FLOATING CLASSROOM
THE PHILIPPINES

The design of a floating classroom for schools located in flood and typhoon-prone areas in South East Asia

Photo by: Noel Celis

Wietse de Haan
Graduation studio 2020

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The design of a floating classroom for schools located in flood and typhoon-prone areas in South East Asia

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Abstract

This graduation thesis comprises a feasibility study and design of a floating classroom which can offer students a safe learning environment in typhoon and flood-prone areas by designing a classroom which is typhoon resilient with a floating foundation. This research is a follow-up study to the Finch Floating Homes project.

One month of field research has provided more insight into the local problems in the schools, climate, materials and wishes from the school. These insights in combination with a literature study on school design, typhoon resiliency and indoor comfort are the basic principles for the design. Additional parameters are set up by analyzing Finch Floating Home and the Makoko floating school and the design principles of the Finch's buildings.

In the design framework, there is a design analysis in which the choices for the design are explained followed by a structural analysis in which the design is tested for its resistance to high wind speeds that can occur with a typhoon and for its buoyancy by using the calculation software Technosoft and Axisvm. Also, passive design strategies which are implemented in the design are explained to make the classroom indoor comfortable.

The result is a design of a floating classroom that is able to offer the students a safe and comfortable learning environment which is ready to be built.

Content

Part A: Introdution

1. Introduction

1.1 Introduction

This graduation thesis comprises a feasibility study and design of a floating classroom for flood and typhoon prone regions in southeast Asia. Every day floods cause significant damage to the houses and thereby major problems to the society in the Philippines. The damage is primarily due to the poor quality of housing and the large number of people living in these flood- prone areas. Previously, Pieter Ham and Joran van Schaik researched a modular floating home commissioned by Finch Floating Homes. Their goal was to design a floating-house to enable Philippine families to live in an affordable, safe, and comfortable homes. This research ended in the building of a pilot floating house "The Finch Floating Home."in Macabebe, Philippines. After finishing the project, the mayor of Macabebe, who happens to be the director of the San Lorenzo School in Santa Rita. She explained that the Santa Rita school also faces daily floods and asked whether it is possible to realize a floating classroom to avoid the regular flooding of the school. This specific request, for a floating school initiated this graduation thesis.

Paragraph 1 deals with the content of the Philippines as a country, the problems caused by natural disasters, and the impact this has on education. Paragraphs 2 and 3 determine the research goals and research questions. The approach of the research and methods used are described in paragraph 4. Finally, the scope and relevance are described.

Figure 1 - Floating house, Macabebe

1.2 Problem Description

In this thesis the problems related to floods in the Philippines are described as an example for the situation in southeast Asia.

1.2.1 Context Philippines

The Philippines is a republic in Southeast Asia and lies in the Western Pacific ocean. The Philippines is an archipelago consisting of more than 7000 islands with a total land area of approximately 300.000 km2 and generally subdivided into three major geographical divisions, Luzon, Visayas, and Mindanao. The two largest islands are Luzon and Mindanao, and together they cover about two-third of the total land area. The capital of the country is Manila, located on Luzon at the Bay of Manila. After 2015 the population exceeded more than 100 million inhabitants, half of them living on the island Luzon. ((PSA), 2019).

Natural Disasters

The Philippines are globally ranked 3rd among all countries to be hit by a natural disaster, according to the World Risk Report 2018. Approximately 60% of the total land area is exposed to the chance it will be affected by multiple climate hazards, and 74% of the population is vulnerable to their impact. (GFDRR, 2017) This is mainly due to the geographical location, which makes the Philipines vulnerable for coastal risks such as typhoons, storm tides, and rising sea levels.

