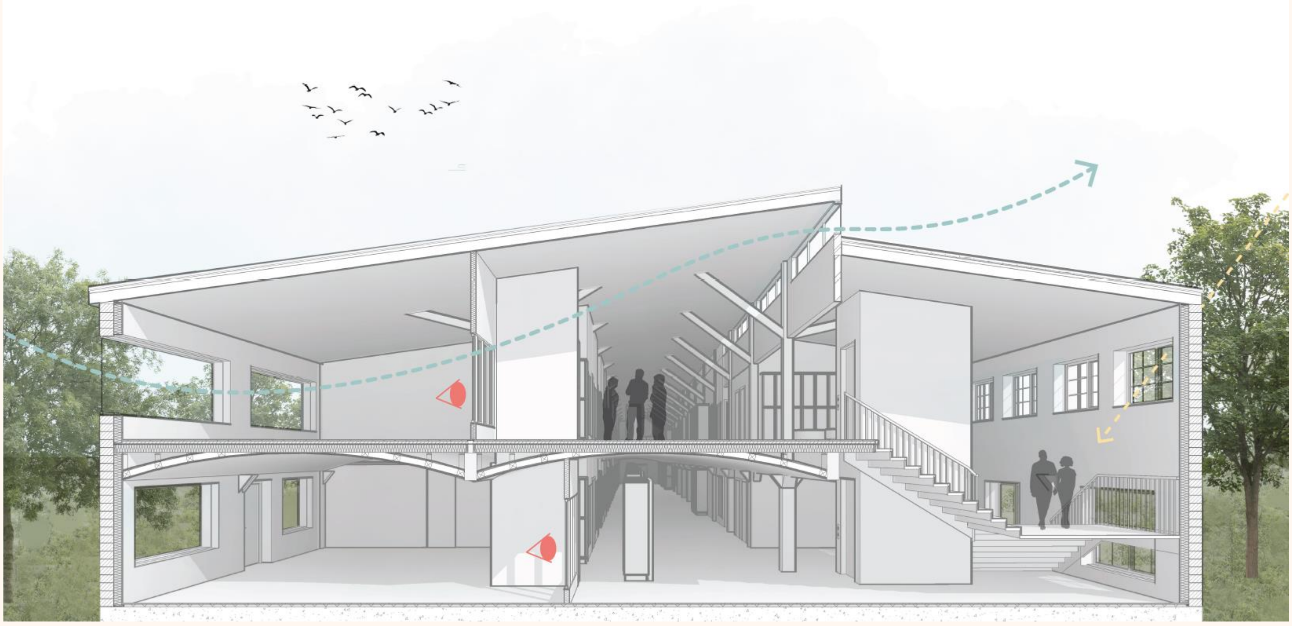


***Figure 47**. Structural, visual and natural ventilation concept for the Heidenreich building.*

EMISSIONS AS DESIGN DRIVERS

Limiting the design's global warming impact became an integral part of the design process, and thus did not feel very limiting. The project started with a thorough analysis of the site and existing buildings, resulting in a digital model and an LCA for the existing structures. The assessment gave some pointers as to which components and materials were responsible for the biggest portions of the GHG emissions, and these findings influenced the initial decisions regarding materials and construction.

It was decided early on to keep a substantial part of the existing building structure, and the focus became: how can we make the best architecture out of the resources we have at hand? Thus, sustainability became a guideline rather than a restraint within the project.

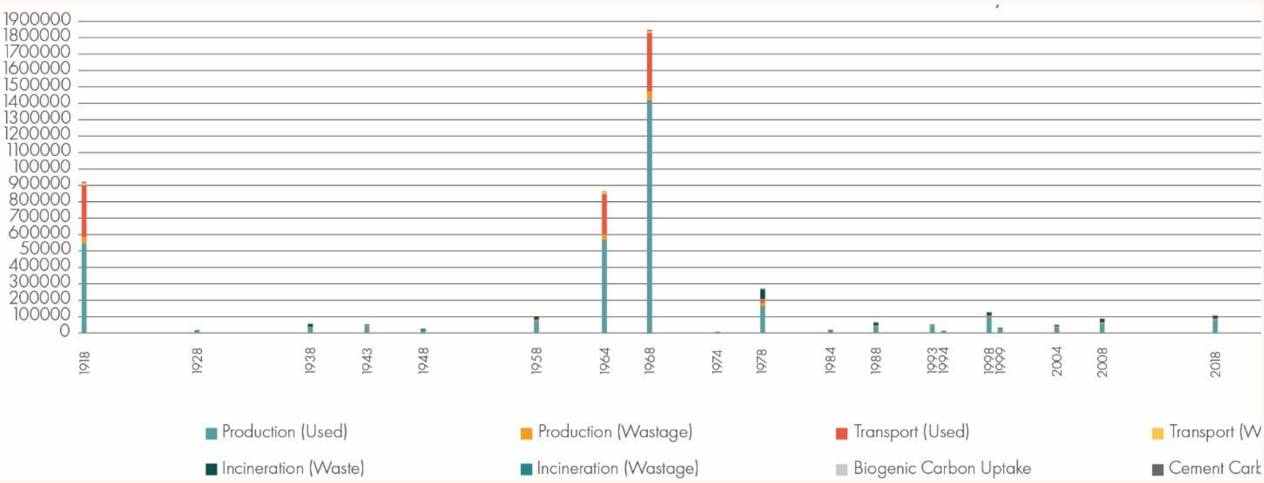


***Figure 48**. Emissions in the time before the intervention in t CO_2-eq.*

For the second part of the design process the needs of the users and the program guided the design decisions. After finding the initial form, the buildings were modelled in Revit[20], and digital twins of the components were created in Reduzer[21]. Here, several construction systems and materials were compared to find the lowest-emissions solutions to reach the project goals. The final part of the design process consisted of switching between BIM and LCA to implement the solutions as they were developed. Although sustainability guided the design, and the final project is heavily influenced by a desire to lower emissions, there are some changes that could have been made, if one had compromised more on the environmental impact goal, such as having more windows and glazing in the facades, changing the roofs of the C-building to better accommodate a large rooftop terrace. Overall, the environmental impact goal offered an interesting approach to the task and resulted in a final design that has great spatial and architectural qualities as well as low emissions.

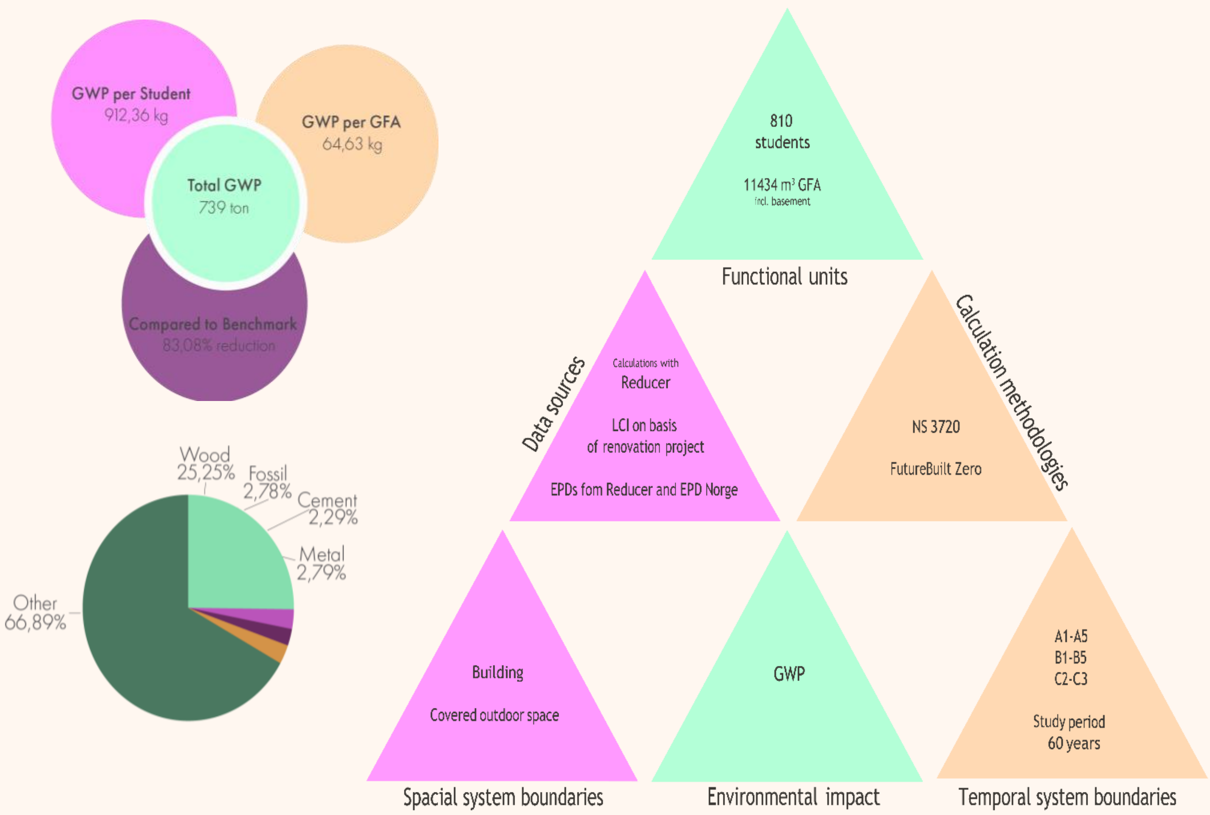


Figure 49. *Material composition and key figures from the LCA and boundaries.*

[20] https://www.autodesk.com/products/revit/
[21] https://reduzer.com/home#home

OmBrick

Authors: Gina Ringnes - Jaap Asmussen - Jennifer Behrendsen - Magdalena Ryszkowska - Nel Visser

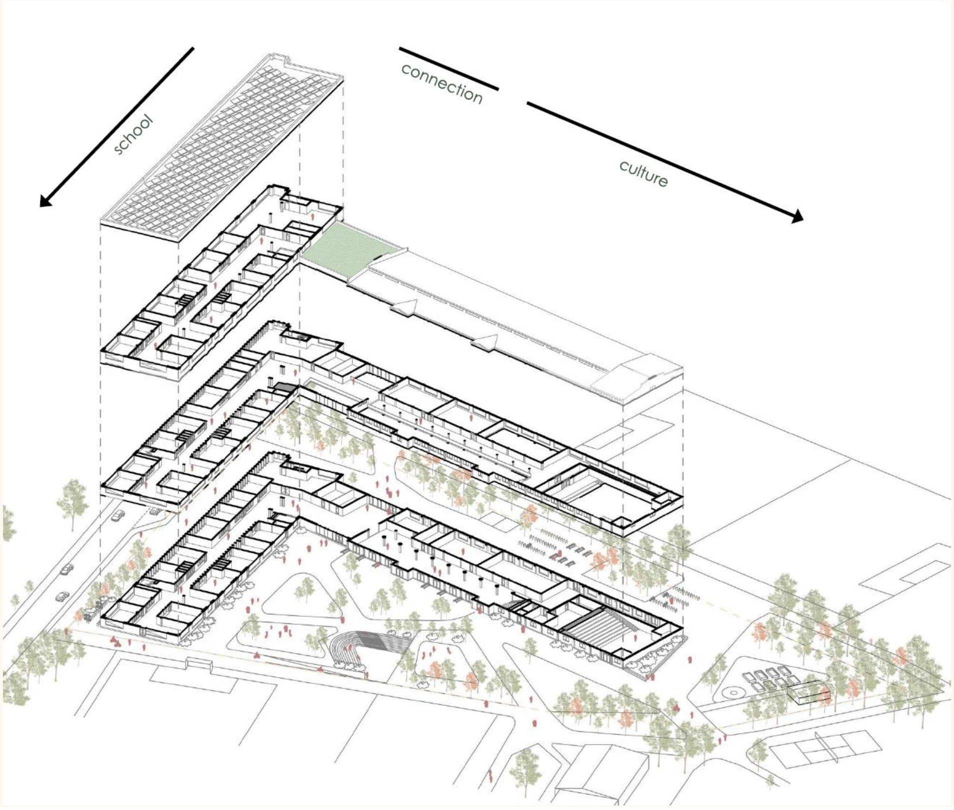


Figure 490. *Proposal illustration.*

VISION

The project presents a proposal for the Voldsløkka school and cultural centre, a secondary school situated in Sagene, a vibrant area in Oslo that attracts a diverse population and offers various amenities to both residents and tourists. The renovation project encompasses three buildings, namely the A building, which faces a busy road and has previously served as office space, the C building, which features a spacious open area, and the Heidenreich building, a listed structure on the property.

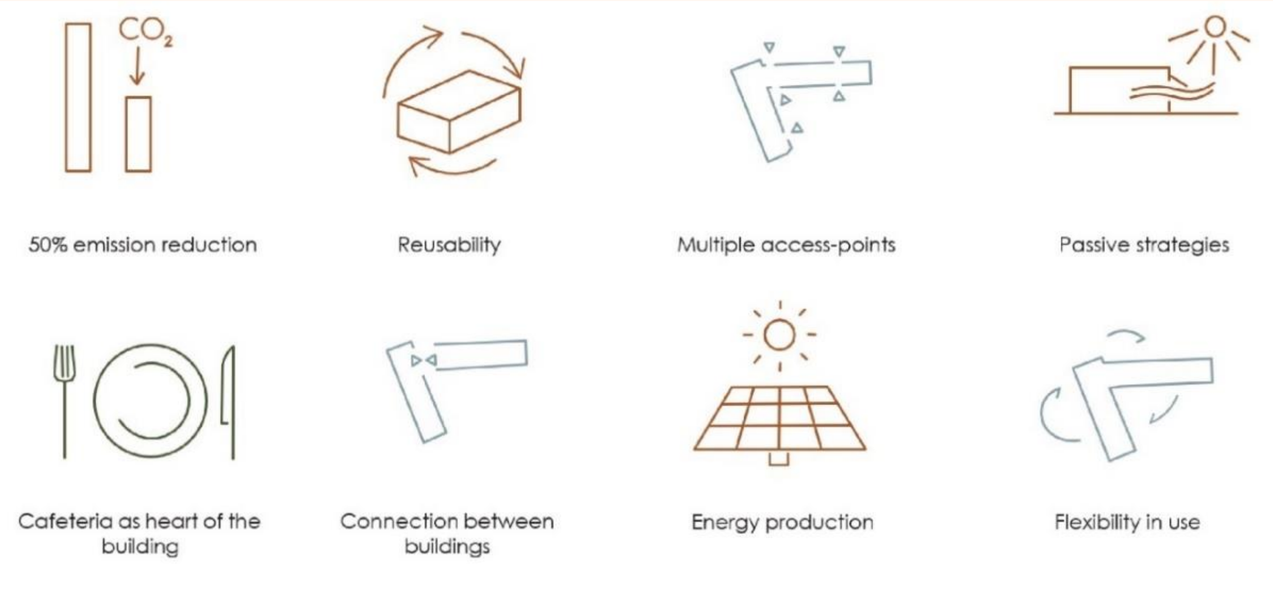


Figure 51*. Primary project goals*

The primary goal of the project was to create a sustainable and functional school with a cultural center on a site with industrial background and 3 different buildings. We obtained it by following our 10 main guidelines (Figure).

Our sustainability goals were:

- Reduce our emissions to less than half of the DFØ benchmark,
- Reuse materials from the building site and make new ones reusable
- Implement passive strategies
- Produce clean solar energy on-site

Our architectural design should include:

- connecting buildings, A and H
- keeping the rooms inside flexible and suitable for different purposes
- creating a cafeteria as the heart of the building

From the site perspective, we wanted:

- several access points to the buildings from different sides
- green outdoors and welcoming courtyard
- limiting the noise coming from the street

DESCRIPTION

Throughout all phases of the design process, our primary principle revolved around minimizing our interventions. We wanted to achieve good outcomes without completely overhauling the existing structures, and by reusing as much of the buildings and the disassembled parts of the buildings as possible. By adopting this approach, we successfully limited CO_2 emissions to a minimum, effectively reducing the school's global warming impact by approximately 87,5% compared to the benchmark.

During the design process, we made decisions that we thought were the best for both the functions and aesthetics of the building, and for lowering the emissions, despite the limitations of working with an existing building. Reusing the brick from deconstructing the C building for the new facades of building A resulted in the project name OMBRICK: The name is a combination of Ombruk (Norwegian for reuse) and Brick.

Designing the project OMBRICK we thought simultaneously about creating a functional school and cultural centre and reducing emissions as much as possible. Most of the savings were obtained by refurbishing (listed) building H, re-purposing building A, and reusing construction elements from building C. Apart from that, we were choosing low-emission materials for newly built parts and extensions such as cross-laminated timber and limiting emission-intensive ones such as glass façades.

The buildings were structured with reference to the Oslo climate. We designed the layout in a way that will create the best possible indoor climate with good natural lighting conditions, well-ventilated spaces, and comfortable temperatures both in the winter and summer months. The courtyard gets plenty of sunlight as well and is protected from the cold winds by the buildings on the north.

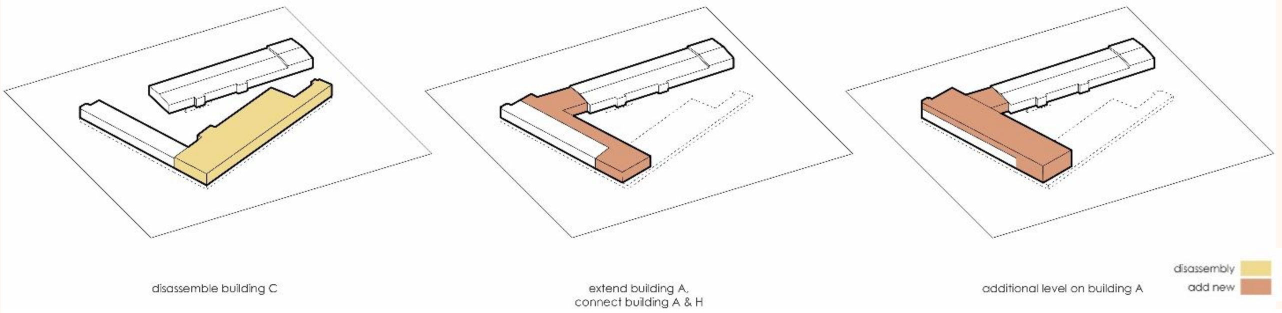


Figure 502 *Concept of the intervention*

Two main functions of the project, school and cultural centre, are clearly divided into two wings of the building (Figure 53). Building A serves as a main space for teaching with a library, art workshops, and teachers' rooms accompanying the classrooms. Building H is the main cultural space with a cafeteria on the ground floor. Both buildings are joined by newly built building B.

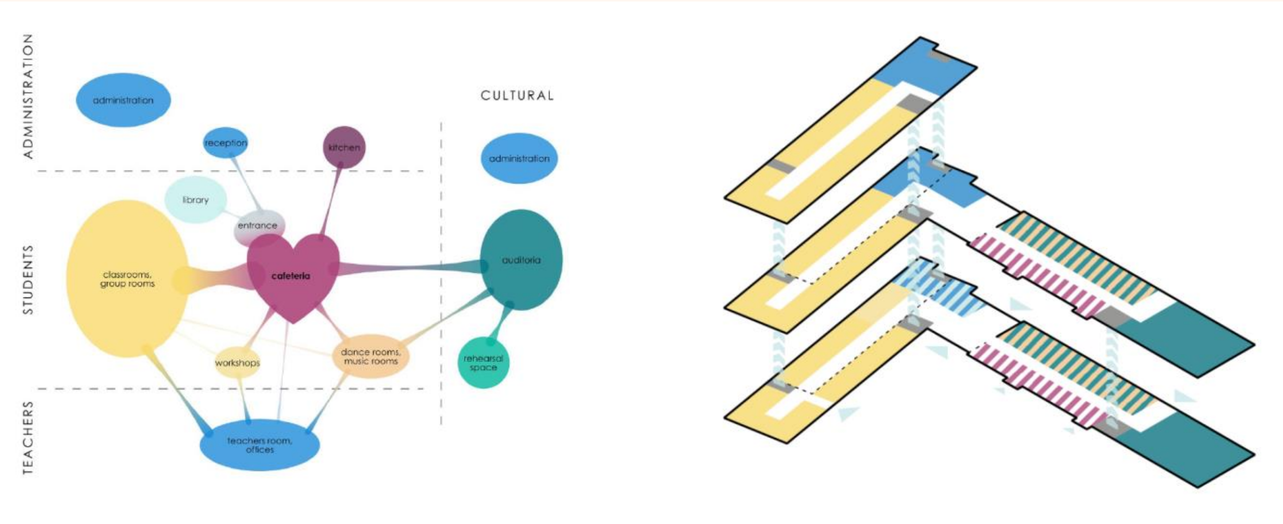


Figure 53. *Distribution of functions*

EMISSIONS AS DESIGN DRIVERS

The reduction of emissions during the use has been in focus for several decades now, the embedded emissions have been invisible for the longest time. Life cycle assessment (LCA) is a crucial tool to display these hidden emissions of buildings.

The calculations for our LCA are done in Reduzer with the NS3720 calculation method for a time horizon of 60 years. When only including LCA phases A1-A4 and B4-B5 this allows a comparison with the DFØ benchmark for new school buildings in Norway. Because we are refurbishing 3 500 m^2 of floor area, adding another 900 m2 inside the preserved envelope and only building 4 000 m^2 new, while still reusing some of the old materials, we expected to achieve the goal of a 50% reduction without many trade-offs.

Our LCA of this project started with comparing the GWP of versions of the elements we considered the most important for our design process. These are the load-bearing system, including columns, beams, and slabs, the external walls, and especially the exterior cladding and the internal walls. After determining this basis, we created versions of all components in Reduzer and linked them to the project masses. To create a more realistic project, we selected mostly products with an average GWP in their respective category instead of low-performing outliers. During this process, we could identify big emitters, decide if the material choice for these is negotiable, and, if so, make precise and impactful changes. To show the full project volume we calculated also the LCA for the schoolyard, even though it will not be included in the comparison with the benchmark. Additionally, we created a flow diagram showing the material flows from the existing buildings to the project or to potential donor buildings and the inflow of new materials (Figure 54).