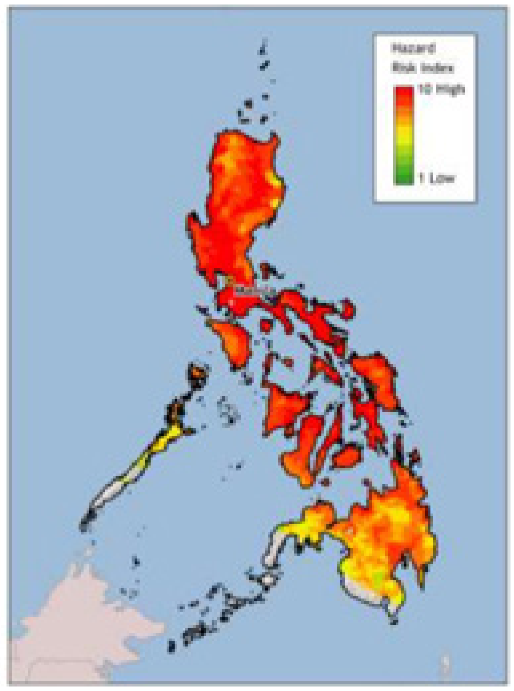


Figure 2 - Hazard risk index (GFDRR,2010)

The location of the Philippines, close to the '' Ring of fire '' between the Eurasian and the Pacific tectonic plate, also increases the risk of earthquakes and volcanic eruptions.

Floods, landslides, droughts, and tsunamis further contribute to exposure to natural hazards. (CFE-DM, 2018) In addition to the geographical location, climate change also plays an essential role in the occurrence of stronger typhoons, sea-level rise, and high storm surges in coastal regions.

The climate in the Philippines is tropical and maritime and can be divided into two major seasons, the rainy season, from June to November and the dry season, from December to May. The geological location near the pacific typhoon belt has a significant impact on the climate and weather conditions of the Philippines. A large part of the rainfall, humidity, and clouds are due to the influence of typhoons. ("PAGASA," n.d.)

The Philippines is the most exposed country to tropical storms. Every year around 80 typhoons develop above the tropical waters, of which about 20 enter the Philippine seas, and 6 to 9 typhoons make landfall. (Wingard & Brandlin, 2013) One of the most deadly typhoons in the last 50 years was the Hayain typhoon, locally known as ''Super Typhoon Yolanda". Around 6300 people did not survive storm Hayain, and over more than a million homes were damaged or even destroyed. (NDRRMC, 2013).

One of the reasons that during typhoon Hayain there were so many victims and houses destroyed is that many Filipinos have moved to the lower-lying area's which have more risk of being exposed to typhoons and floodings. Particularly in the coastal areas like Metro Manila, an estimated one-third of the inhabitants live in informal homes that are often build in substandard materials use a poor construction method. This makes these areas extra vulnerable to earthquakes, floods, typhoons, and the outbreak of diseases. Flood exposure is, therefore, a daily problem in some areas. (UNDRR, 2019).

1.2.2 Basic problem analysis

Typhoons and daily floods have a significant impact on contemporary life in the Philippines. Education in the Philippines is often threatened by these natural disasters discontinue the education for an longer period due to widespread damage to the school's equipment, infrastructure, and facilities. Some schools are used as an emergency shelter, which interrupt continuous education. (Save the Children foundation, 2018) As a consequence of the disrupted education students may fall behind and drop-out of education. For children from a low-income background, it might not even be possible to return to school. (UNDRR, 2019).

In the Philipines, the demand for typhoon resilient and flood resistant accommodations and public buildings is extremely high.

This graduation research will result in a school design that can, up to a certain degree, withstand the destructive impact that typhoons and floods entail The study ultimately may contribute to a more continuous education for all children during periods of heavy storms.

1.3 Research Objective

This section describes the general objective of this research, together with the sub-objectives and the deliverables of this research study.

1.3.1 General objective

The goal of this research is to design a classroom for students living in in a typhoon and flood sensitive area in South- East Asia that can withstand the impact of typhoon and floods to create a safe learning environment.

1.3.2 Criteria

In order to be able to achieve the main objective, it has been split into a number of sub-objectives in order to conduct the research in a more structured manner.

For this research study the criteria listed below were pre-defined.

- Provide a classroom with a floating foundation
- The design should focus on a low-budget prefabricated construction made from local materials
- The indoor comfort facilitate the learning conditions
- Create a child-friendly classroom in which a student feels safe and comfortable.

1.3.3 Final product

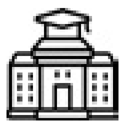
This research must result in a design concept for a floating classroom that is applicable in flood-prone areas of Southeast Asia. Based on an economically prefabricated structure made with local materials that can withstand the effects of typhoon and floods. The classroom must create a safe learning environment.