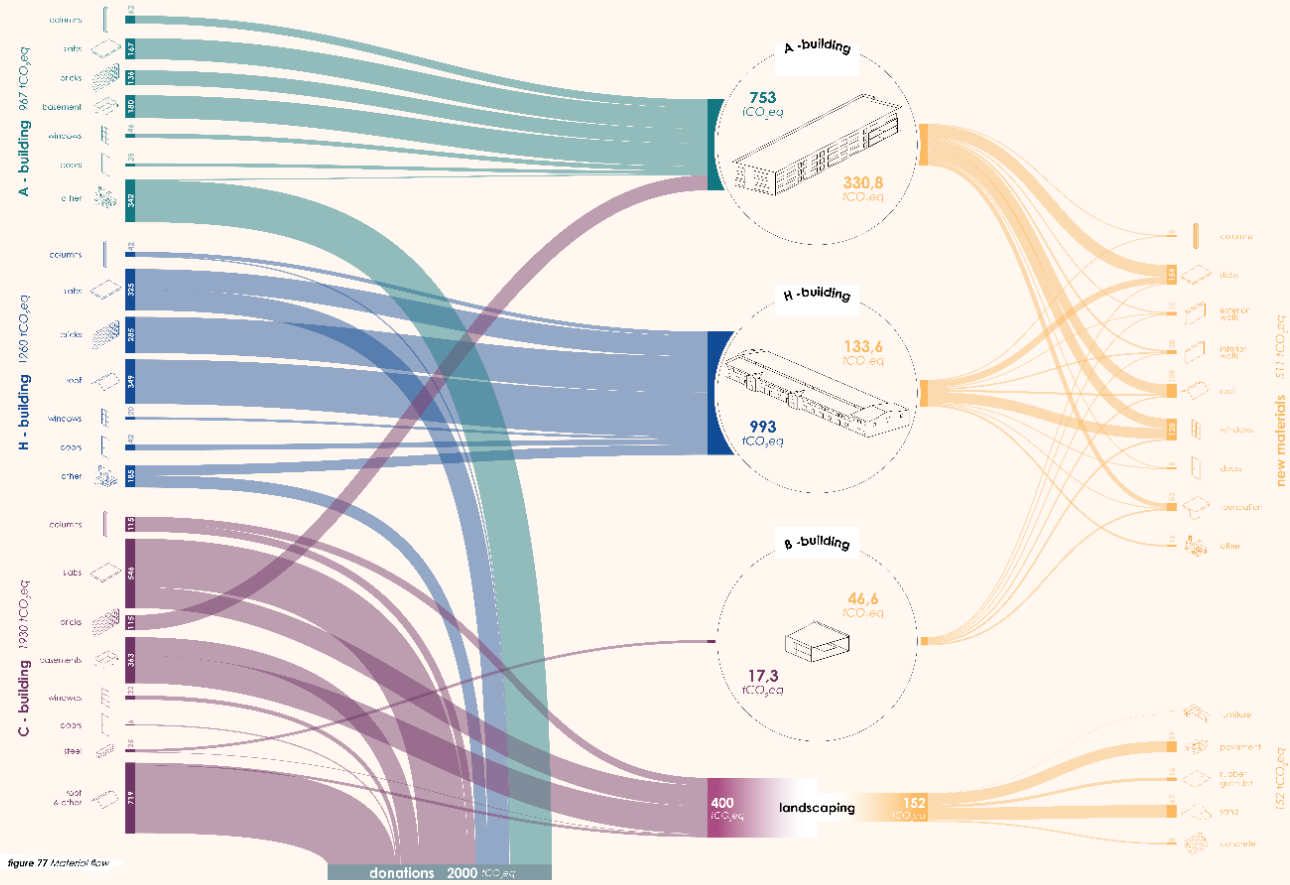


Figure 54. *Material flow chart.*

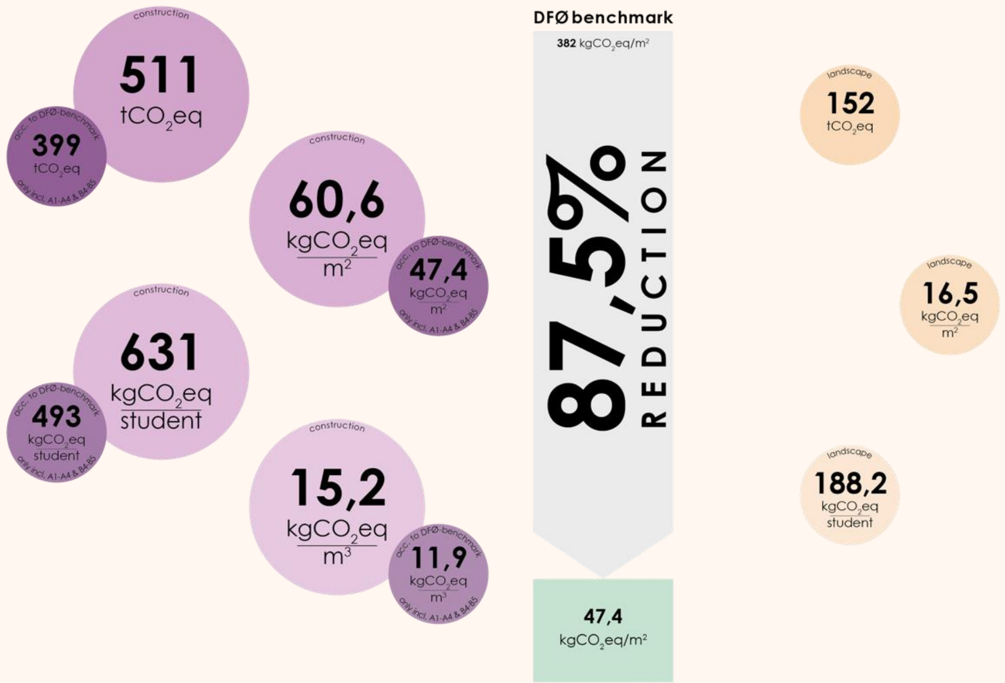


***Figure 55**. Total LCA results*

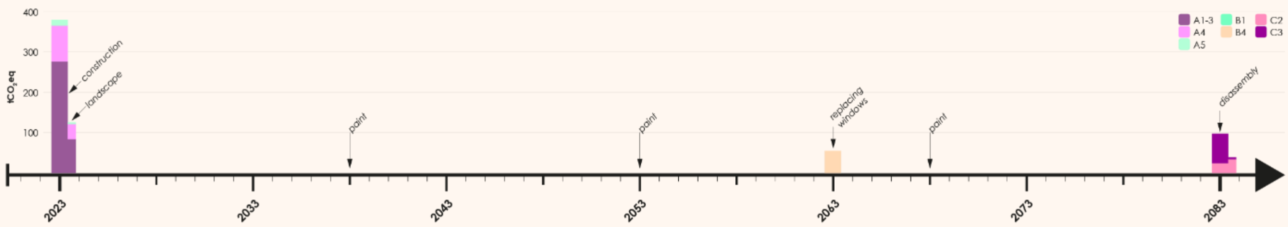


***Figure 5651.** Timeline of emissions*

We conducted a detailed investigation on the placement and GHG emission pay-off times of the PV panels. The panels are located on the roof and façade (between the windows) of building A. We determined that an East-West placement with low angles (1 to 4 degrees) was optimal. For the renewal of the panels, we considered 3 scenarios: two replacements, after 20 and 40 years, one replacement, after 25 years, and no replacement during the 50-year study period, taking into account a deterioration of 0,5% annually. The investigation shows that the most beneficial scenario would be to not replace the PV panels, even though the production deteriorates. However, this model is using the Norwegian electricity mix of 30 g CO_2 per kWh[22]. If other electricity mixes are assumed, the emissions payback time shortens in each scenario.

[22] https://www.nowtricity.com/country/norway/ (May 23, 2023)

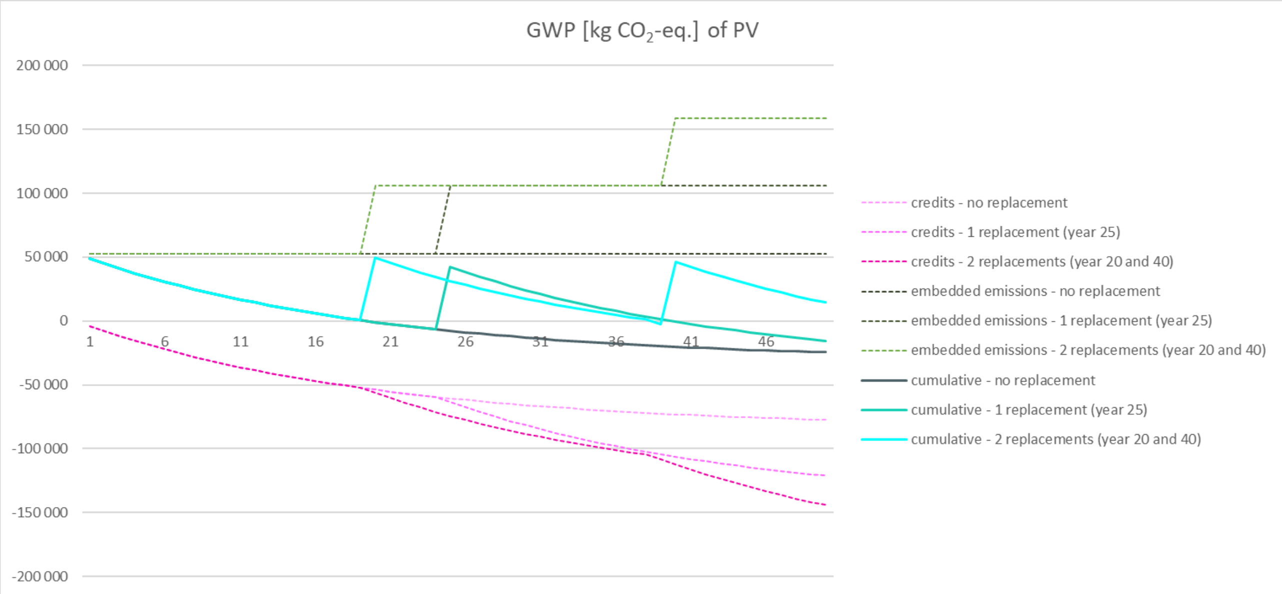


Figure 57*. GHG emissions from PV in three scenarios*

CONCLUSION

Over 60 years the buildings are responsible for 511 tCO_2eq emissions and the landscaping of the school yard for an additional 152 tCO_2eq. While only the buildings will appear in the benchmark comparison, this shows that more than one-fifth of the project's total emissions derive from the often-neglected landscaping. Compared with the benchmark our project reduces emissions by 87,5%. Even if only the newly constructed GFA, but all emissions are considered, this project emits only 80kgCO2eq/m^2 which is still a 79% reduction.

While these results exceed our goals and expectations, it raises more questions about the quality of the benchmark, than proving the quality of our design. Especially the exclusion of the construction (A5) and end-of-life scenarios (C) might be considered questionable. An explanation for this comparatively low GWP can be the preservation of the A and H buildings. Additionally, we are reusing 1200 m^2 of brick from the C building in the new facades, all the doors from the A and H buildings, and the windows of the A building for the interior. The material flow diagram in Figure **54.** 54 visualizes how the newly spent emissions are only a fraction of the emissions of the preserved structures.

Filling the Void

Authors: Nikoo Hamidi - Krzysiek Michalik - Miriam K. Kolstad - Alberto S. Montagut

Figure 58. *Proposal illustration*

VISION

Voldsløkka is an area in Oslo located on the border of the districts Sagene and Bjølsen. The area primarily consists of sports grounds and sports facilities, which has played a central role in the history of the area and the people living there. The site contains three buildings, the A and C building whereby A held the office spaces, C was the production hall. The H building is the oldest on site and its facade is under restrictions of conservation. historical protection which restricts changes to the building.

The goal is to preserve as much of the original buildings as possible through careful planning and analysis while also providing a building that could further serve the local community.

DESCRIPTION

Retrofitting has been the primary focus of the design as it allowed the project to save on emissions while also encourage reuse of older buildings. The existing buildings A & C are mainly made up of precast concrete elements, brickwork and steel. Their construction allows altering of the building as many of the existing components are modular.

The project features a big atrium which aims to fill the void between the existing buildings. Its primary function is to increase light reception in the old building parts, while also serving as the social hub and heart of the school. The atrium also serves as the main route of communication in the building.

In terms of educational spaces, the primary classrooms are organised by year group and are mainly located in building C. For circulation, the building is organised by function and predicted circulation patterns. By distributing the more generic/public services in the new construction, it allows the building to be used outside of school hours as the primary educational areas can be closed off without obstructing the circulation.

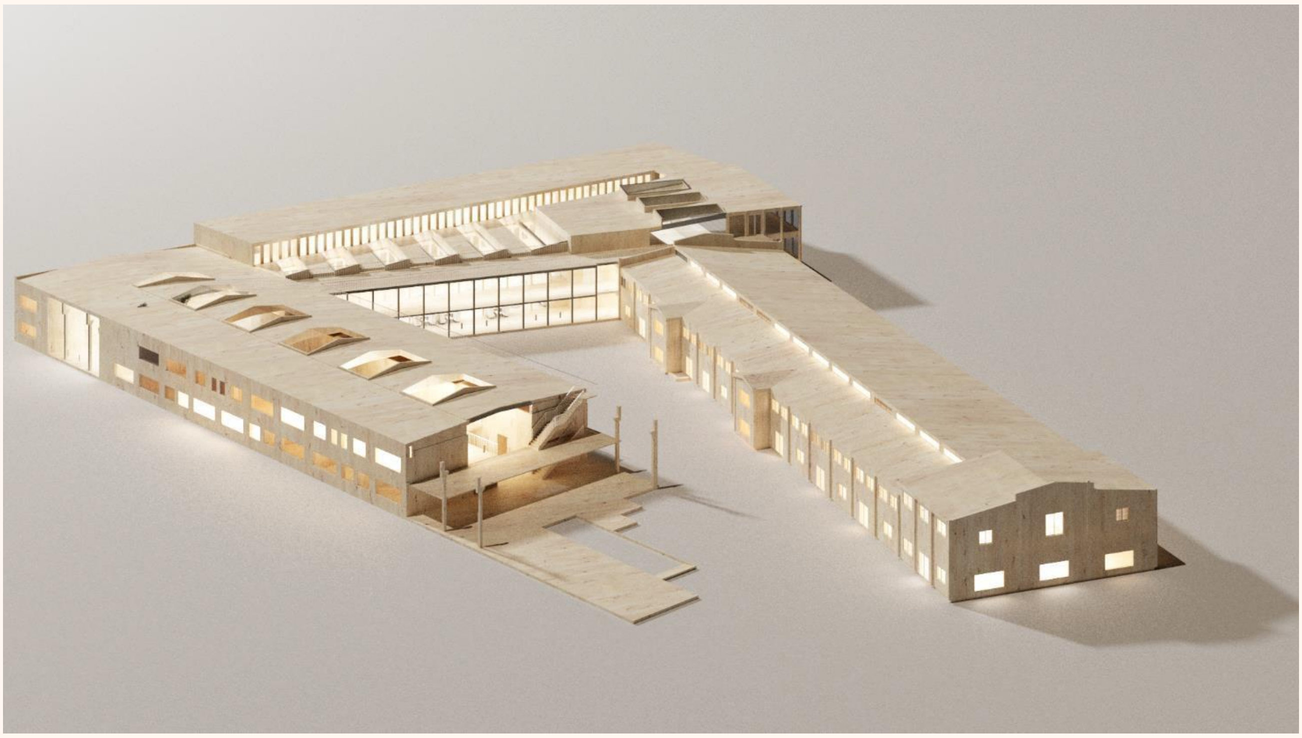


Figure 59. *Full axonometric view of the school project*

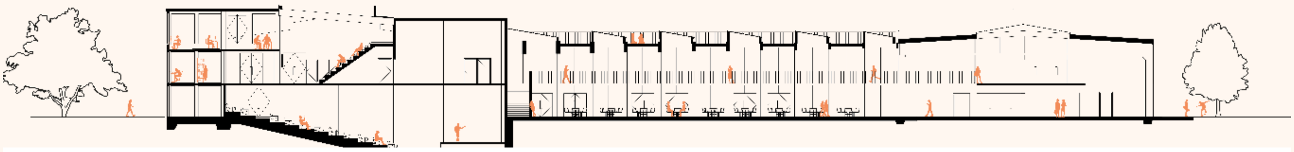


Figure 52. *Long section / Narrative section*

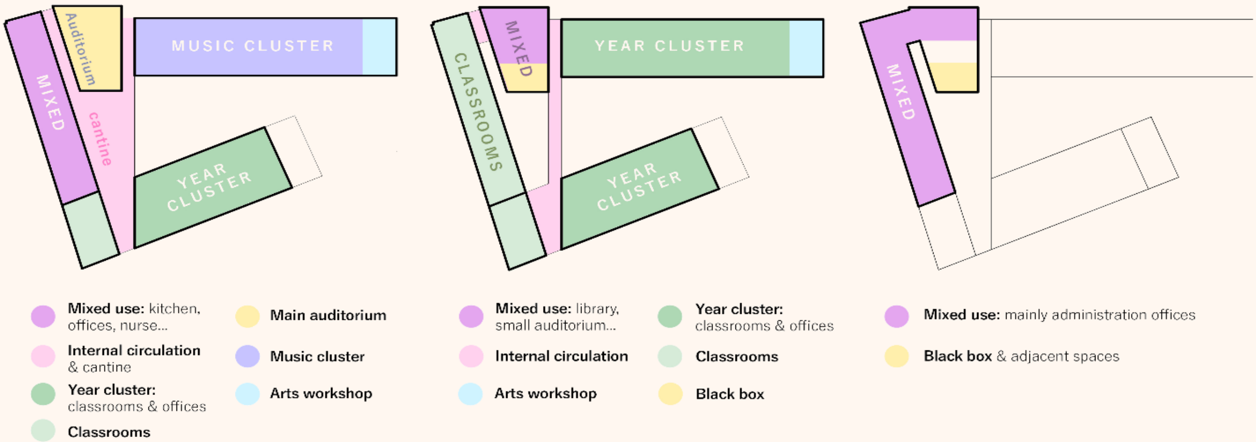


Figure 61. *Program diagrams.*

Figure 62. Blue: preserved / Orange: demolished / Gray: new // floor plan of the ground floor

EMISSIONS AS DESIGN DRIVERS

While the result presented proved to be below the benchmark, there are likely additional changes that could have been discussed further. During the early stages of the design process, some of the main decisions were driven merely by aesthetic purpose, while others were directly influenced by climate or LCA. The basic shape of the new building was already established early in the concept phase. Instead of settling for the first option, despite showing good qualities, it could have been worth exploring other concepts further.

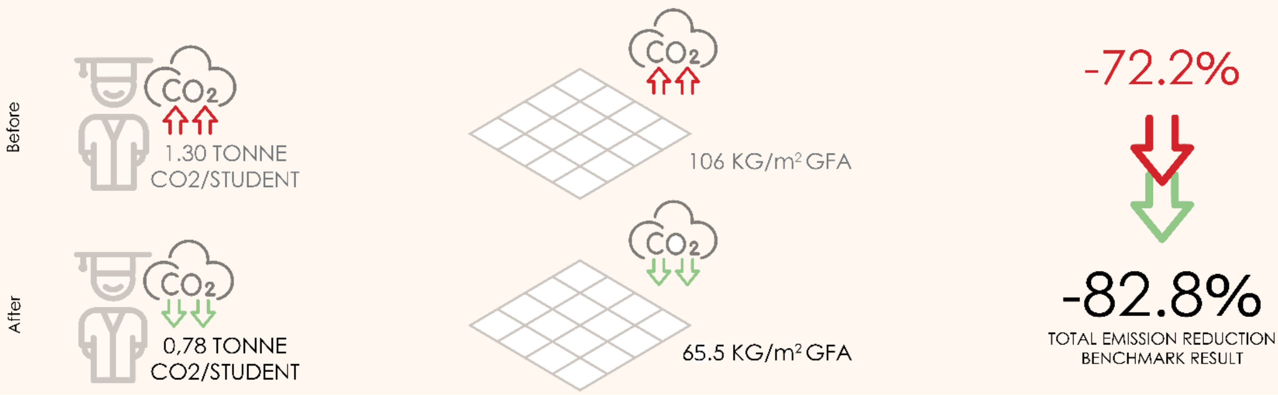


Figure 63. Comparison against benchmark // initial design / final design emissions and mass.

For the final design, instead of only choosing modular wall systems for certain parts of the project, it could be worth investigating if using them for the entire project would sustain the future of the building further, as configuration is less complicated than reconstructing a standard interior wall. While our main focus in reducing emissions was through optimisation of roofs and slabs, investigating alternative materials for walls might also have benefited the project emissions further. In terms of climate, we looked into the possibilities of natural ventilation. This could be a strategy to be investigated further as the configuration of the shape has the potential for it to be successful.

The final proposal managed to successfully merge the new and existing buildings while providing new qualities and functions to the complex. The design choices were highly motivated by environmental drivers and managed to stay far below the benchmark, without compromising on aesthetics and architectural qualities.

This being true, it is also important to point out how lowering the environmental impact sometimes limits the “freedom” to achieve more powerful design solutions, especially in terms of the glass ceilings and walls. These surfaces had to be reduced as a consequence of the high global warming potential of glass. But on the other hand, having to meet these environmental goals also motivated more creative and complex solutions, which in some cases proved to be more architecturally interesting than the initially proposed ones.

If our purpose from the beginning had merely focused on fulfilling the sustainability goals and lowering the LCA results, we would have taken different decisions that would have led to a completely different project. But, in our opinion, the mix of goals, limitations and purposes is what makes architecture interesting and useful from many points of view.

THE EMISSIONS-GUIDED DESIGN PROCESS

In the design process, a combination between BIM (Revit) and Reduzer was employed. To control and vary the GHG emissions data in the best possible way, the BIM model was only used for the take-off of building part masses, e.g., exterior wall areas, slab areas etc. Since the BIM model in an early design phase cannot contain all material layers and quantities, this information is the most reliable information to be taken from such a model. Changes in material choices can be tested in Reduzer and integrated in the BIM model once decisions are made. In the model, consequences of material choices can be evaluated, e.g., connection details.

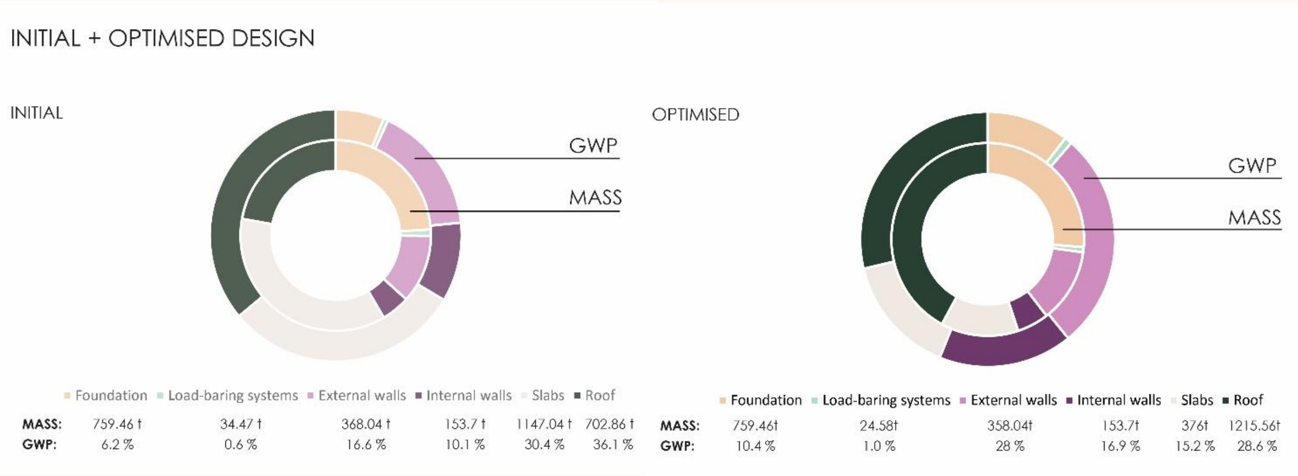


Figure 64. *Documentation of the process of lowering emissions: initial design versus design with low emissions (project "Filling the Void").*

The designers aimed for low emissions in an early stage by evaluating design ideas with the related overall building volumes and functional distributions. To achieve this, the existing buildings were re-constructed as BIM models, allowing the group to assess the materials contained in the buildings on site. Subsequently, building volumes and orientations were tested with a parallel emissions estimation. This gave an idea of the emissions saving by architectural design.

As a basis for the later design stages, construction alternatives were investigated beforehand. This means that each design group had a knowledge base of building parts and minimized emissions on a building part level. Material choice became a combination of material properties, desired appearance and material emissions.

Coupling these building part catalogues with the design at different stages showed the emissions savings potential inherent in material choice. Both a change of materials was considered as well as a building part change. The work in OmBrick is an example of the first strategy, the optimization of roof window area of the project Filling the Void (Figure 64) illustrates the second strategy.

Overall, working on alternative designs to a real-life project was appreciated by the student group and gave valuable insights. One drawback was the almost exclusive focus on embedded emissions due to the course topic. An exploration of the trade-offs involved in minimizing embedded emissions, reusing buildings and materials, conservation of heritage values and plus-energy design, offers potential for further exploration.

SUMMARY

The alternative designs arrived at reducing embedded emissions to less than 20% of the DFØ benchmark for schools (Table 9). The most important factors in this process were:

- Adaptive reuse of the largest part of the building mass
- Reuse of the materials from demolished buildings
- Parallel emissions calculation throughout the design process

Table 9. *GHG calculation results from the student projects in tons of CO2-eq and year (total emissions for the project, 60-year study period, phases A1-A4, B4)*

	Building A renovations	Building C renovations	Building H renovations	Additions	Total	% of benchmark
Voldsløkka 80[3]	365	145	229	0	739	16.9
Ombrick	331	0	134	46	511	12.4
Filling the Void					634	17.1

Since this was an alternative design process, the future architects and engineers did not have any restrictions in terms of costs or practical issues such as storage of building materials during the construction process, factors that can hinder the reuse of buildings. Additionally, adaptation of the Heidenreich building was more flexible. In this aspect, it is remarkable that all design proposals respected the original appearance of the H building to a very high degree, integrating it into the new proposals. There were a number of challenges related to the adaptive reuse of the existing buildings, namely the low ceiling height and the configuration of the buildings on the site. Building C was assessed to shade and obstruct too much of the courtyard to be useful in its entirety. Therefore, the alternative designs resemble the as-built project quite closely in their placement of the buildings on site.

5.4 BENCHMARK THE SOLUTIONS DECIDED AGAINST ARV KPIS

LIFE CYCLE ASSESSMENT

CPCCs in ARV should strive towards 50% reduction in life cycle embodied and operational GHG emissions compared to ex-ante condition or current practice. In this report, the material use and energy demand in final design of the new school building (the S-building) and the renovated existing building (the H-building) have been evaluated against that target. To do this comparison, the life-cycle embodied GHG emissions were estimated with Life Cycle Assessment (LCA), and then benchmarked against current domestic practice.

Calculating the lifecycle global warming impact

LCA in design development

The architects received emissions information about the S-building at two points during the design process: in the development phase and in the detailed design. No LCA was performed for the renovated H-building during the design phases. The early design report ("Klimagassregnskap Skolebygget Voldsløkka skole, 2019-02-28") established a strategy to reduce GHG emissions of the S-building by 40% compared to a reference building. For this calculation "Carbon Designer by OneClick LCA" was used. This tool estimates building part areas for the reference building by generating a shoe box model from basic geometric information, such as gross floor area, number of floors, width and length of the building. Building part emissions are generated through typical materials for the building type "school". The geometry of the reference building shows differences to the designed building but matches the heated floor area and the number of floors (Table 10).

Table 10. *Comparison of the geometry form the reference building and the early design model*[23]

	Reference building	Project (design phase)
Building height	19 m	ca. 22.3m
Building length	108 m	ca. 91.9 m
Building width	18 m	ca. 22.4 m
Floor to floor height	3,5 m	3.8 m
Distance between columns	9 m	Varies. Main columns on long walls are ca. 5.52 m apart.
Number of stairs	2	3 stair cores
Number of floors	5 + basement	5 + basement
Footprint	1 940 m²	2 146 m²
Gross floor area (Brutto areal, BTA)	10 856 m²	not calculated
Heated gross floor area	10 329 m²	10 329 m² (including bridge to H-building)

[23] Norconsult AS: Klimagassregnskap Skolebygget Voldsløkka skole, 2019-02-28 (translated by P. Schneider-Marin, NTNU)

The report shows that most of the savings of the designed building in comparison to the reference building would arise in life cycle phase B6, energy demand in use. The reference building used the minimum legal standard for energy in use, whereas the future building's energy demand was to be 64% lower. Additionally, 5% of the energy demand were to be covered by district heating which has a lower GHG emissions factor (0.09 kg CO_2-eq./kWh) than the electricity mix of Norway + EU 29 (0.13 kg CO_2-eq./kWh).

Table 11. *GHG calculation results from the student projects in tons of CO2-eq and year (total emissions for the project, 60-year study period, phases A1-A4, B4)*[24]

Life cycle module	A1-A3	A4	A5	B4-B5	B6	C1-C4
reduction compared to reference building	14 %	10 %	1 %	20%	64%	8 %

The report concluded that the designed project would save 51% of emissions compared to a functionally equivalent reference building.

During the detailed design phase, the building from the early design phase was used as the reference building (column project "Project design phase" in Table 10), with an adjusted gross floor area of 11 017 m². This is what the architect[25] mentioned in an interview on the high ambitions of the project regarding not only operational, but also embedded emissions. The calculation rules and results are described in the following chapters.

LCA of the S-building during the detailed design phase

The LCA of the S-building was performed by subcontractor Norconsult in two iterations: one for the early-phase design in February 2019 and another one for the detailed design in June 2022. Only the detailed design LCA is used in this benchmarking since it contains the most updated information. The material use for the bridge from the S-building to the H-building is included in the LCA of the S-building. The school has a support system made of solid wood, steel, and concrete. The calculation is a quantitative assessment of emissions of GHGs associated with materials over a lifetime of 60 years, and describes the project's impact on climate change, measured in CO_2-equivalents. The GHG calculation was performed in accordance with the Norwegian standard *NS 3720 Methodology for greenhouse gas calculation for buildings*. The materials were organized into building elements according to the Norwegian standard *NS3451 Table of building elements*, and the life cycle modules are organized according to the Norwegian and European standard *NS-EN 15978:2011*. Of the 134 materials included in the assessment, specific EPDs (Environmental Product Declarations) were used for 60 materials, while generic emission intensities were used for the remaining. Materials responsible for 5% or less of the weight in each building part were to some extent excluded. Technical installations were also excluded. The tool used for the calculations was OneClick LCA. The input data was gathered from various sources:

- Material quantities were extracted from an IFC file dated November 2021 and were supplemented with quantities for the structural materials from the structural engineers.
- Quantities of wastage from cut-off and surplus materials was based on project specific values from the contractor Veidekke for timber framing, wind barrier, CLT, and load-bearing steel (received in

[24] Norconsult AS: Klimagassregnskap Skolebygget Voldsløkka skole, 2019-02-28 (translated by P. Schneider-Marin, NTNU)
[25] interview with Erik Brett Jacobsen, Kontur Arkitekter AS, in Oslo on 30.10.2023

March 2022). For the remaining materials, the quantities of wastage were standard values in the software.

- Material lifetimes are based on standard values in the software. Maintenance and repairs are excluded from the assessment, while replacements of materials are included.
- Transport distances are using location of the specific supplier for concrete, reinforcement, steel and solid wood. For the remaining materials the transport distances were standard values in the software. In all cases, the emission factors used for transport modes were standard in the software used.
- End-of-Life emissions are based on standard values from the software.

Measures taken to reduce emissions during the design process

It appears, with the assumptions made, that total GHG emissions from materials are 2319 tonnes of CO_2e. The most impactful measures taken to curb emissions include:

- A large portion of the concrete used is “low carbon class A”
- 100% recycled reinforcement in concrete structures
- A large amount of recycled steel in the beams
- A significant portion of the beams, columns, exterior walls, interior walls, slabs, were built with wooden materials (the remaining of low-carbon concrete with recycled reinforcement).
- The roof is a lightweight structure, which reduces the material use and the load on the building, furthermore, the roof structure is made of solid timber.

Initial benchmarking of the reported embodied emissions of the S-building

This first analysis is based on the initially reported emissions, with a detailed re-evaluation based on recalculated results presented in subsequent sections. To establish a comparative framework aligned with current Norwegian standards, we examined various potential benchmarks (such as OsloBygg's historical data on school projects, BREEAM-NOR, and FutureBuilt criteria). Selecting a benchmarking reference significantly impacts the outcome due to differences in system boundaries and calculation methods. The chosen benchmark for this analysis is the Norwegian government's recommendations for public procurements, updated in December 2020 by the Directorate for Public Management and Budget.[26,27]. These reference values are intended to be representative of standard Norwegian practice for different typologies. The reference values serve as a proxy for standard Norwegian construction practices across various typologies and exclude basements while providing separate benchmarks for heated and unheated basements. For this analysis, the typologies selected were school buildings and unheated basements. The system boundaries for the reference values encompass specific building elements (22 Load-bearing systems; 23 External Walls; 24 Internal walls; 25 Slabs; 26 Roof; 28 Stairs, balconies, etc.)[28] and life cycle phases (A1 raw material supply, A2 transport (to manufacturer), A3 manufacturing, A4 transport (to the site), B4 replacement, B5refurbishment)[29]. The embodied carbon results for the Voldsløkka school were adjusted to mirror these defined elements and stages.

The findings, shown in Figure and Figure 66. Figure 65 depict the embodied carbon emissions per building element and life cycle phase for the Voldsløkka S-building, alongside the respective reference values. Figure 66 shows how those results compare to the reference, and the percentage reduction

[26] https://anskaffelser.no/verktoy/analyseverktoy/klimagassutslipp-bygg
[27] https://kriterieveiviseren.difi.no/nb/wizard-export/criteria/175_172/220_217#criteria-175
[28] As defined in the NS 3451
[29] As defined in the NS-EN 15978:2011

achieved. The Voldsløkka S-building has a significant reduction for all building elements and life cycle phases, with a total reduction of 51% compared to the reference. The A1-3 stages are contributing to most emissions among the life cycle stages. Among the building elements, the beams (due to steel profiles) and cantilevered slabs (due to cast-in-situ concrete) have the highest emissions. Among material types, construction steel is causing most emissions, and is responsible for roughly one-fourth of total emissions in the building. The construction steel is followed closely by cast-in-situ concrete, and flooring is the third highest material category. Some emission culprits worth mentioning, where there are clear potentials for lowering the climate change impact, are: relatively large technical rooms, steel used for mounting façade elements and glass facades, aluminium framed as opposed to wooden framed windows, and vinyl flooring.

Some limitations of this benchmark comparison against reported results include: Some construction site wastage which is not included in the reference values is included in the Voldsløkka results for B4-5; the emissions from transport, A4, are likely too low in the Voldsløkka results, since both the transport distances and the emission factor for the transport modes are unrealistically low compared to the assumptions made in the reference values; some production emissions, A1-3, may be too low in the Voldsløkka results due to an inaccurate method of "localization", i.e. applying a reduction factor to the emission factors of the products to make them country specific. These limitations cannot be directly addressed in due to the aggregated nature of the reported results. To address these limitations, and, importantly, expand the system boundary of the benchmarking, the LCA of the S-building was performed again from scratch, together with an LCA of the H-building.

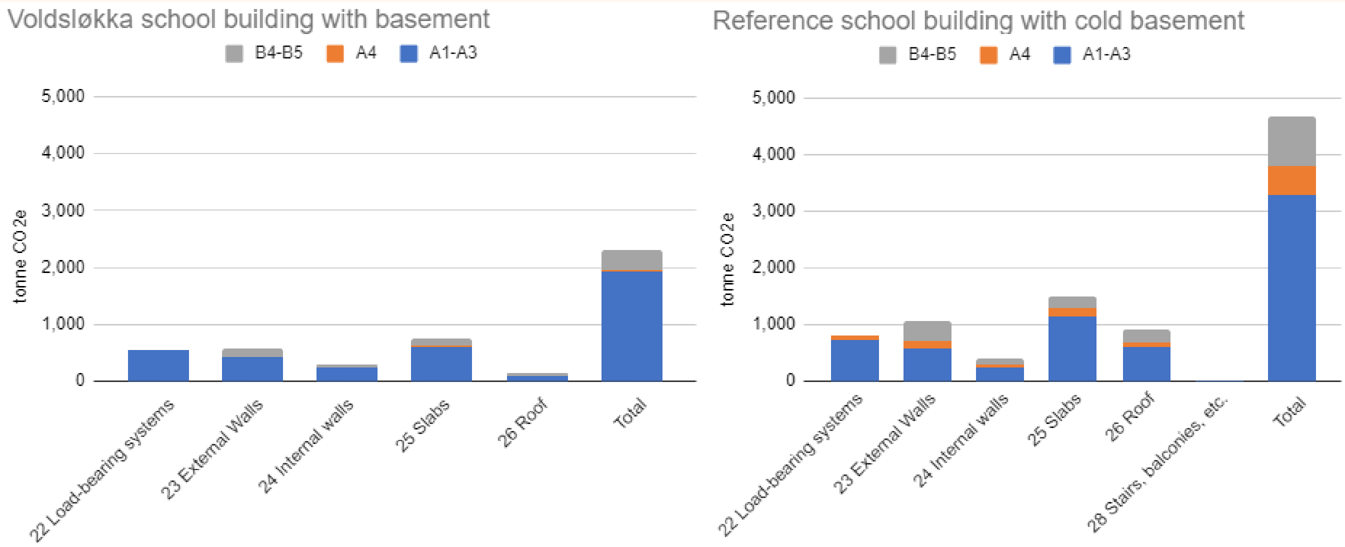


***Figure 53**. The embodied carbon of the materials used in the Voldsløkka school building (left), and the reference values for standard Norwegian practice (right). The results are divided by building elements and life cycle phases. Building element 28 Stairs, balconies, etc. is not included in the assessment due to data not being available.*

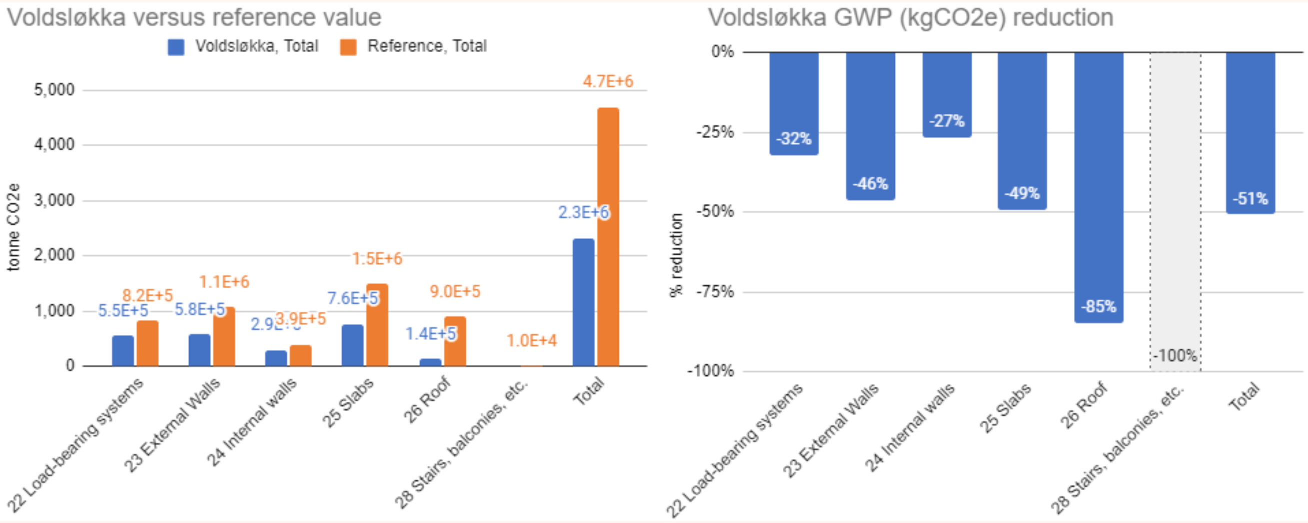


Figure 66. *The embodied carbon of the materials used in the Voldsløkka school building compared to the reference values for standard Norwegian practice (left), and the percentage reduction achieved (right). Results are shown per building element and for the total.*

Recalculating the S-building results for enhanced accuracy and extended analysis

The results from the Norconsult report were of limited nature, given that they only included a selection of lifecycle phases, and did not take into account the energy use during construction and operation of the building. To be able to perform a more extensive analysis, verify the calculations, and compare the results against various benchmarks, the GWP results from the Norconsult report were recalculated. The recalculation was performed in the software Reduzer (reduzer.com), using the same material quantities as were used in the original report. The same EPDs were used for the emission data of the materials, to the extent that it was possible to find the same data. In other cases, where the original report used generic data or the EPDs could not be found, the most suitable data from Reduzer's database was used. In the below comparison between the two separate calculations, the same system boundaries were used for the results. The results from the recalculation and how it compares to the original result can be seen in the figure below.

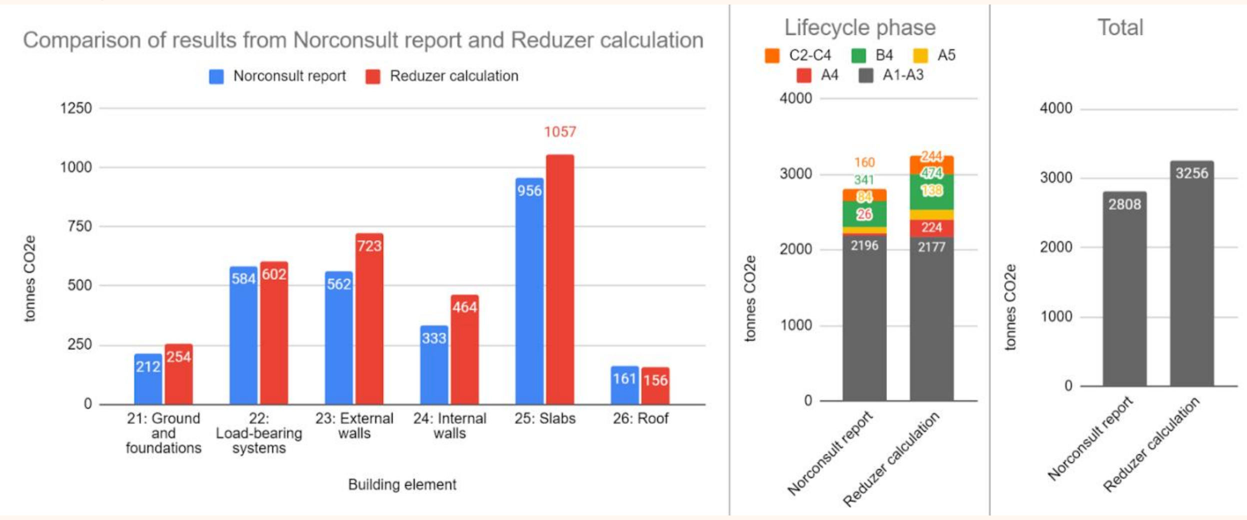


Figure 547. *Results from the original Norconsult report and results from the recalculation in Reduzer.*

From the figure above it can be seen that the results obtained are similar between the two calculations, with the Reduzer results 16% higher for the total than the original Norconsult calculation (calculated in the software One Click LCA). The results are almost identical for the production of materials, phase A1-A3 (less than 1% difference), while the remaining lifecycle phases are consistently higher in the Reduzer calculations for each building element (762%, 64%, 39%, 52% for A4, A5, B4, C2-4, respectively). This is as expected and can be explained by the following factors:

- A4 - Transport of materials from factory to site: The Norconsult results are using the software's standard transport distances for all the products where they don't explicitly changed it. Those standard distances are not from the material production site, as they should be, but are rather from the storage facility where the product is shipped from, leading to underestimations of the transport emissions. Furthermore, the emission intensities of the transport modes are lower in the original calculations, i.e. Reduzer is using an emission intensity factor for transportation which is higher, amongst others because it includes the lifecycle impacts of the transportation as opposed to only considering the direct tailpipe emissions.
- A5 - Wastage materials at the construction site: The wastage of each material at the construction site is based on standard assumptions of a fixed percentage for each product category. The standard values for this assumed percentage are higher in Reduzer. To check the validity of the assumed percentages, the total mass of wastage in the Reduzer calculations was compared with the latest empirical data from the construction project. As of April 2023, the accumulated total reported wastage from the project was 561 tonnes. This is only 2% lower than the assumed wastage mass in Reduzer (572 tonnes), confirming that the assumptions done in the recalculation are more realistic. In addition to the wastage percentages, the transportation emissions of the wastage materials to site and the return to waste handling are higher for the same reasons explained in the bullet point above. Lastly, the incineration of the carbon contained in the product wastage is higher in Reduzer (see C2-C4 below).
- B4 - Replacement of materials: The replacement of materials in the use phase is determined by an assumed service lifetime of each product. There may be some differences in the assumed lifetimes, with shorter lifetimes for some products in Reduzer. However, the main reason for the difference in is that the B4 results also include transport of the replaced materials and production, transport, and incineration of its wastage, thus accumulating the difference explained in the above bullet points.
- C2-C4 - End-of-Life transport to waste handling and waste handling: The transport to waste handling emissions is higher in Reduzer due to the higher transport emission intensity. The incineration emissions are higher in Reduzer because all materials containing carbon are incinerated. Most notably, the XPS insulation, consisting entirely of fossil carbon-based materials, is assumed not to be incinerated in the original calculation, while it is considered incinerated at end-of-life in Reduzer.