1.4 Research Questions

1.4.1 Main research question

"How to design a classroom that offers students living in a typhoon and flood sensitive area in South-East Asia a safe learning environment"

Several secondary research questions were defined to answer the main research question. These secondary questions were subdivided into a number of topics that are important to meet the main objective. The topics are divided into different chapters in which an answer to the secondary research questions is given.

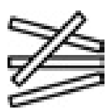


Chapter 3: Schools
What is the impact of natural hazards on an education level? How can are they currently designing schools? How do schools now deal with typhoons and floods? How can we make a school more child friendly? What are the local needs regarding a classroom?

Chapter 4: Indoor comfort
How can a classroom be indoor comfortable and which parameters need to be taken into account? What measures do they apply locally in classrooms to ensure a good indoor comfort?

Chapter 5: Typhoon resilient
How can a school be typhoon resilient and what parameters need to be taken into account?

Chapter 6: Location
What are the local climate characteristics ? What extreme circumstances can occur?



Chapter 7: Materials
Which materials are locally available?

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1.5 Approach and methodology

This paragraph describes the research approach and methodology used to collect the data and information for the research.

1.5.1 Research approach

The research approach was defined by three phases. In the first phase background information was collected on typhoon resilient school design and indoor comfort to identify the design parameters. The established design parameters formed the input of a preliminary design.

In the second phase field research information was collected on location (Macabebe, Philippines). Research focused on the construction methods, available materials, and the actual maintenance conditions of school buildings.

The design parameters from both the background phase and the field research phase were used to collect the input information for the final design phase. In this design phase, a design analysis was made to conclude which aspect of the design is most suitable for improvement and/ or optimization.

1.5.2 Research methodology

Various research methods were applied in this study. In the first phase, qualitative research was conducted in the form of interviews, literature studies, case studies, field research, and questionnaires. During the optimization of the design, the research was continued quantitatively as well as qualitatively.