In conclusion, the recalculation of the results in Reduzer is thought to increase the accuracy of the lifecycle assessment, with more realistic assumptions regarding the transport, wastage, replacement, and end-of-life emissions. Furthermore, the recalculation allows for a more complete system boundary and a more extensive analysis of the results. In the following, the recalculated results are used for further analysis and benchmarking against the KPI.

Emissions from installed PV panels

The S-building is equipped with photovoltaic (PV) panels, featuring 1,107 m^2 on the roof and 746 m^2 on the façade. The Environmental Product Declaration (EPD) of the SunPower Maxeon 3 Mono-Crystalline Photovoltaic Module (registration number NEPD-3087-1726-EN) was used due to the lack of specific emission data for the installed PV types. Additionally, material use for the PV mounting system was added for the entire PV area. An estimated service life of 30 years is assumed for the panels.

Emissions associated with the PV panels, including the mounting system, are depicted in the below figure, calculated using the FutureBuilt ZERO method. These panels contribute to 10% of the total embodied emissions from material usage. Significantly, the electricity generated by these panels is estimated to offset 35% of the total embodied emissions from materials, effectively compensating for the PV panels' embodied emissions more than threefold over the building's 60-year lifespan.

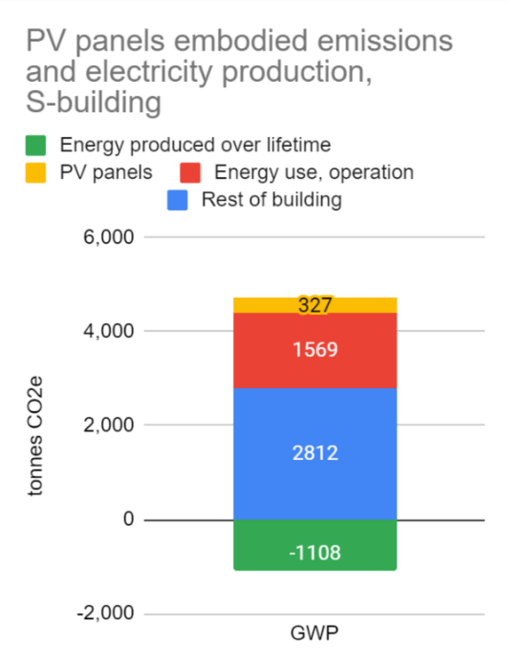


Figure 68. *PV panels embodied emissions and electricity production, S-building*

Emissions from material use in the H-building

The master's thesis "Whole building life cycle assessment of an adaptive reuse of a heritage building: A case study of an industrial building" by Zohaib Ali [07.11.2023] was used to analyse the GWP of the H-building of the Voldsløkka skole with the renovation as it is found today in 2023.

The Heidenreich building is an old concrete factory from 1922 in Oslo and is nowadays listed as a heritage building. A structural integrity report in October 2020 found that the existing building couldn't withstand the required loads. Consequently, all internal spaces and load-bearing structures were demolished, except for the facade and its supporting foundations. The renovation involved the reuse of the facade and foundations, with structural loads now supported by wooden columns, beams, and steel transoms as well as a new roof meeting TEK 17, new windows with a similar outlook and four added skylights.

Zohaib compared different renovation scenarios of the H building, as seen in Figure 69.

	Scenario development
D0	Newly added materials to reach TEK 17 Minimum requirements+ Partial Demolition+ Emissions from retained materials
D1	Complete demolition of existing building and New construction.
D2	Same as D0 with more energy efficiency measures.
D3	Same as D1 and with more energy efficiency measures.
As-Built	New added materials, better U-values for roof and ground as compared to TEK 17 minimum requirements, Partial demolition and in-situ materials.
Hypothetical New Construction	Same as As-built , but without the reuse.

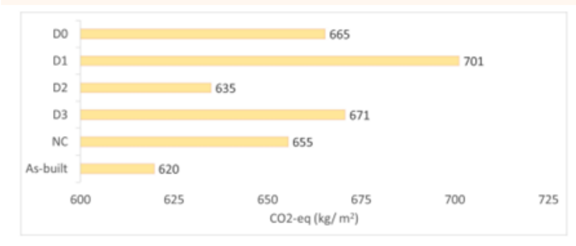


Figure 69. *Scenarios development and comparison in terms of total GWP per m²*

The main findings of Zohaib's thesis are that the refurbishment of the H-building provides greater environmental benefits over alternatives like demolition or and construction. Specifically, it shows that while renovating an existing structure presents upfront embodied emissions, these are considerably offset over time when compared to the environmental impact of constructing anew. However, it is also noted that achieving a higher energy efficiency level, akin to the Passive House Standard, necessitates an extended period, approximately 20 years longer, to offset the initial embodied emissions, when compared to the more modest baseline requirements set by TEK 17 (D0). This analysis points to the balance between immediate environmental costs and long-term sustainability benefits in building renovation and efficiency standards.

For the purpose of this report, only the material inventory based on the "As-Built scenario" from Zohaib were used. The material inventory was used together with the separate energy data from the section below, and the lifecycle global warming potential emissions were calculated in the software Reduzer.

In the below figure, the results from the calculation of embodied emissions from material use in the H-building are shown together with results from the S-building. The system boundary and calculation scheme used here is the same as in the original Norconsult report. Quite naturally, the emissions from material use in the H-building are much lower than those of the S-building, mainly because the S-building is a much larger building with 4 times the gross floor area. When comparing results per floor area, the H-building has much higher emissions than the S-building for the internal walls and the roof, while it has lower for the ground and foundations, load-bearing structure, external walls, and slabs mainly because of reuse of existing materials.

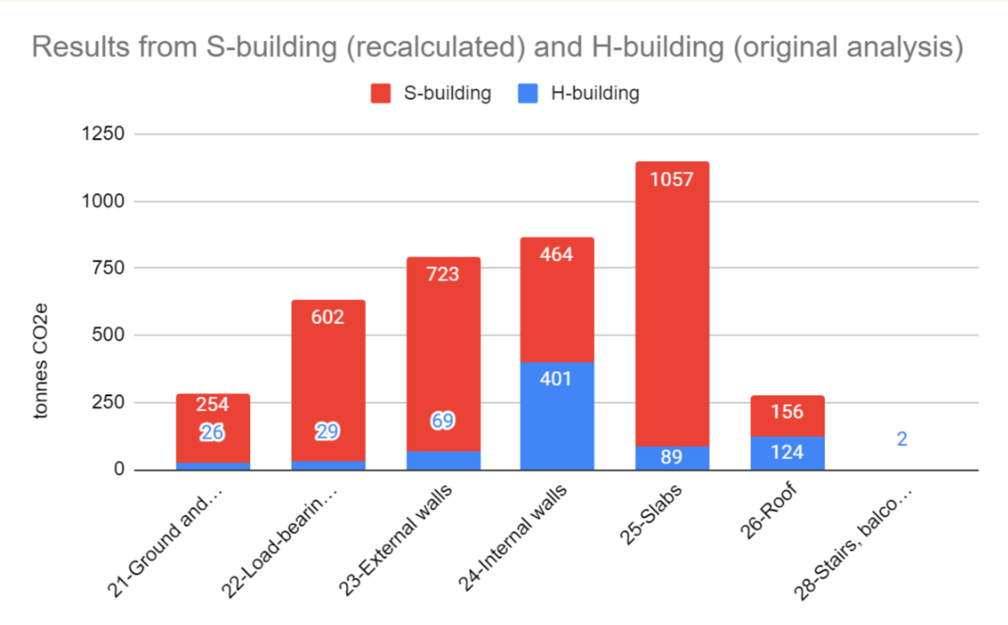


Figure 70. *Results from S-building and H-building*

Emissions from energy consumption

The total energy consumption at the construction site for both the S-building and the H-building is 2199 MWh of electricity and 67629 litres of biodiesel. Assuming 9 kWh per litre of biodiesel, the biodiesel consumption is equivalent to 609 MWh.

The estimated delivered energy demand of the buildings during operation (incl. equipment) are 35 kWh/m^2/year for the S-building, and 109.2 kWh/m^2/year for the H-building. The estimated electricity production from the PV panels on the roof (1107 m^2) and the facade (746 m^2) of the S-building is 24.8 kWh/m^2/year.

The figures below show the calculated emissions from the documented energy use in the construction phase and the estimated energy use in the operation phase. The results are calculated using the FutureBuilt ZERO method.

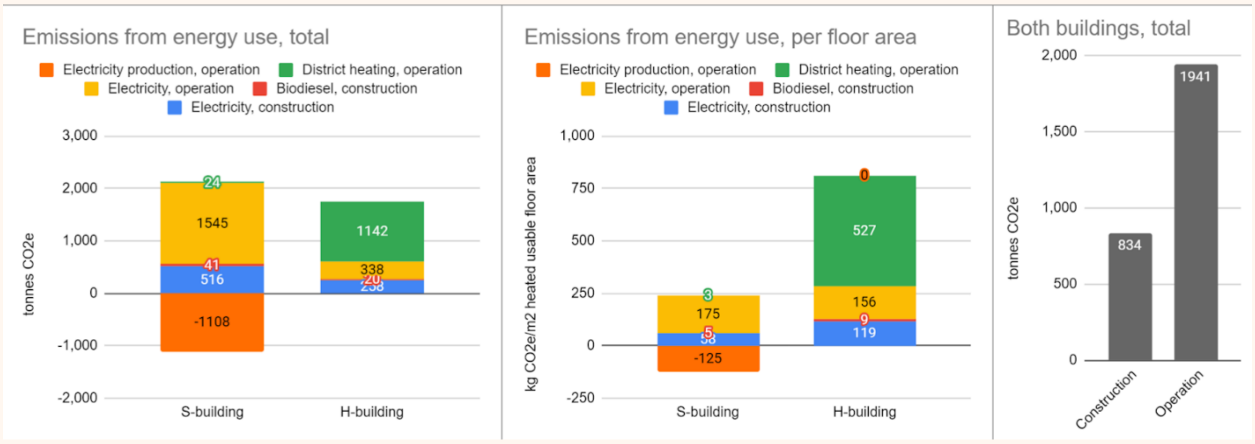


Figure 55. Calculated emissions from the documented energy use in the construction phase and the estimated energy use in the operation phase.

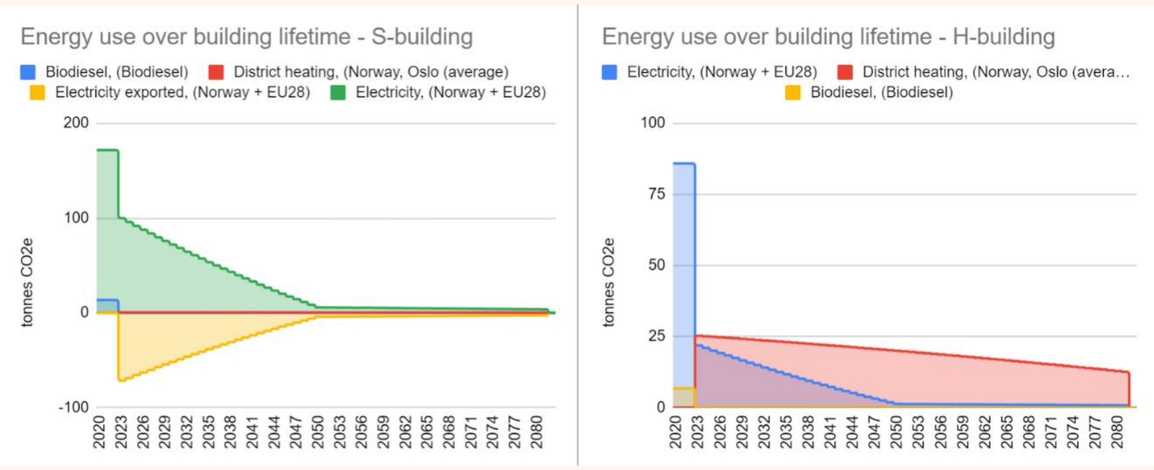


Figure 562. Calculated emissions from the documented energy use in the construction phase and the estimated energy use in the operation phase, per year in the building's lifetime.

Benchmarking results

There are various benchmarking schemes for comparing building LCA results against reference values. Here, the two Voldsløkka buildings are benchmarked against the FutureBuilt ZERO criteria, and the DFØ/BREEAM-NOR criteria.

FutureBuilt ZERO criteria

The FutureBuilt ZERO criteria are part of a voluntary scheme for environmentally ambitious buildings in Norway. The criteria set specifies an exact system boundary of building elements and emission sources that should be included in the results and specifies how the emissions shall be calculated. Thus, the results are comparable across projects, and are also comparable against the criteria values set in the scheme. A building should, according to the criteria, achieve a result which is 50% below the Norwegian standard practice. The benchmark values for the standard practice, and the FutureBuilt ZERO criteria values, are made stricter each year from 2020 until 2050 - according to the national climate goals set by Norway under the Paris agreement. The Voldsløkka school was taken into operation in 2023, and thus the criteria values are taken from that year. The criteria consist of three parts: a criterion for energy use in operation, one for the material use (including energy use at the construction site), and a total criterion consisting of both. The energy used at the construction site (included in the materials benchmark) is only available at an aggregated level for both the S-building and the H-building. To be able to benchmark each building individually, it was here assumed that ⅔ of the construction energy is attributed to the S-building and ⅓ to the H-building.

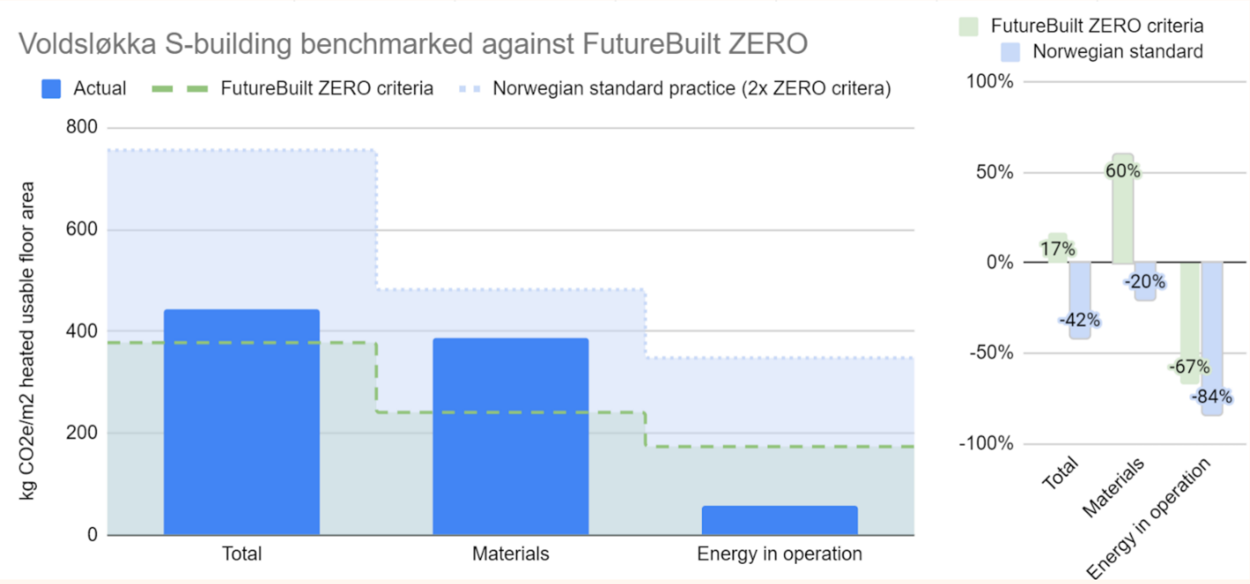


Figure 573. *FutureBuilt ZERO benchmark for the S-building.*

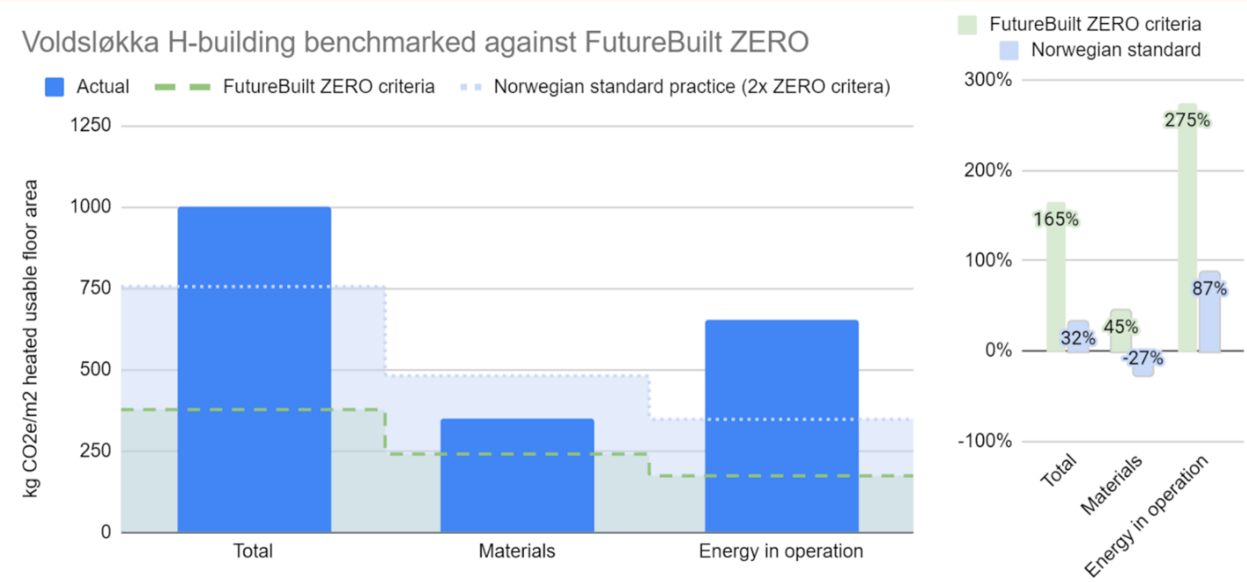


Figure 584. *FutureBuilt ZERO benchmark for the H-building.*

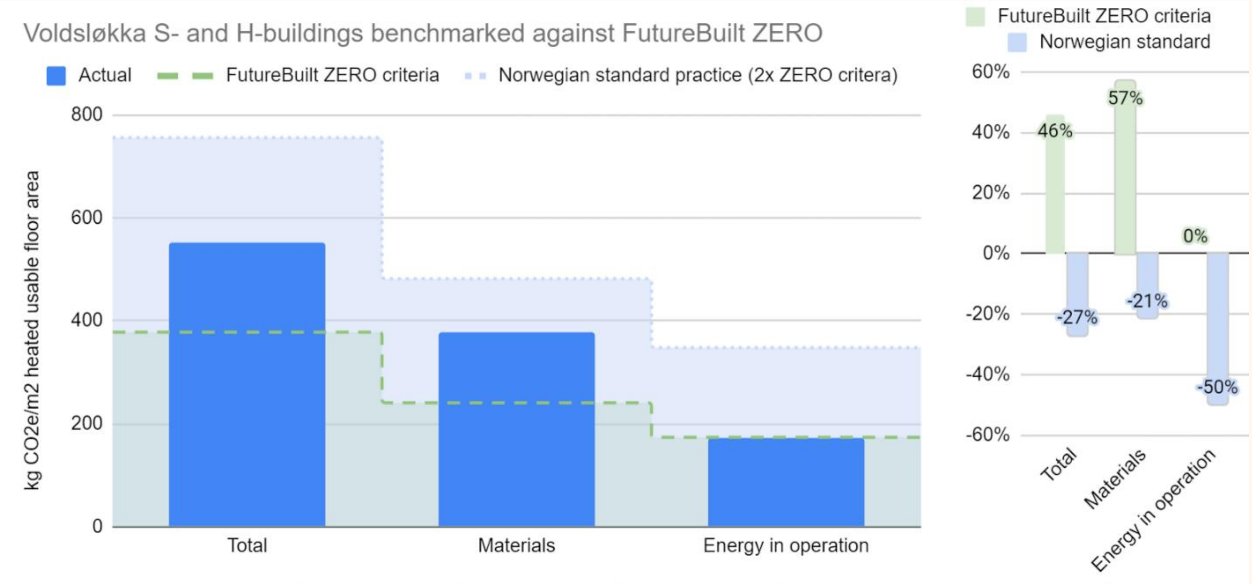


Figure 595. *FutureBuilt ZERO benchmark for the S-building and H-building combined.*

BREEAM-NOR v6.1 criteria

The BREEAM-NOR v6.1 Mat-01 criteria[30] includes all the same materials as in the FutureBult ZERO benchmark, but only includes some of the emissions related to the use of those materials. The included emissions are production of materials (A1-A3), transport of materials to site (A4), production and transport of wastage materials at the construction site (A5), and production and transport of the replacement materials. Emission sources that are included in FutureBuilt ZERO but not in BREEAM-NOR include energy use both at construction site and in operation (A5, B6), biogenic carbon uptake and carbonation of concrete (B1), end-of-life incineration of products (B4, C3), and reusability and exported/self-consumed energy production (D). Thus, this benchmark only captures a portion of the emissions caused by the building over its lifetime. The figure below shows the results of the BREEAM-NOR v6.1 benchmarking. Both buildings together achieve an 18% reduction compared to the benchmark, where the S-building achieves 20% reduction and the H-building 11%.

[30] https://byggalliansen.no/wp-content/uploads/2023/11/BREEAM-NOR-v6.1_NOR.pdf

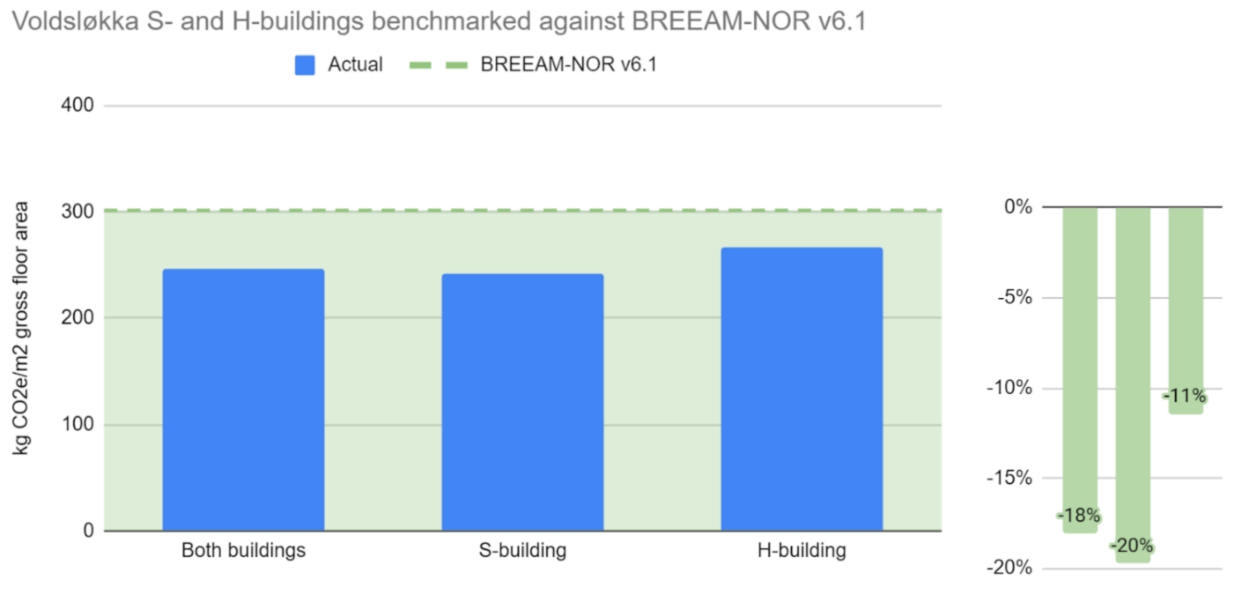


Figure 606. *BREEAM-NOR v6.1 Mat-01 benchmark for the S-building and H-building combined.*

Limitations of the LCA and benchmark comparison

The result in this assessment is to a large degree based on a material inventory of the *planned* construction. The actual materials used when construction is finished might differ from what was planned. For example, the material inventory did not include the building element no *28 Stairs, balconies, etc.,* however, this is not likely to influence the conclusions since that building element is quite insignificant in the reference values. More importantly, the reference values used for benchmarking the results do not include building element no *21 Groundwork and foundations,* which could be included for a more holistic benchmarking, but there are currently no good benchmarks for this building part. The S-building has managed to achieve a low impact in this building part due to use of low-carbon concrete and recycled steel, a benefit that does not show in the current assessment.

ENERGY DEMAND

The energy simulations have been performed in the software SIMIEN[31] by the consultant at Norconsult. SIMIEN is an energy calculation software that is validated according to EN 15265 and were the calculations according to NS 3021:2014 "Calculation of energy performance of buildings — Method and data". The calculations have input data based on statistics of operating time and occupancy from Oslo Municipality. For energy use related to lighting, technical equipment, and heating of domestic hot water data from another school in Oslo (Brynseng Skole) was referred to. Of course, the current energy simulations are theoretical predictions, and the actual energy demand will probably change depending on the actual use of the building and on actual weather conditions.

H-Building (Renovated building)

To check if the planned renovation leads to a reduction in the energy need compared to the pre-renovation level, it is necessary to find a suitable reference for comparison. As pointed out in chapter 5, the H-building is an old cement factory which is being transformed into a cultural building. This means that the pre-renovation reference should be a cultural building. Thus, we have used a reference energy

[31]https://simien.no/?gclid=CjwKCAiAzKqdBhAnEiwAePEjkjP-0ThZcp7aTm_J_U0zYjPFIUWb8hfVvV5sn95zqrRQ5YINXl2GABoCK5kQAvD_BwE

which is based on average measured specific energy use in Norwegian cultural buildings[32]. The simulated energy demand, the representative energy demand, and the calculated difference (in kWh/m^2 & percent) can be found in Table 12. As we can see from the results, the renovated part of the building achieves the target of at least 50% reduction in energy needs compared to pre-renovation levels.

Table 12. *Simulated annual energy demand of the H-building and of the representative similar building.*

Simulated energy demand H-bygget [kWh/m2]	Representative energy demand [kWh/m2]	Difference [kWh/m2]	Difference [%]
119	245	-126	-51 %

Due to the status as a listed building, there were limitations on changes to the façade of the building. The exterior appearance of the façade had to be preserved, and it had to be ensured that no further damages where to be done to it. This also meant that the amount of insulation was limited, as the consultant's (SINTEF) conclusion was that that thicker insulation layers on the interior side of the wall could damage the old brickwork. Therefore, the thickness of the mineral wool insulation was set to a maximum of 100 mm.

S-Building (New building)

A summary of the energy simulations can be found in Table 8. The simulations for the S-building were done to control the building against the plus-energy target according to a previous FutureBuilt definitions. This dictates that one is allowed to discount energy demand from technical equipment if a building has four stories or more. In addition, one can discount some of electrical energy demand from district heating. The amount of discountable Sustainable shares is calculated by using a weighting factor of 0.43. For the project it is assumed that the annul energy production from the PV system will be 229 848 kWh. It is important to note that numbers for the PV output are assumed, and not yet simulated. As shown in Table 13 this leads to a positive energy balance where the building produces 2.7 kWh/m^2 year more than it uses. This is within the FutureBuilt definition that dictates that plus-energy buildings should deliver 2.0 kWh/m^2 or more back to grid on an annual basis.

Table 13. *Simulated annual energy demand of the S-building.*

	[kWh/m2]	[kWh]
Total energy demand	56,6	502989
Total electric energy delivered	37,1	329915
Technical equipment	13,3	117843
Sustainable shares from District Heating	0,68	6003,8
Assumed energy production PV	25,9	229848
Total energy delivered	2,7	23779,8

[32] https://publikasjoner.nve.no/rapport/2016/rapport2016_24.pdf

INDOOR ENVIRONMENTAL QUALITY - DAYLIGHTING

Daylighting simulations have been performed by external consultant in the project to control against the requirements in TEK 17 and SKOK (standard requirement specification Oslo municipality) and inform the design of the buildings. Daylight factor was used as the metric for assessing the indoor daylighting levels. Daylight factor is stated as a percentage of the daylight that hits an unshielded external surface. When calculating the daylight factor, the sky model (CIE Overcast Sky) is used as a starting point. Daylight factor is calculated at a point inside, measured 0.8 m above floor level and 0.5 m from adjacent inner and outer walls.

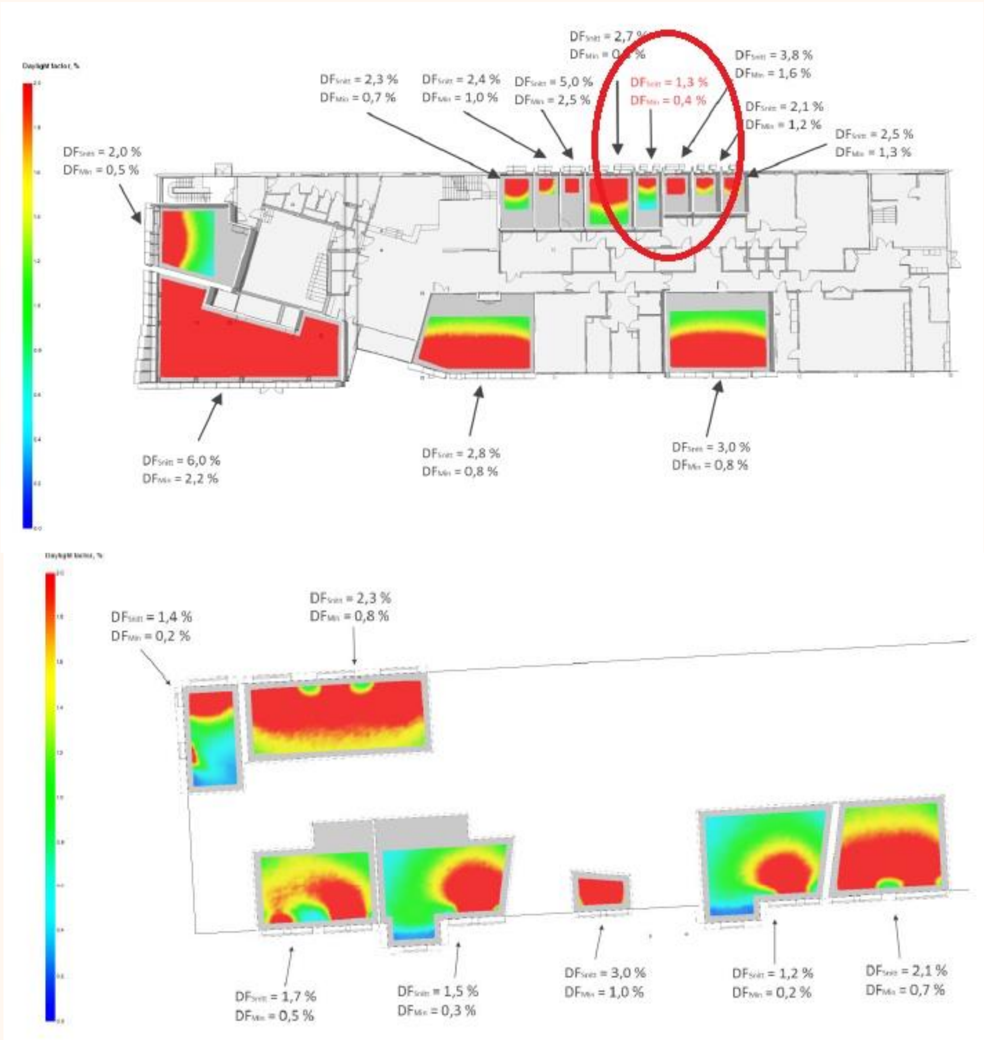


Figure 77*. Daylight simulations for (top) the S-building and (bottom) the H-building. The red circle highlights a room that was found to have insufficient daylighting.*

The simulations were done in the simulation's software IDA ICE[33], and performed for selected rooms deemed most critical. Examples of output from these simulations can be found in Figure 77 Where simulations revealed potential for insufficient daylighting, as shown, there has been a constant dialogue between the different building designers' groups to adjust according to the simulations results. Possible solutions were to change the size of the window, to change the functions of the room or to highlight specific ways the rooms should be furnished.

[33] *https://www.equa.se/en/ida-ice/validation-certifications*

LIFE CYCLE COSTING AND EMISSIONS

The calculation of Life cycle costing (LCC) of the Voldsløkka project (S-building and H-building) is based on the energy-target scenarios developed and described in Work package 8, D8.5. 'Report on streamlined LCA-LCCA comparing alternative solutions and scenarios'. A summary of the method used for the scenarios definition and the results from the energy calculations, the LCA, and the LCC are given in this chapter.

The goal of the scenario analysis is to provide an overview of the life cycle environmental impact and cost of alternative designs of the demonstration project, namely the S-building and the H-building for the Oslo demo. A coherent definition of energy targets (which determine the scenarios) is proposed in D8.5, to harmonize the results across the different demonstration projects and allow comparative analyses among them. As described in D8.5, the general scenarios for the new constructions are proposed to span from the legal minimum standard (NZEB) to plus energy building (PEB). For the renovation of existing buildings, the proposed scenarios span from the status of the building energy efficiency before renovation up to a plus-energy renovation. Specifically, for the Voldsløkka project, the following scenarios have been developed:

- New school building (S-building):
    - Reference scenario (minimal upgrade of TEK17 requirements)
    - First upgrading step (NZEB level)
    - Second upgrading step (plus-energy building, as built)
- Renovated cement factory to cultural building (H-building):
    - Reference scenario (renovated building, as built)
    - First upgrading step (TEK17)

As the H-building was formerly a cement factory, an energy analysis of the pre-renovation status was not done due to the different use of the building. Moreover, given the H-building is protected, it was decided to develop two scenarios only: the renovated building as-built today and an upgrading to TEK17. To make the H-building reach the TEK17 standard, external insulation has to be installed, which would be in contrast to the requirement of protecting the original façade appearance and materiality. For this reason, a third scenario with an even higher energy ambition than the TEK 17 was not developed, given the unsuitability of its application.

The calculation of the LCC of both the S-building and the H-building are based on the differences among the scenarios given by the additional insulation, a photovoltaic system, and the energy savings given by the improved building energy performance. As per the S-building, the goal was to downgrade the building performance of the as-built plus-energy construction to reach a reference value equivalent to the TEK17 building code. To do so, the insulation value of the external walls, roof, and ground floor, the envelope air tightness, and the value of thermal bridges, were increased. The efficiency of the ventilation system (specific fan power and heating recovery), of the thermal system (ground source heat pump), and of the domestic hot water (heating recovery), were left unchanged as they were outside the scope of the streamlined cost calculation. For the H-building, it was decided to improve the insulation performance of its envelope to reach an NZEB level. Similarly for the S-building, the energy system was left unchanged across the two scenarios. The resulting energy use for the S-building are shown in Table 14 and Figure 78, and for the H-building in Table 15 and Figure 79.

Table 14. Results of energy demand and energy use of the scenarios for the S-building.

S-building	Energy demand (kWh/m²)	Weighted delivered energy (kWh/m²)		Total delivered energy (kWh/m²)	Upgrading / reference
		Electricity (98%)	District Heating (2%)		
Reference (TEK 17)	69.2	38.2	0.3	38.5	100 %
1st upgrading	57.7	34.6	0.2	34.8	90 %
2nd upgrading (as-built)	57.7	9.8	0	9.8	25 %

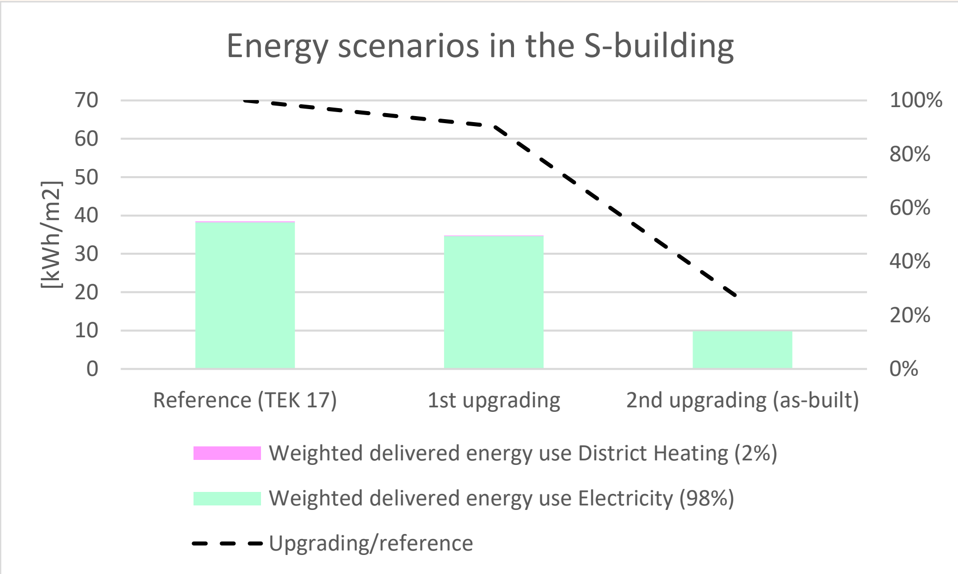


***Figure 618.** Results of delivered energy and their ratios between the scenarios for the S-building.*

Table 15. Results of energy demand and energy use of the scenarios for the H-building.

H-building	Energy demand (kWh/m²)	Weighted delivered energy (kWh/m²)		Total delivered energy (kWh/m²)	Upgrading / reference
		Electricity (DHW + other)	DH (heating)		
Reference (as-built)	116.9	30.9	33.7	64.6	100 %
1st upgrading (TEK17)	101.1	30.3	26	56.3	87 %

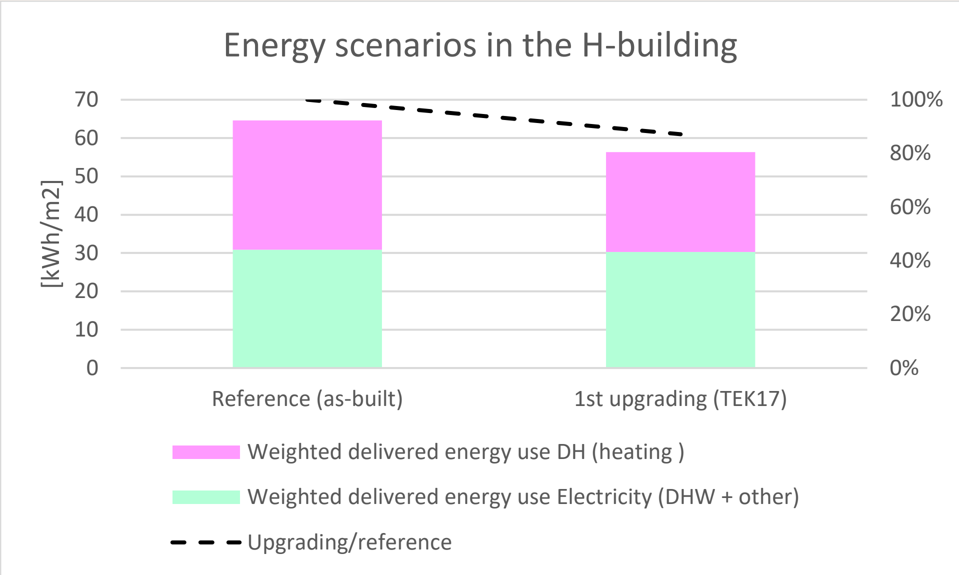


Figure 79. *Results of delivered energy and their ratios between the scenarios for the H-building.*

As shown in Table 14 and Figure 61, the difference of delivered energy between the reference scenario (TEK17) and the first upgrading (NZEB) is minimal due to the limited effect of the additional insulation and lower thermal bridges. The 1st upgrading scenario gives a 10% reduction of delivered energy use. The installation of the PV system in addition to the energy efficiency solutions of the 1st upgrading, defines the 2nd upgrading scenario (corresponding to the as-built S-building) which give a 75% reduction of delivered energy in comparison to the reference building. As shown in Table 15 and Figure 79, a further improvement of the energy efficiency of the as-built scenario of the H-building gives 13% lower delivered energy in comparison to the reference scenario. The values of delivered energy shown in Table 14 and Table 15, are used for the calculation of the buildings' LCCs and emissions.

Cost benefit analysis

In the LCC calculation, the delivered energy reduction achieved through implementing upgrading measures is considered as a benefit and calculated for the whole calculation period. To have a better understanding of the life cycle costs and benefits happening in the subsequent years, the discounting method is employed to determine the present values of future cash flows. Within this framework, the benefit-cost ratio (BCR), representing the ratio of the total net present value of benefits to the total net present value of costs, serves as a criterion for evaluating the profitability of the investment.

Assumptions:

The system boundary applied in the Oslo demo project is based on key phases: the production cost (A1-A3), the maintenance cost (B2), the replacement cost (B4), and the operational energy cost (B6). It should be noted that the LCC assessment incorporates benefits derived from the reduction in operational energy costs resulting from enhanced building insulation and energy generation via PV panels.

The LCC assessment in this project incorporates a key indicator: the BCR derived from the Net Present Value (NPV) of costs and benefits. To facilitate the discounting process, a 3% discount rate is employed, in accordance with the recommendation from the Ministry of Finance in Norway for public buildings with a lifespan ranging from 40 to 75 years[34]. This discount rate aligns with the acceptable rate recommended by the European Union[35].

The study period is 60 years, aligning with the calculation period for LCA of this demo project. Due to the unavailability of cost data, the general data from the Norwegian price book[36] has been employed. It is crucial to acknowledge that there is a possibility that actual cost data might be lower than these general estimates, suggesting the need for a sensitivity analysis.

Concerning the maintenance cost, the assumption is that 1% of the initial investment cost accounts for the maintenance cost of PV panels[37] However, no maintenance activities are specified for the insulation in the building façade. In the LCC assessment, the replacement cost of building components depends on their relative service life. In this project, the assumed lifetime of PV panels is 30 years[36], while the insulation is expected to align with the defined building service life, which is set at 60 years[38].

Table 16 and

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[34] Det Kongelige Finansdepartment. Prinsipper og krav ved utarbeidelse av samfunnsøkonomiske analyser. Oslo, 2021.
[35] Commission, E. The European Commission, "COMMISSION DELEGATED REGULATION (EU) No 528/2014 of 12 March 2014, 2014.
[36] Norconsult. Norsk Prisbok 2023. Norconsult informasjonssystemer, 2023.
[37] Lugo-laguna, D., Arcos-Vargas, A., & Nuñez-hernandez, F. A European assessment of the solar energy cost: Key factors and optimal technology. Sustainability, 1-25, 2021.
[38] Kono, J., Goto, Y., Ostermeyer, Y., & Frischknecht, R. Factors for Eco-Efficiency Improvement of Thermal Insulation Materials. Key Engineering Materials, 1-13, 2016.

Table **17** provide details on the investment costs associated with insulation on walls, roofs, and floors, categorized by their types and thicknesses. Additionally, Table 16 includes data related to the investment cost of PV panels. All unit cost data are derived from the Norwegian price book, including material, labour costs, and surcharge values, and converted to EUR with the exchange rate of 0.1.