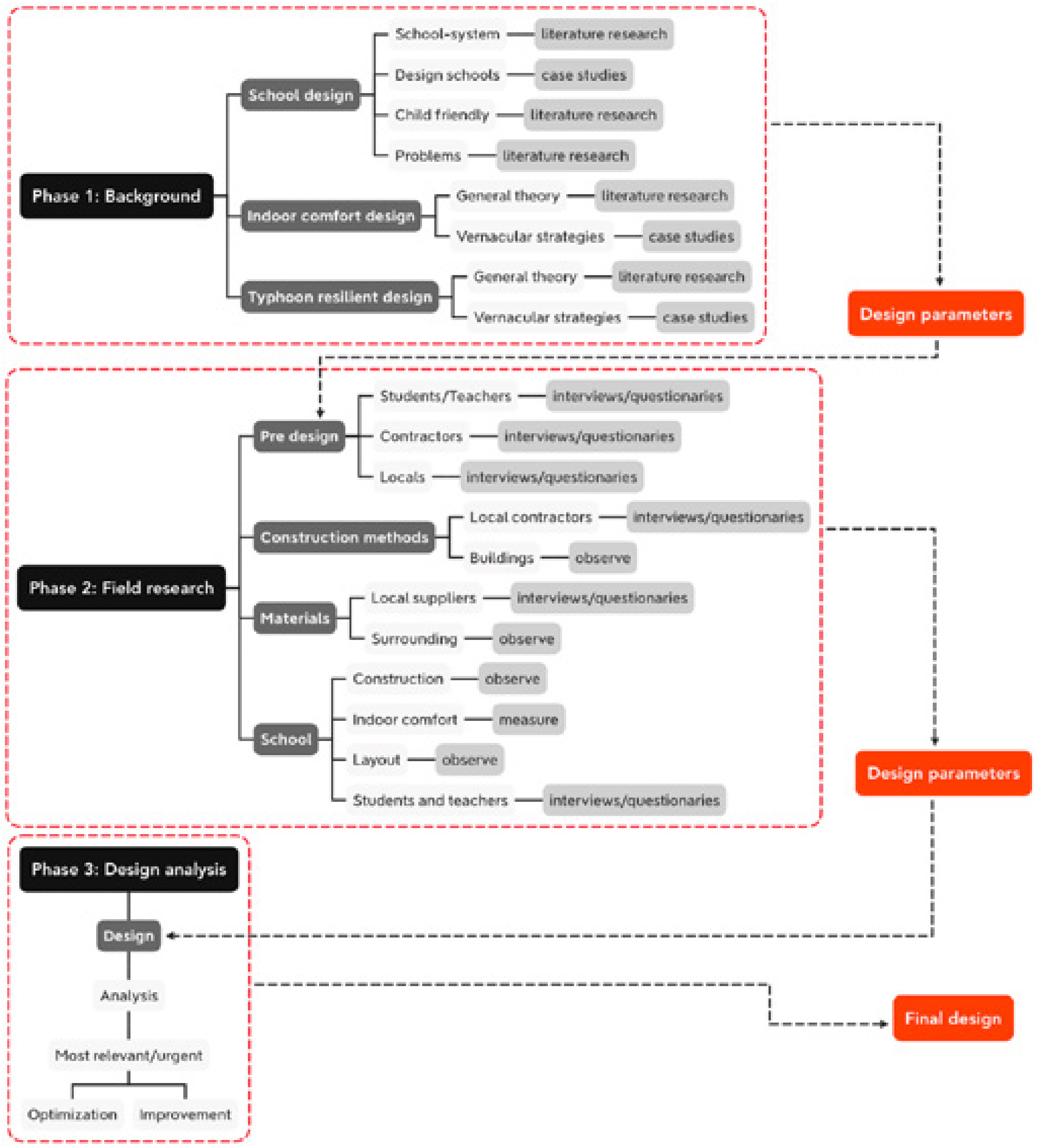


Table 1 - Research steps

1.6 Scope and relevance

1.6.1 Scope

The objective of this research study was to design a classroom that is safe during the occurrence of typhoons and floods that allow continuous education. The design intends to be a concept of a floating classroom that can be used anywhere in South East Asia where floods and typhoons occur.

For this research, a field location, suffering from floods was chosen in the Philippines, Santa Rita, Macabebe. The San Lorenzo school in Santa Rita volunteered to build the first floating classroom. The design of the flooting classroom was based on the climate conditions of the Philippines and the local materials available in the area around Macabebe.

1.6.2 Relevance of research

The impact of floods and typhoons causes cancellation and disruption of classes, physical damage to school buildings, and diverse problems in teaching as poor motivation and concentration of students, shortage of teaching materials, lack of classrooms, and lack of time to finish classes. (Ardales, Espaldon, Maria, & Lasco, 2016) The need for climate-resilient and child-friendly school buildings is high. This thesis intends to design a floating classroom that contributes to a better learning environment for students living in flood-prone areas and offer them a continuous period of education and minimize the risks of accidents during floods.

Floods like those in the Philippines, occur at multiple regions in South East Asis. Worldwide there are problems with floods that have a negative impact on providing education in the flooded areas. The concept of the floating classroom can be applied in these places in the world and may have a positive impact on education.

Figure 3 - Satellite view of the location of the San Lorenzo school (source: Google Earth)

Part B: Background

2. Design principles

2.1 Introduction

During the previous design process of the floating home, design principles have been included in the design, which represents the vision of the company Finch Homes, namely developing buildings in a modular way that can adapt to different environments and circumstances. This vision is based on the three main principles of the company: sustainability, adaptability and health. The design of a floating classroom is a continuation of the floating home design principles.

Paragraph 2.2 discusses the sustainability priciple. Paragraph 2.3 explains the theory behind the principle adaptability. The health principle is discussed in paragraph 2.4. Paragraph 2.5 explains a added principle about safety. Paragraph 2.6 concludes the chapter with the parameters that were used in the design.