Table 16. *Improvement measures, areas, and unit costs in the new S-Building*

Building	**Improvement stage**	**Wall***			**Roof****			**Floor*****			**PV panels******	
		Added insulation thickness (mm)	Area (m^2)	Unit cost (€/m^2)	Added insulation thickness (mm)	Area (m^2)	Unit cost (€/m^2)	Added insulation thickness (mm)	Area (m^2)	Unit cost[1] (€/m^2)	Area (m^2)	Unit cost (€/m^2)
S - Building	1st	120	2759	44.66*	200	917	27	50	2247	13.1	-	
					100	749	16					
					75	193	10.1					
	2nd	Same as 1st improvement									1853	233.1

* Isolasjon utenpå bindingsverk med plastholdere, mineralull
** Isolasjon på tak, XPS
*** Isolasjon i gulv på grunn, EPS
**** BAPV - 0,15 kWp pr. m^2. Inkl. montering og innfesting > 100 m^2

Table 17. *Improvement measures, areas, and unit costs in the renovated H-Building*

Building	**Improvement stage**	**Wall***			**Roof****		
		Added insulation thickness (mm)	Area (m^2)	Unit cost (€/m^2)	Added insulation thickness (mm)	Area (m^2)	Unit cost (€/m^2)
H - Building	1st	300	976.6	111.7	150	1735	21.5

*Kontinuerlig utvendig isolasjon, mineralull, t = 300 mm, festet med lekter til bakvegg av massivtre o.l.
**Isolasjon på tak, XPS

Results

Table 18 provides a concise overview of the project's cash outflows, including the NPV of initial investment, maintenance, and replacement costs for the improvement stages of both buildings.

Table 18. *Cash outflows of the two buildings in different improvement stages (€)*

Building	**Improvement stage**	**NPV of total initial investment cost**	**NPV of total maintenance cost**	**NPV of total replacement cost**
S- Building	1st	(191,303)	-	-
	2nd	(623,237)	(121,293)	(183,290)
H- Building	1st	(146,388)	-	-

The cash outflows of this project include energy-saving costs arising from insulating facade components and the costs associated with energy generation through the installation of PV panels. For a more comprehensive understanding of the energy-saving and generation costs, the energy prices for electricity and district heating have been extracted. Table 19 outlines three values assumed in the LCC assessment of this project. The calculation of cash inflows has been performed based on these three criteria for energy price valuation.

Table 19. *Description of criteria for the energy prices regarding the electricity and district heating*

Criteria for the energy price	**Electricity**	**District Heating**
	€/kWh	
1- General assumption[39]*	0.1	0.1
2- Average cost of the current year[40]**	0.08	0.14
3- Average cost of the last 5 years[4040]***	0.07	0.09

* Based on historically energy prices in the Oslo area.
** Due to the unavailability of data, the average cost of the electricity is based on 2023, while this value for the district heating is based on 2022 data.
*** The last 5 years are 2019-2023 for the electricity price and 2018-2022 for the district heating price

[39] General assumptions of energy cost are based on the calculations performed by Oslobygg for their cost analysis of future projects. The reported values are slightly higher than the averages of the last 5 years to include future unexpected increases of energy cost in the cost feasibility of their projects.
[40] https://www.ssb.no/en/energi-og-industri/energi

Given that energy cost saving is the sole benefit considered in the cost-benefit analysis, Table 20 precisely details the values for the cash inflows resulting from energy savings and generation.

Table 20. *Cash inflows of the two buildings in different improvement stages (€)*

Building	Improvement stage	Criteria for the energy price	NPV of total benefits (energy savings)	NPV of total benefits (energy generation)
S - Building	1st	1	93,363	-
		2	72,596	-
		3	67,802	-
	2nd	1	93,363	625,787
		2	72,596	475,598
		3	67,802	450,566
H - Building	1st	1	51,270	-
		2	69,882	-
		3	47,854	-

Figure 80 visually represents the trade-off between NPV of all costs and benefits for various improvement stages in the two buildings, based on three different criteria for energy prices. Under the specified assumptions, the S-building demonstrates that the second improvement (insulation and PV panels) combined with the first energy price criteria results in the highest BCR of 0.66. However, it is important to note that this ratio falls short of economic profitability (BCR would have to be higher than 1). In the case of the H-building, the results indicate that adding insulation to the wall and roof may not be economically viable under the defined assumptions. Further exploration in the discussion section outlines potential conditions that could result in improved BCRs.

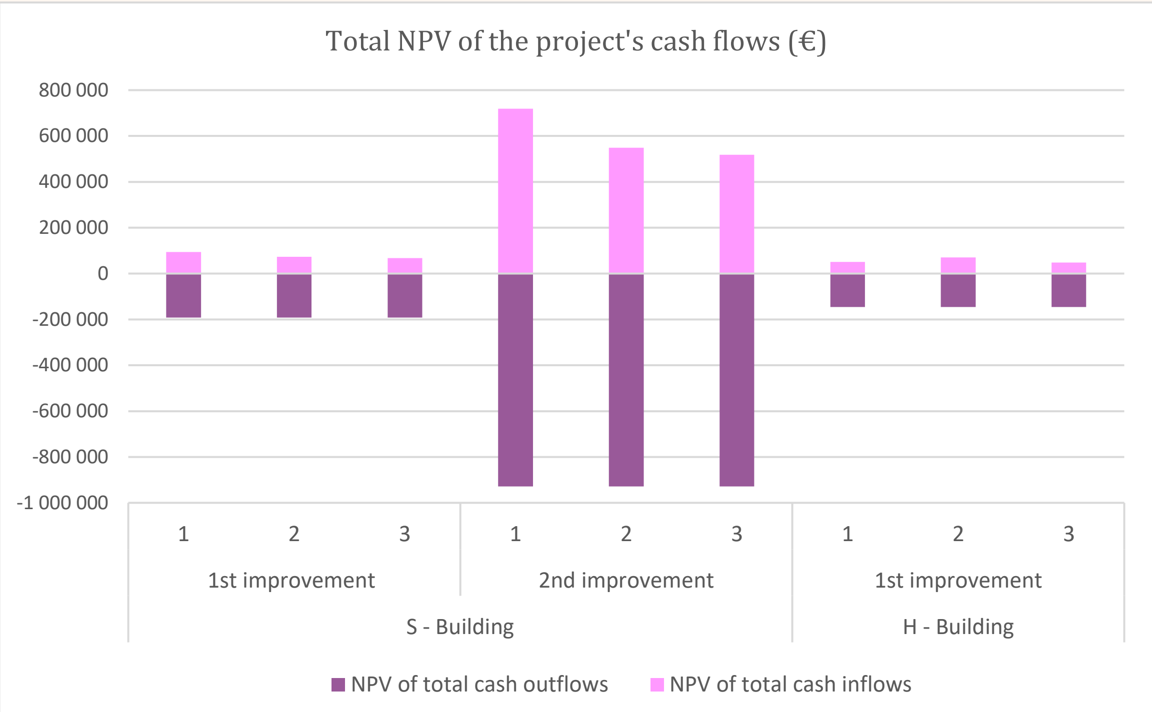

Figure 80*. Trade-offs of the NPV of costs and benefits related to both buildings in the Oslo demo project*

Discussion

The new S- building

The simple payback period for the first improvement of the S-building spans from 58 to 80 years, depending on different criteria for energy prices. As for the second improvement of the S-building, this period varies from 25 to 34 years across the same range of criteria for energy prices.

Given the shorter lifetime of PV panels compared to the calculation period, necessitating replacement in the 30th year, the NPV of the replacement cost for the added PV panels accounts for approximately 21% of the total NPV of costs in the second improvement scenarios. It is worth noting that the BCR for these scenarios would still not exceed 1 if there were no requirement to replace the PV panels in the 30th year.

Considering both the maintenance and replacement costs of all PV panels, the NPV of these two costs is approximately 33% of the total NPV of costs in the second improvement scenarios. In the context of the first energy price criteria, excluding these maintenance and replacement costs could potentially lead to a BCR exceeding 1, indicating the economic profitability of this scenario.

The energy price plays a crucial role in determining the profitability of this project. For the first improvement of the S-building, the project could become profitable if the energy price for electricity and district heating rises to 0.2 €/kWh. In the case of the second improvement, an increase in the energy price to 0.13 €/kWh could alter the BCR to 1.

The initial investment cost is an additional factor that has the potential to alter the economic profitability of the project. As previously discussed, the prices utilized in this analysis are general values extracted from the Norwegian price book. Considering the possibility of real prices being lower than the general data (due to various factors), a sensitivity analysis, Figure1, has been conducted to assess the impact of variations in the initial investment costs on BCRs.

In this analysis, the initial investment costs are reduced by 10% to 40%, and the results are compared with the general cost assumptions. The findings of this analysis reveal that the only scenario with potential economic profitability is the first scenario in the second improvement stage of the S-building, where the energy price is the highest and PV panels are included in the analysis. In this case, a 10% decrease in the initial investment costs of both insulation and PV panels could significantly alter the BCR. In other cases, while these changes might lead to higher BCRs, they may not surpass the threshold of 1.

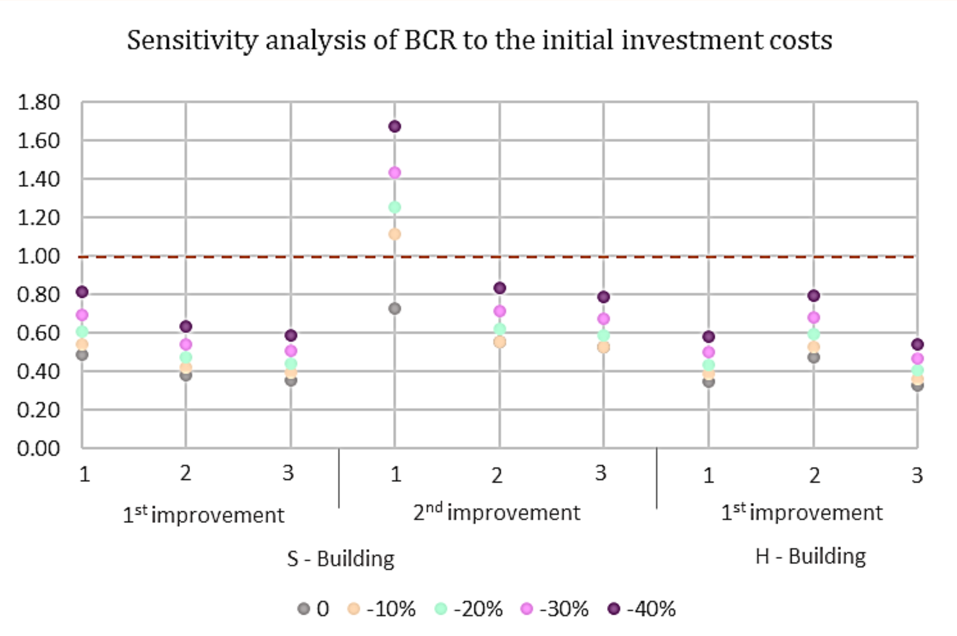

Figure 81. *Sensitivity analysis of BCRs of different scenarios to the initial investment cost*

The renovated H-building

The simple payback period for the improvement of H-building varies from 60 to 87 years, depending on different criteria for energy prices.

In the scenarios related to the improvement of H-building, employing the second criteria for the energy price—specifically, 0.08 €/kWh for electricity and 0.14 €/kWh for district heating—resulted in the most favourable outcome among other scenarios. This can be attributed to two key factors: a) the higher district heating price in the average cost of the current year (0.14€/kWh) compared to the general energy price suggested by OBF (0.1€/kWh), and b) the fact that the heating consumption of the H-building relies entirely on district heating sources.

To comply with the LCA calculation, a 60-year period is also considered for the calculation period of the H-building. It is important to highlight that, in a trade-off between the NPV of costs (specifically insulation costs) and benefits (energy savings resulting from insulation), selecting a shorter calculation period would lead to reduced profitability of the project. In this scenario, the NPV of energy-saving costs would decrease by 29% if a 30-year calculation period is considered.

For the first improvement of the H-building, the project could become profitable if the energy price for both electricity and district heating increases to 0.28€/kWh.

Cost effectiveness of emissions reduction

To evaluate the effectiveness of energy-efficient solutions in reducing greenhouse gas (GHG) emissions, two key indicators—carbon payback time and mitigation value—are employed across various improvement stages in the two buildings. The carbon payback time represents the duration required to offset the initial embodied carbon while the mitigation value index is derived from the ratio of the carbon reduction achieved by the improvement solution to the total cost of the that solution. This index, expressed as kg CO_2/€, represents the amount of carbon reduced per 1€ invested in the solution.

To determine the carbon reduction amount of various improvement solutions, the initial embodied emission resulting from the production of these solutions is subtracted by the total annual operational emission savings achieved through their implementation. Furthermore, the initial costs of the implemented solutions are referenced from Table 16 and

Table **17**.

Assumptions:

Table 21 presents the EPD data related to various types and thicknesses of insulation materials in both buildings, along with PV panels installed on the S-building. These values are sourced from the EPD-Norge with one exemption, mineral insulation which is sourced from the Norsk prisbok. The following assumptions are consistent for all EPD data:

- The functional unit for all elements is 1 m^2.
- The embodied emissions values are based on the product stage (A1-A3) in accordance with NS 3720.

Table 21. *EPD data related to the improvement's solutions in the two buildings.*

Material description		**Physical properties**	**Impact categories**	**Reference**
Category of resource	Material specification		GWP-total [kg CO2 eq. /m^2]	
Insulation	Mineral wool	120 mm	3.71	Norsk prisbok[36]
		300 mm	9.62	
	EPS	50 mm	3.55	EPD-Norge[41]
	XPS	75 mm	8.32	
		100 mm	11.1	
		150 mm	16.65	
		200 mm	22.2	
PV	Mono-crystalline solar panels	130Wp (Façade)* 400Wp (Roof)	77	
	Mounting system for photovoltaic systems – flat roofs	Baseplates in steel, a connector in steel and aluminium and profiles in aluminium.	42	

*Due to the unavailability of EPD data related to PV-panels with 130 Wp, the value related 400Wp panels is considered for them.

To calculate annual operational emission savings resulted by implementation of these solutions, the CO_2 factors for the electricity and district heating need to be specified first. In this analysis, two different approaches for defining these emissions intensity are considered, presented in

[41] https://www.epd-norge.no/

Table **22**.

Table 22. *Emission intensities for electricity and district heating.*

Reference	Energy type	Emission intensity [$kgCO_2eq/kWh$]	Energy type	Emission intensity [$kgCO_2eq/kWh$]
1[42]	Electricity, (Norway + EU28), 60 years forecasted average	0.13	District heating, Norway, expected average over the next 60 years	0.09
2[43]		0.09		0.15

Results

and Table 23 provide a detailed overview of GHG emissions effectiveness corresponding to the improvement stages considering two distinct criteria of energy emission intensities described earlier. In the context of the S-building's first improvement stage, the carbon payback time for implementing façade insulation ranges from 12.2 to 17.1 years. With the integration of both insulation and PV panels, the carbon payback times extend to higher values, ranging from 12.7 to 18.3 years, depending on the emission intensities considered in the calculation. Despite the high efficiency of PV panels in reducing carbon emissions compared to the initially invested embodied emissions, the necessity of replacing the PV panels and the following embodied emissions results in higher carbon payback time for the second improvement stage.

Considering the H-building, the carbon payback time for the 1st improvement varies from 32.6 to 51.2 years. This considerable variation results from the disparities in the emission intensities of district heating, outlined in

[42] Norconsult AS v/ Tom-André Olsen. Klimagassregnskap Skolebygget Voldsløkka skole. 2019.
[43] Resch E et al., FutureBuilt Zero - A simplified dynamic LCA method with requirements for low carbon emissions from buildings, IOP Conf. Ser.: Earth Environ. Sci. 1078. 2022.

Table **22**, as this energy source constitutes the primary heating consumption in the H-building.

Mitigation values are calculated to reflect the economic profitability of these solutions while considering the carbon-reduction target. For both improvement stages and emission intensity criteria in the S-building, the 2nd improvement results in higher mitigation values — 1.86 and 1.29 kgCO_2eq per unit cost for the 1st and 2nd emission criteria, respectively. This indicates that investing one unit of cost in the 2nd improvement (Insulation + PV panels) can potentially lead to a greater reduction in greenhouse gas emissions per unit cost compared to the 1st improvement. The mitigation values of the 1st improvement stage in the H-building range from 0.68 to 1.07 kgCO_2eq/€ depending on the defined emission intensity.

Table 23. GHG emission effectiveness of different improvement scenarios in both buildings based on the 1st criteria of energy emissions.

Building	Improvement stage	The initial embodied emission +replacement emission ($kgCO_2eq$)	The annual operational emissions savings ($kgCO_2eq$)	Total operational emissions savings [60 years] ($kgCO_2eq$)	Carbon payback time (year)	Mitigation value ($kgCO_2eq$/€)
S-Building	1st improvement	51,414	4,222	253,344	12.2	1.32
	2nd improvement	415,344	32,761	1,965,675	12.7	1.86
H-Building	1st improvement	85,492	1,671	100,245	51.2	0.68

Table 23. GHG emission effectiveness of different improvement scenarios in both buildings based on the 2nd criteria of energy emissions.

Building	Improvement stage	The initial embodied emission +replacement emission ($kgCO_2eq$)	The annual operational emissions savings ($kgCO_2eq$)	Total operational emissions savings [60 years] ($kgCO_2eq$)	Carbon payback time (year)	Mitigation value ($kgCO_2eq$/€)
S-Building	1st improvement	51,414	3,001	180,050	17.1	0.94
	2nd improvement	415,344	22,758	1,365,510	18.3	1.29
H-Building	1st improvement	85,492	2,620	157,194	32.6	1.07

Discussion

Cost effectiveness analysis (CEA) is a practical tool for evaluating one or more specific benefits which can hardly be converted into the monetary values. In this report, the life cycle emissions and energy reduction are two values resulting from implementing the improvement solutions. As there are various discussions around monetizing GHG emissions, CEA allows the project to be evaluated from this aspect.

The obtained results show the importance of the initial embodied emissions of the improvement solutions and the emission intensity of energy sources used in these two buildings. Comparing the effectiveness of insulating and installing PV panels, even though the unit costs of insulation materials are lower than PV panels, the impact of these panels in reducing operational emissions are considerably higher, resulting in higher mitigation values. This also leads to the carbon payback time of not lower but very close to what are resulted from the 1st improvement.

Comparing the carbon payback times to the results of the cost benefit analysis, it is notable that the increased embedded emissions pay off over time, whereas the increased investment costs only pay off under very specific circumstances (low investment costs, high energy prices). A parallel between the two analyses is the fact that the only potentially profitable solution for building S is also the solution with the highest GHG emissions savings per unit cost. This solution is identical with the as-built solution.

Operational emissions play a pivotal role in shaping the overall environmental impact of a building throughout its life cycle. The choice of energy sources employed in a building can significantly influence on its total carbon footprint. In this section, two different references are employed to compare the impact of these values on the effectiveness of proposed improvement solutions. The outcomes highlight that the time required for a building to offset its carbon emissions is closely tied to the emission characteristics of the energy sources in use.

Limitations:

While this study provides insights into the life cycle costing and emissions of the demo project, it is important to address its limitations outlined below:

1. The effectiveness of building components, such as insulation and PV panels, may decrease over time, potentially impacting the energy savings from insulation and the energy generation from PV panels. Notably, this analysis does not account for any degradation rate in the performance of PV panels and insulation.
2. The use of general cost data simulates a decision process as it might take place in an early design stage. It will be revealing to compare this with cost data from the as-built solution, as it will shed light on the robustness of cost considerations in the design process.
3. Electricity produced by PV panels is considered solely for the building self-consumption, with no feed-in tariff for electricity to the grid.
4. According to the EN 15459[44], the discount rate might be different for various types of costs, due to different rates of inflation for energy, human operation, components, etc. However, this analysis employs a similar discount rate of 3% across diverse cost types.
5. In this report the emission intensities of electricity and district heating are based on the average forecasted emissions for Norway + EU28, while relying on the Norwegian energy mix with a significant share of renewable energy could considerably change the effectiveness of the improvement solutions.

Conclusion:

This section explains the life cycle costing and emissions for various energy levels defined in the Oslo demo project. Key insights derived from these assessments include:

- The analysis highlights the influential role of energy prices in determining project profitability. Variations in electricity and district heating prices significantly impact the economic evaluation, as demonstrated in both the S-building and H-building scenarios. In addition, potential strategic increases in energy prices play an important role for achieving project profitability.
- Sensitivity analysis on initial investment costs reveals that, across most scenarios, a decrease, up to 40%, in costs leads to a better BCR but not surpassing 1. However, the second improvement in the S-building, i.e., high insulation standard and a large PV area, could achieve economic profitability with a 10% reduction in initial investment costs.
- The selected 60-year calculation period aligns with LCA requirements but significantly influences project profitability. A shorter period could considerably decrease the NPV of energy-saving costs, emphasizing the need to carefully consider the calculation period.
- Comparing these buildings, the carbon payback times are relatively shorter in the improvement stages of the S-building, emphasizing the importance of lower initial embodied emissions and higher operational emissions savings in this case.

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[44] Standard, E. EN 15459-1:2006 Energy performance of buildings- Economic evaluation procedure for energy systems in buildings. 2006.

- Across improvement stages in the S-building, the integration of PV panels resulted in higher mitigation values than adding insulation, indicating its potential for a greater reduction in greenhouse gas emissions per unit cost.
- The analysis of the H-building shows that adding large amounts of insulation has very long payback times and would be far from being economically profitable. As this scenario would also be detrimental for the architecture of the building and its heritage value, it can be excluded from all points of view.

5.5 SUMMARY

PROCESS

Design process of Voldsløkka

One of the most important decisions taken in the early urban planning process was the decision against privatization as residential development in favour of a public function as a school project. This not only ensured the needed school capacity for the area but made it possible to develop the site as a connector with the adjacent green areas and as a meeting point for the areas' children and youth. Moreover, the school is a pilot project, adding the function of cultural hub to the learning areas of the school. To achieve this, several alternative options for the development were proposed and evaluated. Finally, the site was purchased from the private developer who had proposed the residential development.

The further development of the plan included the decision to demolish two industrial buildings that were on the site which were not regarded as historically valuable. The school and cultural hub development allowed for the preservation of the Heidenreich building with historical value, which had been planned for demolition in the residential development. The preservation in turn triggered tight regulations on the possible alteration of the building. These were addressed in close dialogue with the building preservation authority.

The urban planning process also resulted in the placement of the new school building on the West side of the property to give a new façade to the road and keep connectivity with the park. At the point of this decision, the vision to develop the school as a plus-energy building had not been adopted and was consequently not considered.

The decision-making process in the planning phase involved as main actors the private entity initiating the process (Uelands gate 85 AS (UG85AS)), the Oslo City Planning and Building Agency (PBE), the Oslo City Council for Urban Development (BYU) and the Oslo City Education Agency (UDE). Later in the process, the Oslo City Water and Sewerage Agency (VAV) were involved and Dark Arkitekter AS prepared a feasibility study and a concept selection study.

For the later design development, the main client was the Oslo City Education Agency (UDE). For the guidelines on the renovation of the Heidenreich building, the Oslo City Office for Building Preservation (BYA) was instrumental. Oslobygg led the design phase with Norconsult and Spinn Arktitekter, amongst others, as consultants, and Veidekke as the main contractor.

After the design development phase, instead of the customary process of choosing a contractor who is solely responsible for the construction development and construction, the architect and fire consultant continued into the detailed design phase. This ensured continuation of the design in coordination with the contractor, who was expected to propose multiple solutions to the design team. Solutions were discussed and decisions were taken based on which solution best fitted the design concept.

Alternative designs of Voldsløkka

In the interdisciplinary design studio "Emissions as Design Driver", part of the international master's programme in Sustainable Architecture at NTNU, students were given the task to design alternative solutions for Voldsløkka school. Various alternatives and scenarios are considered, such as a combination of demolition and new building(s), reuse of materials from on-site or elsewhere, and / or adaptive reuse and supplementary buildings. LCA calculations accompanied the design process, and the results supported decision making. The main design task required an identical program to the school as it is built today. However, the students were challenged to retain as much as possible of the existing buildings and were allowed to work more extensively on the Heidenreich building than permitted in the real process. The students' design project was to specifically focus on the following two priorities:

- Reduction of embedded greenhouse gas emissions over the life cycle of the school
- Use of existing buildings or building materials

Three projects are presented in this report: *Voldsløkka 80³, OmBrick,* and *Filling the Void*. All the three projects aimed at reusing the existing building A and parts of building C and adapt their structures for the new educational and cultural activities. An extensive life cycle assessment was performed on these projects in different stages, from early design to the final projects. Additionally, material flows resulting from the project were visualized. By partially reusing the structure of the A and C buildings and using low-emission and secondary materials, the proposed projects achieved at least 80% lower GHG emissions than set in the benchmark. In this emissions-guided design process, the teams developed high quality design, addressing all the space requirements sets for school and cultural programs.

Energy, cost, and GHG emissions of early design scenarios

In synergy with the activities of WP8, a set of scenarios of different energy targets for the S-building and the H-building were developed. The scenarios considered the variation of insulation level and air tightness of these two buildings to define energy targets that span from a TEK17 construction to a plus-energy building for the S-building (as-built of the S-building), and from an energy class-B (as-built of the H-building) up to a TEK17 construction for the H-building. The variation of the insulation value of the buildings envelopes shows minimal differences of delivered energy. These are up to 10% less for the S-building and 13% for the H-building. This is because the starting point for the S-building (TEK17) is already a quite well insulated construction, whereas the extent of the possible intervention in the H-building is limited by the old construction and its status as protected building. The addition of the PV system to the S-building determines a much higher reduction of delivered energy (75% less than the TEK17).

A life cycle cost analysis was carried out by calculating the Net Present Value (NPV) of the above-mentioned scenarios. The results show that for the S-building, the simple payback period for the first improvement of the S-building spans from 58 to 80 years, and for the second improvement from 25 to 34 years, depending on different criteria for energy prices. The calculation of the NPV shows that both the 1st and 2nd improvements do not give positive results, meaning the calculated design scenarios are not profitable. Specifically for the 1st improvement, the high investment cost is not compensated by the low energy price, whereas for the 2nd improvement, the high cost for maintenance and replacement of the PV system does not pay back the initial investment. For the H-building, the simple payback period varies from 60 to 87 years, depending on different criteria for energy prices. On the other hand, the calculation of the NPV does not produce positive results, due to the high investment costs and the low energy price.

The calculation of the payback time of the embodied carbon emissions in the two buildings gives the following results. The carbon pay-back time of the S-building's 1st improvement stage ranges from 12.2 to 17.1 years, whereas for the 2nd improvement it ranges from 12.7 to 18.3 years, depending on the emission intensities considered in the calculation. Despite the high efficiency of PV panels in reducing carbon emissions compared to the initially invested embodied emissions, the necessity of replacing the PV panels and the following embodied emissions results in higher carbon payback time for the second improvement stage. Considering the H-building, the carbon payback time for the 1st improvement varies from 32.6 to 51.2 years. This considerable variation results from the disparities in the emission intensities of district heating, which constitutes the primary heating consumption in the H-building.

The comparison between the carbon payback times and the NPV shows that increased embodied emissions pay off over time, whereas the increased investment costs only pay off under very specific circumstances (low investment costs, high energy prices).

ARCHITECTURAL QUALITIES

Goals

The project specifications from the Regulatory Plan aim at developing a sustainable local community. Areas of prioritization contain environmental criteria (reduction of noise, air pollution and GHG emissions), concrete development prescriptions (preservation and strengthening blue-green-structures), as well as qualitative goals (sustainable urban environment, environmentally friendly urban spaces). Amongst the measures, prioritizing architectural heritage plays an important role. The latter directly led to the preservation of the Heidenreich building. Because of its historic value, the building was kept and could only be transformed on the inside while maintaining the appearance of the building (scale, shape, detailing, use of materials and colours). For the new building, dimensioning considered a flexible floor plan layout. Two variants for a multi-purpose hall were considered in the Regulatory Plan (underground and integrated), but for its high cost and unpractical use in the school building (as mentioned by the Sagene Sports Association[45]), it was decided to plan the construction of a new separate sports hall in the nearby plot[46]. The design of the outdoor spaces uses an innovative open surface water solution. Goals for these areas included an integration with the existing natural environment to achieve a green feeling as well as making the area fit for increased rainfall by using natural and permeable surfaces. The rainwater management influenced the placement of the new building, as the distance from the street is to allow enough space for local water surface management. However, the Blue-Green factor was allowed to be lower than stipulated for residential projects, as the surface area is expected to be intensely used.

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[45] Uelands gate 85, Voldsløkka, bydel Sagene Planforslag til politisk behandling Detaljregulering, Saksnummer 201214524. https://innsyn.pbe.oslo.kommune.no/saksinnsyn/casedet.asp?caseno=201312704
[46] https://innsyn.pbe.oslo.kommune.no/saksinnsyn/showregbest.asp?planid=201214524

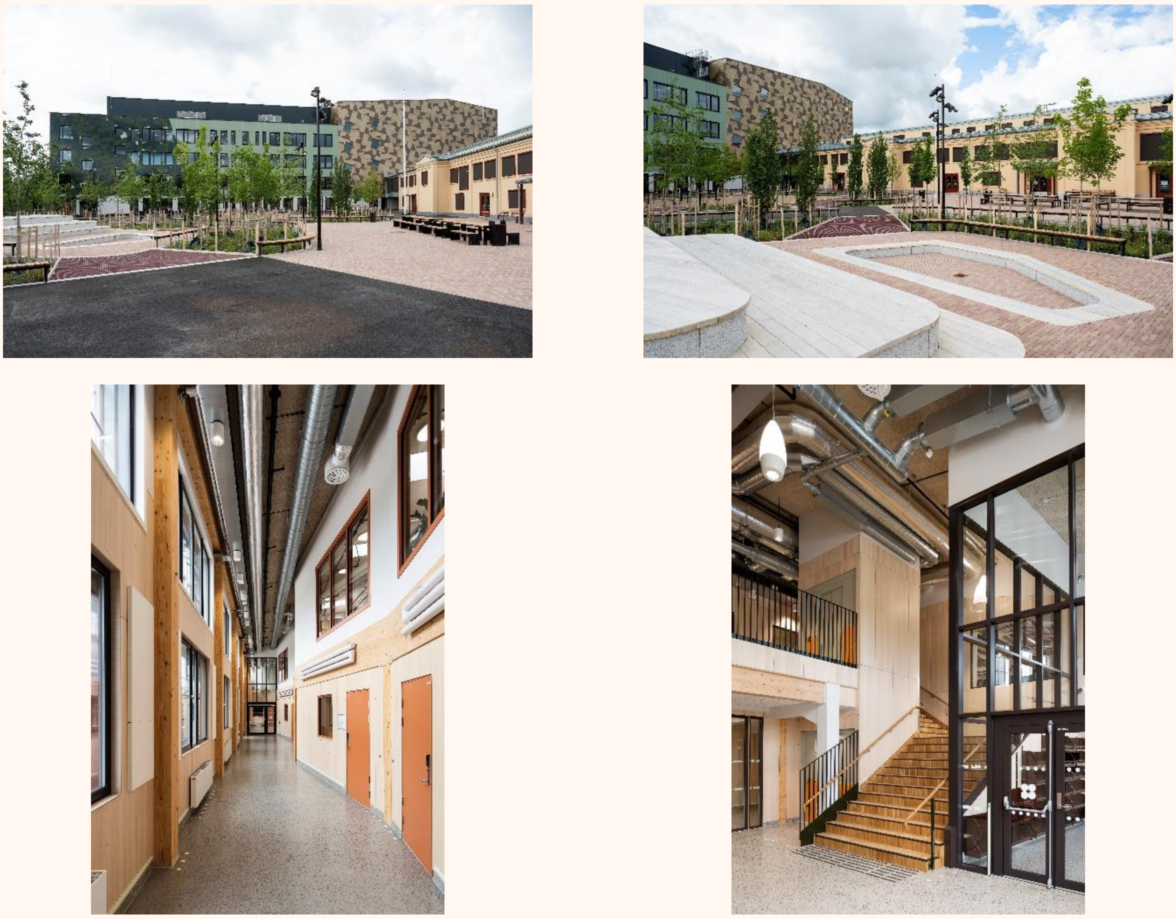

Figure 82. *From top, clockwise: view of the schoolyard and of the S-building (on the left in photo) and H-building (on the right in photo), view of one of the islands in the schoolyard, view of the North foyer to the S-building, view of the North corridor in the H-building. Photos by Finn Ståle Felberg/Oslobygg KF.*

Programming and general appearance

The school has a multi-use concept, with spaces made available for cultural activities within and outside of school hours. This required for the spaces with more than educational use to be located close to each other with a flexible closing system that gives access to different user groups. The users were engaged in a user participation process to locate the different functions (school only, cultural only, both). Teaching areas are configured such that a flexible use of the spaces is possible with varying sizes of student groups. The bridge that connects both buildings is housing the kitchen for the adjacent school canteen that serves as a meeting point for the users of both buildings. The facade appearance of the new building (S-building) was strongly influenced by two factors. On the one hand, the Regulatory Plan specifies high aesthetic quality and a limited selection of materials, as well as transparency for the bridge between the S-building and the H-building. On the other hand, due to the plus-energy goal, the exterior wall had to be well insulated to low-energy building standard and PV production had to be located on the facade at the same time. In addition to these requirements, easy maintenance was considered in the façade design. These factors resulted in a timber frame curtain wall system, with a glass and PV cladding that can be replaced without damaging the exterior walls. The integrated PV system design uses novel, angular and coloured modules with high degree of standardized module sizes and fastening solutions, significantly reducing the time and costs of applying such a system.

For the historic building, the guiding principle was to safeguard the building's exterior appearance originating from 1935. Therefore, the building had to be insulated from the inside and the clear height under the roof was lowered to keep the original exterior height. Windows were replaced by new windows mimicking the original windows. On the interior, historic elements of the structure and installations were refurbished and reused.

The design of the outdoor spaces takes its starting point from the storm water management concept and aims to connect the schoolyard with the surrounding Voldsløkka area. This integrated design concept emphasizes the potential of vegetation and open surface water handling to create attractive outdoor spaces. This is achieved by introducing "green islands" and combining them with edge zones and circulation zones. All green areas were planted with native vegetation, with a focus on the potential benefits on local climate i.e., reduction of the heat island effect and the abatement of pollutants.

Process and ambitions

According to the architects[47], there are similarities to a regular school design process. Oslobygg have been responsible for building Oslo's schools for many years and have established standards that every school building has to fulfil. The requirement to connect to and integrate existing or historical buildings is quite common in school projects. What distinguishes Voldsløkka skole is the integration of the cultural school, as the program and activities are less set and often react to existing building structures they are housed in. KulturEtaten was involved in defining the program and anticipated activities and the predicted number of students. Additionally, the plus-energy goal was set for the first time, such that the architects worked within the framework of a tightly sealed and insulated building envelope and the ambition to integrate a large PV area. In this sense, Voldsløkka is a pioneer project, data from which will be used for future school projects.

Detailed solutions

The façade design exemplifies the necessity to synthesize between requirements of a plus-energy building and the desire for a non-uniform colourful façade. Additionally, the building's orientation follows the urban design, enabling a larger green area towards Voldsløkka park, but offering larger East and West facades for PV production, which receive less insolation than a South façade. The design team's answer to these requirements is a multi-layered system which treats the cladding, PV panels, windows and insulated wall parts as technically independent units. For these units, the number of variations is limited, but design variation originates in the combination and overlapping of the layers. The design strategy focuses on panel-to-panel and panel-to building-surface connections for easy installation and replacement of components. These can be easily replicated and varied for other buildings and contexts. For the refurbished building, an interior insulation system was installed, while the roof was replaced keeping its original appearance. The focus was to strike a balance between safeguarding the integrity of the historic building while making it as energy efficient as possible within the constraints.

SOCIAL QUALITIES

The school will serve as a HUB for involvement, engagement, and teaching pupils about energy transition technologies and sustainability. The building will include a demo-space for citizens' and children's education with a focus on new technologies like storage, electrical vehicles, renewables, etc. This will house and promote activities such as green ambassadors and influencers promoting energy efficient behaviour and circular solutions to their peers. Participatory methods where play, engage, inform, and educating young people and through them also their parents, are envisioned here. The

[47] interview with Erik Brett Jacobsen, Kontur Arkitekter AS, in Oslo on 30.10.2023

decision to use the plot for a school rather than privatizing it contributes to the social qualities, especially because pupils will come from two neighbourhoods with differing demographics and social backgrounds. In the design process, user participation was engaged in design development, when the distribution of functions was developed.

ENVIRONMENTAL SUSTAINABILITY

The environmental goals of Voldsløkka school are ambitions: The school is to be the first plus-energy school with a 50% reduction in GHG emissions compared to a regular school. This decision was made in the concept phase of the building and pursued throughout the design and construction process. Additionally, the project features an emissions-free construction site. The project adheres to the 2014 definition of plus-energy buildings that allows to disregard the electricity use from technical equipment in the accounting of energy use. Per the 2018 definition, the school might not be plus energy, but with user engagement and awareness it is to be seen if the monitoring might show a different picture.

The design process dealt with a trade-off between spatial (orientation) and aesthetic (no office-building-look) requirements and the goal of a plus-energy building, requiring a well-insulated building with large areas for electricity production. The compact design of the school building in combination with the façade system that was especially developed for this school answers to these requirements with an architecturally ambitious solution.

To achieve the envisioned reduction in GHG emissions for the new building, the use of "low carbon class A" concrete played an important role. This was combined with circular material strategies, with 100% recycled reinforcement in concrete structures and a large amount of recycled steel in the beams. Additionally, the use of wood helped to reduce GHG emissions, because large part of the load bearing structure as well as all the exterior and interior walls were built with wooden materials. The roof is a lightweight structure of solid timber, which reduces the material use and the load on the building.
In the historic building, circular renovation strategies were employed, where most of the walls and windows were reused and upgraded to new energy performance standards. The emissions from this have not been calculated and will be subject of the next report.

6. INNOVATIONS IN THE VOLDSLØKKA DEMO

A brief description of the innovations for the design phase of the Voldsløkka demo is presented in this chapter. Four innovations are identified on the different levels of the general progress of the development, ranging from the planning and design to the demonstration level. In the first year of the project implementation, several target groups were recognized as the final beneficiaries: architects, developers, city planners, consultants, and material producers.

(1) Climate adapted design using an innovative open surface water solution. The concept is a green and different schoolyard where vegetation and surface water management are used as a resource to create good and varied outdoor spaces. The design of the outdoor green area will ensure the use of vegetation to optimize water management and, at the same time, create a varied and appealing outdoor environment. Pollutant-absorbing plants have been proposed. This innovation is in the experimental phase.

(2) Effective application of low-carbon concrete with 40% lower embodied emissions than standard. This innovation is in the demonstration phase (Technological Readiness Level, TRL, 9).

(3) Digital design for optimum life cycle performance. BIM and AR technology are used to evaluate the performance of the building development from the environmental, architectural, and economic perspectives. The evaluation of the buildings and infrastructure is made by considering their life cycle environmental impact, cost, and energy use, the inclusivity of the local community, the use of indoor and outdoor space, water management, noise and pollution, and aesthetic. This innovation is in the experimental phase.

(4) Circular renovation design strategies are developed by mapping of locally available building materials and components from existing and going-to-be demolished buildings. Most of the walls and windows in the old factory will be reused and upgraded to new energy performance standards to save embodied GHG emissions from building material use. This is part of the energy renovation design of cultural heritage building using a circular renovation strategy. This innovation is in the design phase.

An overview of the identified innovation types, their expected impacts call categories (EIC), and technological readiness levels for these innovations is given in

Table **24**.

Table 24. ARV innovations for Norwegian DEMO linked with the design phase.

Innovation title	**(1) Climate adapted design using an innovative open surface water solution**	**(2) Effective application of low-carbon concrete**	**(3) Digital design for optimum life cycle performance**	**(4) Circular renovation design strategies**
Innovation Type	Product / Technical Solution, Guideline / Instruction	Product / Technical Solution	Product / Technical Solution, Method/System	Product / Technical Solution, Process, Method, Guideline / Instruction
Progress Phase	Testing / experimental	Demonstration	Testing / experimental	Design and development
Expected TRL	9	9	8	8
Expected Impacts	**C**ircular **E**conomy and **R**esiliency, **S**ocial-environmental qualities, **K**nowledge creation	**C**ircular **E**conomy and **R**esiliency	**C**ircular Economy and Resiliency, **S**ocial-environmental qualities, **E**nergy flexibility and security of supply, **K**nowledge creation **S**martness	**C**ircular Economy and Resiliency, **S**ocial-environmental qualities, **E**nergy flexibility and security of supply, **K**nowledge creation
Target groups	Architects Consultants City planners	Contractors, Consultants, Material producers	Architects Consultants City planners	Architects, City planners, Entrepreneurs, Developers

7. BEST DESIGN PRACTICES AND CHALLENGES

CONSIDERATIONS ON THE PRIVATE/PUBLIC PLANNING INITIATIVES

The regulatory process that preceded the design development of the Voldsløkka project was originally initiated by a private actor, Uelands gate 85 AS (UG85AS), which was the company owning the plot of land in Voldsløkka. UG85AS proposed a Regulatory Plan for housing development, thus following its natural interest for commercial development for this area. As pointed out by Nordhal[48], the critical difference between the private and public planning proposals lies in the interests that drive the development process. For private actors, the interest of commencing a planning proposal is not based on the future land use of the area but mostly on being able to commence a private housing or commercial development. Moreover, the type of development is further influenced by market demand and cost assessment. On the other hand, publicly commenced planning initiatives are often driven by local population growth and needs for housing or public services.

According to Holsen[49], the planning system is built on two assumptions. The first deals with the public task to define and establish the planning activity and the second with the municipal task to overview the planning development. There are no restrictions on which actors have the right to participate in the planning process, since its aim is to present the plan that is best for the community. The municipality, as the central actor, is responsible for coordinating the process with the overall plans and to ensure the population has the right to participate and give opinions. Holsen highlights that the privately driven planning process deviates from the ideal process described in the Planning and Building Act. This is because a private actor does not have to abide to any formal obligations, such as the involvement of the municipality, until a regulatory proposal is advanced. This results in a difference perception of the steps that lead from the regulatory phase to the design development. From a private developer perspective, planning, designing, and building processes are experienced as one process, while the Planning and Building Act describes the planning and building process in two different sequential steps. This difference is reflected in the way the planning process is structured. The Planning and the Building Act illustrates an ideally vertical structure, with the municipality as the main driver, whereas today's reality with private initiators reflect a horizontal structure, with the private actor in central position. Since the municipality is no longer the driving actor, the degree of participation from the population is limited by the interest of the private actor to involve only those parties considered necessary.

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48 Berit Nordahl. Private development initiatives and the public planning authority - some reflections on collaboration and power relations. FUS, Tromsø 18.-19. June 2001.

49 Terje Holsen. Negotiations Between Developers and Planning Authorities in Urban Development Projects. disP - The Planning Review. 2020.

CHALLENGES IN THE H-BUILDING

The regulations for the protected historical buildings set by the Office for Buildings Preservation (BYA) are rather strict. Facades of protected buildings cannot generally be changed since their appearance is worth being preserved. Most of the significant changes in the H-building could be implemented in the indoor spaces, where most of the existing non-load bearing structures were demolished to make the space for the new cultural functions.

The limitations imposed to the façades made it impossible to use external insulation, thus limiting the energy performance of the building. The H-building was energy retrofitted to reach an energy class B by adding internal insulation, retrofitting the existing windows and installing new ones, and installing a new roof. PV panels were not allowed to be installed on either the south façade or the roof.

Figure 62. *Photo of the exposed façade (right in the picture) and cultural spaces (left in the picture) in the north side of the H-building. Photo by Nicola Lolli (SINTEF).*

Despite the new indoor layout, some parts of the original concrete and wood structural elements were maintained. These elements were typical of the time when the building was built and showed its history as cement factory. The construction team from the contractor (Veidekke) was very helpful in identifying small details of the H-building construction (corner stones, inscriptions in some of the façade stones, traces of old openings that were closed, etc) that were then highlighted in the renovation process. The design team, therefore, chose to design large indoor spaces which can allocate different functions while maintaining the historical testimony of the building. It was challenging to incorporate the new programme in the H-building as the space layout had to consider the preservation of the original structural elements and the roof height. The roof height could not be changed because this would have changed the façade's appearance. This restriction made it complicated to fit the technical services in the building at a minimum free height from the mezzanine floor, as shown in the technical section.

CHALLENGES FOR ACHIEVING A PLUS-ENERGY TARGET

Three main challenges were faced by OBF and the design team to achieve a plus-energy building for the Voldsløkka project. These are described below.