Figure 1 - Walkway of Collegio de San Lorenzo

2.2 Sustainability

The worldwide climate change and the increased usage of natural resources demands more sustainable buildings. Architects, designers and engineers have a unique opportunity in the implementation of sustainable building principles at the design development stage of a building project to reduce the environmental impact buildings. The A more sustainable building approach has a high potential to make a valuable contribution to sustainable development of the society. Sustainability is a broad and complex term which has become one of the significant items / focus points in the building industry. The idea of sustainability in this project aims to be resource and energy-efficient in the use of materials, energy, water and land conversation. (Akadiri, Chinyio, & Olomolaiye, 2012) In this reseach project, sustainability principles were defined as efficient use of materials, energy and water.

2.2.1 Energy conservation

The goal of energy conservation is to reduce the consumption of fossil fuels, as well as to increase the use of renewable (wind and solar) energies

Choise of materials and construction methods
The right choice of materials and construction methods have an essential role in reducing energy consumption. Choosing materials with a low embodied energy will reduce the energy consumed through extracting, processing, transporting and manufacturing the materials.

Renewable energy sources
Energy conservation means implementing renewable energy sources such as wind and solar power.

Passive energy sources
In addition to renewable energy, there is the use of passive energy like natural ventilation, building orientation etc.

2.2.2 Material conservation

A large amount of the building materials used in the built environment come from non-renewable mineral sources. Therefore it is important for the material conservation to reduce the use of these non-renewable materials; this should be incorporated for consideration at the project initiative and design phases. (Akadiri, Chinyio, & Olomolaiye, 2012)

Local and natural materials
Natural materials are generally lower in embodied energy, require less processing and are less damaging to the environment. Wood is an example of a natural material. The use of local building materials can reduce the environmental burdens. The shorter transportation routes reduces air pollution produced by vehicles. In addition, these materials support the local economy.

Waste minimization
Aims to limit and reduce the generation of waste throughout the whole building process. This will also reduce the volume of reuse, recycle and disposal waste, which provides also a financial benefits.

Reuse and recycing
Recycling products contribute in the reduction of environmental burden, especially the use of resources and waste creation.
Reuse of buildings materials from previous buildings result in a reduction of demolition waste. Èxamples of reusable building materials are functional components such as window frames, wooden beams, barrels, roof sheets etc.

Maintenance
The building must be designed in such way that the regular cleaning and maintenance can be performed in an energy and cost effective manner. that provides enough space or that is easy to disassemble for regular cleaning and maintenance This will increase the sustainability of the building. let the construction keep its high quality if all the building elements remain well maintained.

2.2.3 Water conservation

In parts of the Philippines, water usage already causes significant problems. The extraction of groundwater leads to ground subsidence and seawater intrusion. That is why buildings must be as self-sufficient as possible in their water use. Collection of rainwater can be an efficiant way to generate water for the building. In addition, changes like water-efficient plumbing fixtures, the recycling of water and use of grey water are options to reduce the usage of freshwater.

2.3 Adaptability

Adaptability of a building is the ability toalter function of the building in response to substantial changes. Changes in the function of buildings may become necessary for economically, technical, physically or legislative reasons and the needs and expectations of its occupants. The overall characteristic of adaptability is the ability to respond to this substantial change. (Russel, p. and Moffat, 2001) Since the floating classroom will provide a safe place during floods, it is interesting to see how adaptable the design is when used as a temporary function of an emergency shelter during a flood.

Flexibility
The design is able to allow minor shifts in the space planning.

Convertibility
The design is able to allow changes in use within the building. This could be a change of function but also a change of space for example physical activities inside the classroom

Expandability
The design can be expanded if necessary or to add an extra addition to the building. This expansion can be on constructive level as well as on spacial planning.

Durability
Use of materials, methods and assemblies that require less maintenance, repairs and replacement.

Design for deconstruction and recycling
Design the building in such a way that it includes not only a construction blueprint but also a deconstruction blueprint. So contractors now which building components can be reused and how to disassemble them.

2.4 Health

An essential purpose of a building is to provide a healthy and comfortable environmental and indoor climate for human activities. This is a crucial role of the designer to give the occupants a physiological comfort, physiological satisfaction and productivity when they are in the building.
The concept of health is essential in identifying the idea of a "sustainable building" in terms of building performance. (Akadiri, Chinyio, & Olomolaiye, 2012) The building performances considered are thermal comfort, acoustical environment, daylighting and natural ventilation. (In chapter 3 indoor comfort these building performances will be looked into more in detail.)

Thermal comfort
Thermal comfort plays a significant role in the satisfaction and productivity of an occupant. The environmental parameters that determine the thermal comfort are temperature, humidity, air velocity and the personal parameter: clothing together with the activity level. Especially in a warm and humid climate like that of the Philippines, the building needs to be cooled for example with natural ventilation, reflective materials, solar shading etc.

Acoustical Environment
A good acoustical comfort supports the well-being and feeling of occupants inside buildings. Research has shown that well-designed acoustical environment in offices or schools help to improve the concentration and enable better communication. Especially inside a classroom learning is more effective when students can comfortably hear and understand their teacher. Some solution for improving the acoustical comfort can be realized by the use of sound insulating materials, good orientation, proper selections of windows, etc.

Daylighting
Daylight increases the occupants' health and well-being. Good daylighting means levels of sunlight which are sufficient to see correctly without glare or excessive contrast.

Natural ventilation
Natural ventilation can be used to supply outside air, remove smells and pollutants and most important to remove heat from spaces, people and mass. A good ventillation can also control moisture accumulation.

2.5 Afforadability

Affordability is measured by the cost relative to the amount that the purchaser is able to pay. Affordability strongly dependents on country and target group. In the Philippines, public schools are mainly subsidized by the government while private schools are financed from private founding. Often the government and private schools have limited resources. Therefore. low budget floating classroom are highly needed, so that more schools can afford floating classrooms.

Manufacturing and labour cost
The working hours consist of the hours that it takes to manufacture the components and the hours it needs to assemble the building at the construction site. By making use of With clear blueprints of the components and instructions on how to manufacture the components and to assemble the building on-site, many working hours can be saved.

Material cost
At the design, dimensions of the building and the amout and type of components selected should be balanced with respect to construction and costs. The use of recycled and/or reclaimed building materials can be considered to reduce the cost.

Transportation cost
In general, locally manufactured building components are cheaper than those imported. For local components the transport cost are relative low and free of custom fee. For large and heavy building components the transport cost more money, Possibly, the can be avoided at material selection during the design.

2.6 Safety

One of the essential principles of sustainable design is to protect its occupants from human-made disasters such as fires and natural hazards like floods, typhoons etc. Certainly, for school buildings were (young) children come together the safety demands are high.

Resist natural hazards
For the Philippines, heavy storms and floods are the most frequent occurring natural hazards. With the design of a floating school building/ classroom the design is anticipating for floods. The dimension of the floating foundation may decline the impact of risks. The design and the materials used will determine if the building can with-stand heavy storms.

Part B: Background

3. School design

3.1 Introduction

School education is essential in the lifelong journey of the child, of their intellectual and psychosocial development (Unicef, 2009). It is therefore of great importance that children, regardless of the circumstances, have the opportunity to attend school. There is a need for a new solution for the design of school buildings that will allow children to go to school in unusual situations. The goal of this chapter is to get a better picture of the educational system in the Philippines and the problems they face due to natural disasters.

This chapter starts with a short summary explaining the history of the development of education and the way the educational system in the Philippines is operating. Paragraph 2 describes the problems that arise in and around school buildings due to the influence of natural disasters. Paragraph 3 provide the standard school module, which is designed according to the guidelines of the Department of Education of the Philipines. Paragraph 4 explains the theory of making classrooms more child-friendly and the design strategies that go along with this. Paragraph 5 is a summary of the demands the national building

Figure 1 - Seatings in a classroom of the Macabebe High School

3.2 Educational system

The evolution of the education system of the Philippines has enormously been influenced during the colonial period of the country. The colonial history has included periods of Spanish, American, and Japanese control and domination. The country's educational system went through several stages of development during the different periods of occupation. The most significant contributions came during the rule by the Americans starting in 1898. During this period, English was introduced as the primary language of schooling, and a system of public education based on the United States school system was established together with a new department of public instruction. Since 2001 the department of public instruction is called the department of education (DepEd). The DepEd supervises all elementary and secondary education institutions and provides for the establishment and maintenance of a complete, adequate, and integrated system of primary education that are relevant to the goals of national development. ("Department of Education Mission, Vision, Core Values and Mandate," n.d.)