Limitations given by the Regulatory Plan

The Regulatory Plan was quite detailed with regard to the location of the new school and its overall appearance. Most of all, the defined north-south alignment of the school, along Uelandsgate, that was made to ensure a continuous line of sight between the southern and northern parts of the Voldsløkka park, was a sub-optimal orientation with regard to the electricity production from façade-installed PV panels. At the time of the regulatory process, the plus-energy goal was not discussed nor decided for the project. The reasoning behind the decisions in the Regulatory Plan were mainly done to limit the visual impact of the new building, to define a new street front on Uelandsgate, and to shield the school courtyard from the road traffic. When the plus-energy goal was decided by OBF for the school building, the design team had to deal with a small south-facing façade and two long east- and west- facing façades, which is not the best condition for façade-installed PVs to maximise their electricity production. The design work on the PV façade started between the end of 2018 and the beginning of 2019. The building construction started in 2021, when the market-available PV technologies had already advanced in terms of performance and efficiency. Thus, the design of the PV system was based was not based on the most up-to-date technologies, and this had a strong impact on the overall design of the PV system. In addition, it was required that the appearance of the school facades should not be that of large monotonous surfaces. The choice of the coloured palette for the PV modules and their rotated installation were solutions found to make the facades more dynamic and appealing, but had limitations with respect to the efficiency of the PV energy production.

FutureBuilt definition of plus-energy buildings

At the beginning of the preliminary project (described in Chapter 5.1), OBF and the design team decided to make the Voldsløkka project a pilot for the first plus-energy school in Norway. Therefore, they relied on the plus-energy definition given by FutureBuilt[50] in 2014:

> *"Energy use related to the operation of the building must be at least compensated over the year through the production of renewable energy. To be considered a plus house, surplus energy of 2 kWh/m^2 BRA per year must be produced [...]. For buildings over 4 storeys, it can therefore be permitted to deduct energy use for technical equipment, i.e., that the building must be considered as plus energy including the energy items heating, hot water, fans, pumps, lighting and cooling."*[51]

The definition of plus-energy building was thereafter updated in a new issue by FutureBuilt in 2018 by removing the above-mentioned exception for taller buildings.

> *"For some building categories, especially for hospitals and nursing homes, but also for multi-storey (over 3-4 floors) hotel buildings and commercial buildings, it will be very demanding or impossible to achieve plus house level with current technology and with standardized usage times and internal loads. For these building types, it may therefore be appropriate to use a lower level of ambition than FutureBuilt plus houses, e.g., something that lies between FutureBuilt nZEB and plus-energy building."*[52]

However, at the time of the updated definition, the preliminary design was already well ahead, including the design of the technical installations that would have made it a plus-energy building according to the initial FutureBuilt definition. OBF and the design team worked on possible alternative designs and solutions to evaluate the possibility of having the school building complying with the newly issued definition, but none of the alternatives produced satisfactory results with this regard. OBF and the design team therefore decided to keep the original design in compliance with the first FutureBuilt definition. As mentioned above, the plus-energy definition applies to the new school building and not to

[50] https://www.futurebuilt.no/English
[51] https://www.futurebuilt.no/content/download/5861/55365
[52] https://www.futurebuilt.no/content/download/28126/157914

the renovated H-building. This is because the restrictions given by BYA on the building renovation did not allow for more energy-efficient solutions regarding wall insulations and installations of PV on the roof.

Ventilation requirements from the SKOK (standard requirement specification by Oslo Municipality)

The ventilation requirement given in the TEK17 standard requires a minimum of 23 m^3 of fresh air per person per hour[53]. Considering the number of students and employees in the school, this amounts to about 13 m^3/h per m^2 of floor area. To reduce the energy losses from the ventilation system, a demand-controlled system was installed, which provides 7.2 m^3/h of fresh air per m^2 of floor area when the rooms are occupied, and 3.0 m^3/h per m^2 when the rooms are not occupied. A demand-controlled system ensures that as soon the CO_2 concentration increases in the room, the amount of ventilation air flow and fresh air intake increase to deliver sufficient fresh air for the occupants. Moreover, OBF and the design team, in agreement with UDE, decided to make use of more efficient rotary heat exchangers than those recommended in the SKOK. The SKOK advises to use fixed-plate heat exchangers and to limit the use of rotary heat exchangers. This is to avoid the possible occurrence of extract air to recirculate in the intake and enter the rooms. However, the amount of extract air was calculated to be a maximum of 2.4% of the total fresh air intake. Since the amount was expected to be so small, UDE agreed on the use of rotary exchangers to allow its testing in this pilot building, for evaluating the feasibility of a large-scale implementation in future plus-energy school buildings.

Connection to the local district heating system

The Voldsløkka project is within the concession area of the local district heating system. This requires an obligation to establish the needed infrastructure for connection between new buildings and district heating network. According to the FutureBuilt definition of plus-energy buildings, the credit of renewable energy use from district heating to the delivered energy is given by multiplying the delivered energy by 0.43[54]. On the other hand, the energy saving given by using a ground source heat pump (GSHP) is in the range of 0.22 of delivered energy use, by assuming an GSHP performance factor of 4.5. The difference between 0.43 and 0.22 represent additional energy savings given by installing a GSHP instead of connecting to the district heating. Therefore, OBF and the design teams decided to have the energy and heating need of the school building covered by the GSHP. The GSHP covers between 80% and 95% of the heating load throughout the year, whereas the remaining 5%-20% is covered by the district heating during the coldest days of the year. For the H-building, it was decided to cover the heating demand by district heating only, as the use of a GSHP was not considered to be cost-effective.

CHALLENGES FOR DESIGN AND DEVELOPMENT OF THE SCHOOL YARD

As described in Chapter 5.1, the school yard was designed in such a way that the areas for vegetation and floor surfaces can be concurrently used for on-site storm water management and for outdoor school activities. The landscape architects (Østengen og Bergo AS) faced the challenge of ensuring enough space for the school outdoor activities (playgrounds, meeting places, passageways, sport fields), for the cultural activities (stages and arenas), and for the school logistic and management (safe meeting points, and access to rescue, medical, and logistic services). Such requirements were given by the Oslo City Planning and Building Agency in the documentation for school areas. This gave little space for green

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[53] https://dibk.no/regelverk/byggteknisk-forskrift-tek17/13/i/13-3/
[54] https://www.futurebuilt.no/content/download/5861/55365

surfaces and surfaces suitable for storm-water retention. The concept was therefore developed by looking at how to connect and integrate the schoolyard in the surrounding parks. This was done by investigating the viewpoints from the schoolyard towards the park, the passageways that led from the parks to the schoolyard and through it, and which sport activities were complementary to the activities already available in the surrounding parks. This investigation determined the main entrances to the S-building and H-building and the consequential division of the schoolyard in areas to be dedicated to the above-described functions (storm water management, playgrounds, passageways, safe meeting points, and so on). To make sure all the required areas could be fitted in the small footprint of the schoolyard, the landscape architects developed the design by layering the different activities on the same area. In such a way, the floor surfaces for the storm water management were layered below the areas for meeting points and passageways, next to the playgrounds. The layering concept was developed by placing the surfaces for water retentions (green areas in the islands) and of those for rainwater run-off (the channels leading to the islands and around them) below metal grating.

Such an innovative design led to a more complex management and maintenance of the green and blue areas in the schoolyard. Typical schoolyards are designed to have green areas placed on the border of large hard-surfaced areas suitable for outdoor school activities. This ensures that cleaning and maintenance of such hard-surfaced areas is easy and not costly (by, for example, making an easing cleaning from the build-up of leaves and fallen twigs). By integrating green and blue areas in the middle of the schoolyard, a more time-consuming maintenance is required to make sure that the plants thrive, and the water run-off is not obstructed. This solution necessarily leads to a higher maintenance cost than what is needed for typical schoolyards, and most of all, needs additional expertise for the work to be properly carried out. In such a perspective, knowledge transfer and formation of the groundskeepers on how to properly maintain the schoolyard is needed before and during the operation phase of the building. In addition, education of school children on how to use the outdoor space is needed to make sure they know which are the dos and don'ts (for example, not trampling the growing plants), and this necessarily requires the involvement of the teaching staff.

The implementation of the landscape design was challenging for the construction company, because of the innovative solutions, which were not known to the company employees. This led to misunderstanding on how some solutions should have been developed and implemented. In such a perspective, the landscape architects suggested that a better communication with the construction company and a deeper involvement in the construction process would have made the implementation phase smoother. The definition of such an integrated collaboration should be set in the procurement contract, to make sure that all the parties involved are aware of their mutual roles and responsibilities.

DESIGNING WITH EXISTING BUILDINGS

The alternative designs for the school show that the highest embedded emissions savings can be achieved when on-site materials and buildings are used. However, the students' projects did not take into account the emissions for energy in use. It is very likely that the energy demand target would have to be adjusted even for a non-listed building, if it was renovated. A full account of embedded emissions in comparison with operational emissions of the alternative designs was out of the scope of the students work. Since the area covered with photovoltaic panels is already fully used in the actual project, it is uncertain if the plus-energy target would have been achieved when reusing the existing building. A life cycle based zero emissions target, on the other hand, that takes embedded emissions into account, would have been a possibility. The student teams unanimously said that the process was challenging, but the existing buildings added a quality to the final projects that was not achievable without keeping the buildings.

EMISSIONS-GUIDED DESIGN PROCESS

Emissions savings are considered mainly from two perspectives: Comparing alternative solutions in the concept stage and evaluating material choices during the design process. The alternative designs show that the inclusion of the existing building offered high savings opportunities in embedded emissions and material use. To feed this process with concrete numbers on the actual emissions saved, is subject to uncertainties, both concerning the existing buildings and the quality and properties of the materials contained in them, as well as the comparable alternative designs. Multiple factors other than emissions need to be considered, such as costs, flexibility of spaces, accessibility, appearance etc.

The alternative design process also showed high savings potential from material choices. This is a parallel to the as-built project, where materials were carefully selected to keep emissions at a minimum, e.g., the extensive use of wood and the use of low-emission concrete.

8. FUTURE UPDATES

The next edition of this report will include more details, lessons learned and experiences from the constructed project and analysis of the design of the new sports hall to be built next to the Voldsløkka project.

The life cycle cost and emissions analysis for buildings S and H will be supplemented with actual data from the completed project. This will provide information on how robust results from LCA and LCC can be used in decision making during the design process.

A further evaluation of the architectural qualities of Voldsløkka school will be conducted involving the users and living lab participants.

The preliminary design of the sports hall is currently being developed, and SINTEF, NTNU will be collaborating with OBF on the energy and environmental aspects of this project, in synergy with the activities in Task 6.2. The design phase is expected to take place for the whole of 2024 and part of 2025. The construction phase is expected to take place from the summer 2025.The building is planned to reach at least an NZEB level (and possibly a plus-energy level) equipped with a large photovoltaic system (for a total annual electricity production of at least 220 000 kWh), a ground-source heat pump, an efficient ventilation system and heat recovery, a grey water heat recovery, and a highly insulated building envelope. Oslobygg has set high standards for reducing the embodied environmental impact of the sports hall, by setting specific requirements for virgin and reused materials. These requirements and other aspects will be addressed in the upcoming activities.

Moreover, in synergy with the activities in WP3, the architectural quality of the Voldsløkka project will be investigated through a set of interviews with the local community, to have an overview of how the aesthetic and architectural quality of the project is perceived. This activity is carried out following the debated that the development of the Voldsløkka project generated in the community of Norwegian architects. It is therefore interesting to investigate the opinion of those non-experts that will use either the school or the cultural buildings.

APPENDIX A - FUNCTION AND ROLES OF THE DIFFERENT STAKEHOLDERS INVOLVED IN THE REGULATORY PROCESS OF VOLDSLØKKA

***Landowner** and promoter of the first regulatory process*

Uelands gate 85 AS (UG85AS): Company owner of the plot of land in Voldsløkka and proponent for a regulatory process for housing development.

***Administrative authorities involved in the** regulatory process*

Oslo City Planning and Building Agency (PBE): The Planning and Building Agency is responsible for the municipality's overall spatial planning, planning and building case processing, map management, and map and division business. PBE Led the regulatory process for Voldsløkka, and it was the reference authority for UG85AS.

Oslo City Council for Urban Development (BYU): the city council leads the Oslo Municipality's administration, and it is responsible for implementing the political decisions made in the city council. The city council and the individual city council members implement such decisions via the subordinated Agencies. Under the BYU the following Agencies are placed: Oslo City Property and Urban Renewal Agency (EBE), Oslo City Planning and Building Agency (PBE), Oslo City Office for Building Preservation (BYA). Gave directive/inputs to PBE regarding the development of the Voldsløkka area and the regulatory process.

Oslo City Education Agency (UDE): the Agency is responsible for the operation, development, follow-up and guidance of educational activities within the laws, frameworks and guidelines laid down by national and municipal authorities. UDE was involved by PBE in meetings and workshops to give inputs on the two alternative designs in Voldsløkka.

Oslo City Urban Environment Agency (BYM): the Agency is responsible for the management of common areas such as streets, squares, parks, open spaces, sports facilities, fields and the inner Oslo fjord. BYM is also responsible for monitoring the air, water and soil quality, and noise level withing the recommended values. BYM was involved by PBE in meetings and workshops to give inputs on the tow alternative designs in Voldsløkka.

Oslo City Water and Sewerage Agency (VAV): the Agency supplies Oslo's population with drinking water and handles the wastewater. The Agency is responsible for the operation, maintenance, and renewal of the city's treatment plants, pipelines and pumping stations for both drinking water and wastewater. Other important tasks are management of water source areas, supervision of the waterways in the city, guidance and information to customers. VAV was involved in meetings and workshops by PBE to give inputs on the two alternative designs in Voldsløkka.

Oslobygg KF (OBF): Oslobygg KF is Oslo municipality's real estate company. OBF owns, develops, builds public buildings in Oslo (such as kindergartens, schools, care homes, nursing homes, cultural buildings, sports facilities, fire stations and national facilities), and it is responsible for their management throughout their life span. Oslobygg KF is under the Oslo City Council for Industry and Ownership. OBF was not directly involved in the regulatory process but mentioned as the developer of the area.

External consultants

Dark Arkitekter AS (DAAS): Architect office hired by UG85AS for the Regulatory Plan development. DAAS was involved by PBE in meetings and workshops to receive inputs and propose alternatives on the residential development design in Voldsløkka.

Asplan Viak AS (ASVAS): consulting company hired by PBE for evaluating the traffic noise levels and storm water management in the two Regulatory Plan proposals.

COWI AS (COAS): consulting company hired by PBE for carrying out geotechnical analyses of the area ground stability, and damage assessment to the Heidenreich building in the residential development alternative.

External actors that submitted remarks to the two alternative development designs during the public review of the Regulatory Plan of Voldsløkka

Administrative authorities

Sagene city district (BYSA): one of the 15 administrative districts of Oslo City.

Nordre Aker city district (BYNA): one of the 15 administrative districts of Oslo City.

Oslo City Property and Urban Renewal Agency (EBY): the Agency is the Oslo Municipality's landowner and promoter of the development of the city. The Agency's activities are as such:

- To develop areas for the construction of housing, industry and other public purposes
- To enter into development agreements and coordinate urban development projects
- To clean up contaminated land and carry out various environmental measures
- To buy and sell property
- To manage and rent properties

Oslo City Fire and Rescue Service (BRE): the Service works to ensure fire safety and fire prevention throughout Oslo city. It provides an emergency response systems to handle large-scale fires and accidents.

Oslo City Renovation and Recycling Agency (REG): the Agency is responsible for collecting and managing household waste in Oslo. The waste is sorted out and sent to the different waste processing facilities (biogas processing for food waste, plastic recycling, burning for energy recovery). REG is under The City Council's Department for the Environment and Transport.

Oslo City Office for Building Preservation (BYA): Byantikvaren is Oslo municipality's professional advisor in all matters relating to the preservation of architecturally and culturally-historically valuable buildings, facilities and environments and archaeological cultural monuments.

Oslo City Education Agency (UDE)

Oslo City Urban Environment Agency (BYM)

Oslo City Water and Sewerage Agency (VAV)

County Governor of Oslo and Akershus (FMOA): The County Governor is the chief representative of King and Government in the county, and works for the implementation of Storting (Parliament) and central government decisions. The County Governor explains central policy documents in the local context, being aware of each municipality's ability to provide. Experts from the County Governor 's office supervise local activities, advise and instruct – with due respect to the political judgement of the local government. The County Governor may look into local decisions regarding the rights of any individual in the fields of health and social care, education, building and planning, and may change the decision to the benefit of the individual. Other important fields of action are environment protection, agriculture, emergency planning, local government finances and family matters.

Norwegian Water Resources and Energy Directorate (NVE): NVE is a directorate under the Ministry of Petroleum and Energy and is responsible for the management of Norway's water and energy resources. NVE works to reduce the risk of damages associated with landslides and flooding. The directorate aims to ensure an integrated and environmentally sound management of the country's water systems, promote efficient energy markets and cost-effective energy systems, and contribute to efficient energy use. NVE bears the overall responsibility for maintaining national power supplies.

Public associations

The Nature Conservation Association in Oslo and Akershus (NOA): is a democratic member organisation which works for protecting the nature and the environment in its region. NOA contributes to develop solutions that safeguard nature, through spreading knowledge about nature and contributing to the enjoyment of nature by the residents of Oslo and Akershus.

Oslo Sports Circle (OIK): OIK is an organizational link in the Norwegian Sports Confederation and Olympic and Paralympic Committee (NIF) and organizes all sports teams in Oslo.

Skeid (SK): Skeid is a Norwegian football club from Oslo.

Sagene Sport Association (SAIF): SAIF is the sport association of Sagene District.

Oslo and Akershus Corporate Sports Associations (OBIK): OBIK is a member of Norwegian Sports Confederation, and it provides companies and families with a social arena where to get involved into physical activities.

Private companies

Ruter AS (RAS): plans, coordinates, and orders public transport in Oslo and former Akershus (now part of Viken county). All transport services are performed by various operating companies on behalf of Ruter AS.

Hafslund Nett AS (HNAS): energy provider company.

Others

Private citizens

FUNCTION AND ROLES OF THE DIFFERENT STAKEHOLDERS INVOLVED IN THE DESIGN PHASE OF VOLDSLØKKA

Project developer

Oslobygg KF (OBF): Oslobygg KF is Oslo municipality's real estate company. OBF owns, develops, builds public buildings in Oslo (such as kindergartens, schools, care homes, nursing homes, cultural buildings, sports facilities, fire stations and national facilities), and it is responsible for their management throughout their life span. Oslobygg KF is under the Oslo City Council for Industry and Ownership. OBF led the design phase of the Voldsløkka project development.

Undervisningbygg (UBF): UBF is the group under OBF leading the development and management of education buildings.

Client

Oslo City Education Agency (UDE): the Agency is responsible for the operation, development, follow-up and guidance of educational activities within the laws, frameworks and guidelines laid down by national and municipal authorities. UDE was involved in meetings with OBF to provide guidelines and suggestions on the design choices.

Norwegian Education Union (UF): UF is one of the largest unions for educators and teaching professionals. UF, on behalf of the teaching staff, was involved in meetings with OBF to provide guidelines regarding the physical environment conditions.

Norwegian Student Organization (EO): EO represents and advocates for all pupils and apprentices to the politicians, the media and the rest of society. EO trains and educates students and student councils in speaking up for themselves at their school.

Designers

Spinn Arkitekter AS (SPAS) and Kontur AS (KOAS): design consultants for the new school construction and renovation of Heidenreich building.

Østengen og Bergo AS (ØBAS): design consultant for the school landscape and outdoor garden.

Technical consultants

Dr. Tech Olav Olsen (DROO), Ny Struktur AS (NSAS), Norconsult AS (NCAS), Heiberg & Tveter AS (HTAS), Erichsen & Horgen AS (EHAS), Brekke & Strand Akustikk AS (BSAS), COWI AS (COAS)

External auditors

Verkis AS (VAS), Afry AS (AFAS)

Contractors

Veidekke AS (VEAS): the main construction company.
Øyvind Moen AS (ØMAS)
Several subcontractors

External public authorities

Norwegian Labour Inspection Authority (ARTY): the Norwegian Labour Inspection Authority is a governmental agency under the Ministry of Labour and Social Affairs. It has administrative, supervisory, and information responsibilities in connection with working conditions and occupational safety and health. It is audited by KOAS/SPAS on behalf of OBF to request the authorization for the new construction of the school and renovation of the Heidenreich building.

Sagene city district (BYSA): BYSA is audited by KOAS/SPAS on behalf of OBF for the assessment of plans for local and outdoor areas in accordance with regulations on environmental health protection in kindergartens and schools, in connection with the establishment of Voldsløkka school in Uelands gate 85.

Oslo City Urban Environment Agency (BYM): BYM is audited by OBF for approval of the landscape design and storm water management strategy and planning.

Oslo City Office for Building Preservation (BYA): BYA is audited by OBF for approval of the renovation design of the Heidenreich building.

Oslo City Water and Sewerage Agency (VAV):
VAV is audited by NCAS for receiving advice and evaluation of the wastewater and water management plan in the Voldsløkka project.
VAV is audited by VEAS for approval of wastewater management during the construction activities of the Voldsløkka project.
VAV is audited by Båsum Boring AS for approval of drilling of 14 boreholes for the energy system of the Voldsløkka project.

Oslo City Planning and Building Agency (PBE):
PBE is audited by KOAS/SPAS on behalf of OBF to give approval of the Voldsløkka project and to start the project (building permit).
PBE is audited by KOAS/SPAS on behalf of OBF to give approval for drilling 14 boreholes for the energy system of the Voldsløkka project.
PBE is notified by KOAS/SPAS on behalf of OBF of the Voldsløkka project activities. This documentation is used to notify the neighbourhood of the commencement of the project. With this regard, HNAS and Tåsen Housing Association provided feedback and remarks to KOAS/SPAS on the project activities. BYM provided an assessment regarding the possible conflict of the project with the neighbouring plots BYM was managing.
PBE is audited by KOAS/SPAS on behalf of OBF to ask dispensations on the regulatory provisions defined for dimensioning (height and footprint) of the multi-purpose hall, the new school building, the bridge connecting the new school building and the Heidenreich building, location of parking spaces, and the daylight level in some of the school classrooms.

APPENDIX B - GLOSSARY OF TERMS

Table 25 Abbreviations used in the report.

Abbreviation	Description	References
CPCC	Climate Positive Circular Communities	See ARV Deliverable D2.1 for a detailed definition of CPCC: LINK
EPD	Environmental Product Declaration	https://www.environdec.com/home
GHG	GreenHouse Gas	https://www.britannica.com/science/greenhouse-gas
GWP	Global Warming Potential	https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Global-warming_potential_(GWP)
LCA	Life Cycle Analysis	https://en.wikipedia.org/wiki/Life-cycle_assessment
LCC	Life Cycle Costing	https://en.wikipedia.org/wiki/Life-cycle_cost_analysis

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