Education in the Philippines is offered through formal and non-formal education. By law education in the Philippines is compulsory for thirteen years, starting from the age of 5 (kindergarten) to 18. Formal education consists of 13 years of education that is organized in a structure of 1 + 6 + 4 + 2 years. The first year is the kindergarten (age 5) followed by six years of primary school (age 6-12) followed by four years of junior high school (age 13-16) and then two years of senior high school (age 17-18) after the successful completion of this trajectory; the student obtained his high school diploma. This is one of the shortest-term periods of formal education worldwide. The academic school year starts in June and ends in March for a period of approximately 40 weeks. The higher education system uses a semester system that is subdivided into a fall semester, winter semester, and an optional summer semester.

After students have obtained their high school diploma, they have the option to move on to higher education. There are around 2300 higher education institutions in the Philippines which 70% of them are private institutions. All of these CHED, commission of higher education. To be admitted to higher education, students need the renewed senior high school diploma. Filipino higher education is subdivided into three phases: the bachelor, master, and Ph.D. In addition to these 3 phases, there is also the so-called associate degree. This is a level of qualification between the high school diploma and a bachelor's degree and takes 2 to 3 years

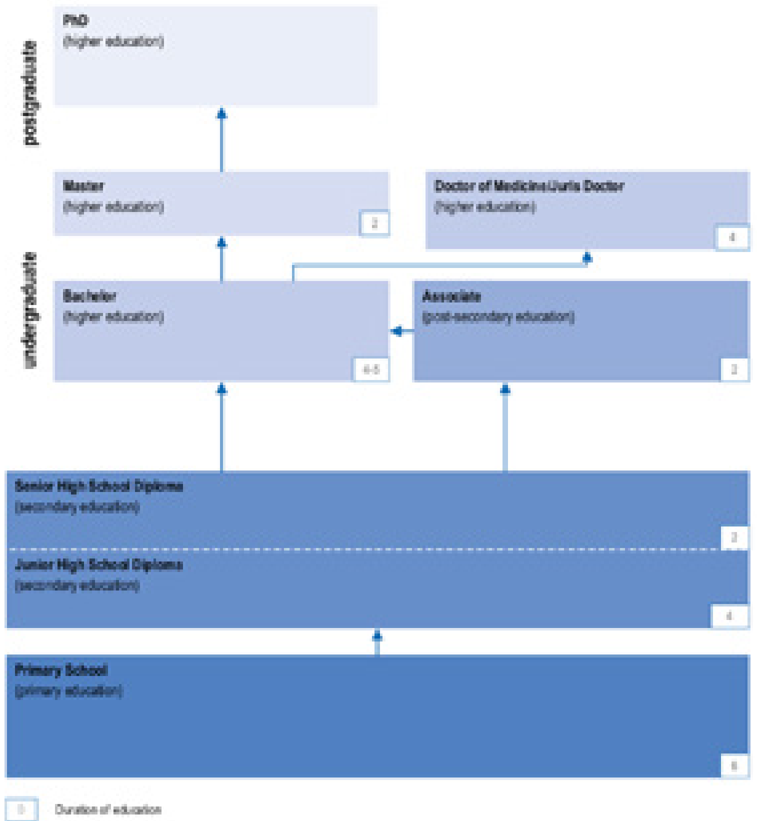


Figure 2 - School system Philippines (Nuffic, 2019)

3.3 Impact of natural disasters

3.3.1 Impact on schools

The education in the Philippines is often threatened and disrupt by typhoons, floods, earthquakes, volcanoes, and tsunamis. Particularly, floodings associated with typhoons, heavy rainfall, and monsoons has proven to be a significant problem for schools in the Philippines. (Cadag et al., 2017) According to the database of the DepEd, in the schoolyear 2009-2010, at least 260 schools (34%) of a total of 769 schools in Metro Manila were affected by floods. (DepEd, 2014) In 2013, there were 833 schools and universities exposed to flooding or located near flood-prone roads in Metro Manila. (Lapena, 2013)

The impacts of floodings on an educational level can be mainly categorized in the suspension and disruption of classes, absence of students due to inaccessibility and problems with transportation and schools and homes as a poor learning environment.

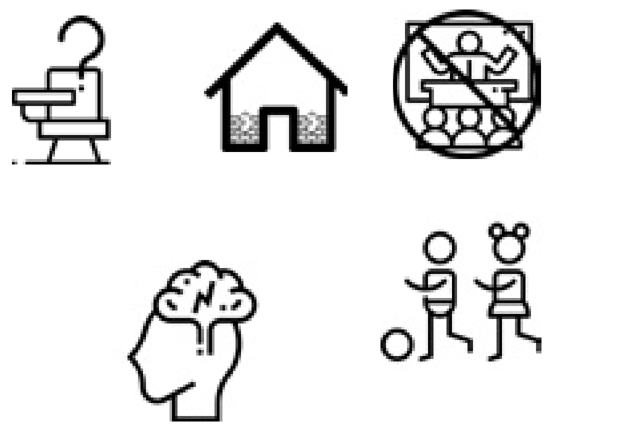
Suspension and disruption of classes
Classes in high- and elementary schools are automatically suspended when typhoon signal two is declared. This means that winds of 60 kph up to 100 kph can occur. When there are floodings on a large scale, the suspension of classes may take as long as two weeks. When a typhoon or flood comes to an end, the suspension mostly just continues because of the damage that needs to be restored. Schools that have been used as an emergency shelter for evacuees may even be longer closed than two weeks. Also, if there is no threat of a typhoon, the local government and school principal can suspend the classes if they see the situation is getting dangerous. Average rainfall with a high-tide often leads to knee-level floodwater, which results in the suspension of classes as well. (Cadag et al., 2017)

Absence due to inaccessibility and transportation problems
In case of bad weather conditions, fewer students go to school because of fear of flooding and inaccessibility of roads. Teachers notice that in times of floodings, there is a higher rate of absence among students. especially from students coming from a lower- income family due to they typically live in informal settlements and situated in flood-prone areas. (Cadag et al., 2017)

School and homes as a poor learning environment During a natural disaster, many learning materials are often lost, and it can sometimes take until the end of the academic year before they are replaced again. The same applies to students who live in informal settlements and who were unable to save their school materials during a natural hazard. Much damage also occurs after the disaster, schools that have been used as an emergency shelter often report that much damage has been caused by poor evacuation management and the loss of school materials. The damage caused in school and the presence of evacuees in schools has a negative impact on the school as a learning environment. Due to the presence of evacuees, classrooms are used as shelters, which ensures that lessons are moved to the corridors or other classrooms. (Cadag et al., 2017)

3.3.2 Impact on students

The impact of natural hazards also has a negative impact on the students themselves. The frequent interruption of education affects the students in being unable to concentrate and to maintain study habits, which leads to poor performance at school. Children who attend the affected schools also report that they have less time to play outside and meet up with friends because of the poor environment inside school. (Cadag et al., 2017)



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3.4 School module

To get a better understanding of how people in the Philippines look at the designs of school and, in particular, the design, materialization, and creation of a pleasant indoor environment. Several design modules set up by the department of education were analyzed. (DepEd, 2010)

During the field trip, students, teachers and local people were interviewed to learn more from their experiences, problems, and to hear possible recommendations about the school buildings.
A short analysis of the layout and the materialization was made to evaluate applicability for the design of a floating school.

All the school modules are designed according to the national building and the national structural code of the Philippines and designed to withstand 250 kph wind velocity and major earthquakes. (DepEd, 2010

Layout
The floor plan of school buildings with one classroom is roughly rectangular. In school buildings with more than one classroom, the classrooms are connected one after the other, resulting in an elongated rectangular floor plan. This usually happens up to a chain of five classrooms, depending on the size of the plot. If more classrooms have to be realized, there will often be decided to build a new storey on to the building.

On both sides of the building's façade are openings created that, in combination with the long rectangular shape and a good orientation of the building, can stimulate the effect of breezes that can easily blow from one side of the building to the other. The classrooms are connected through one long hallway on the outside of the school building. All the school modules are equipped with a so called cable roof shape.

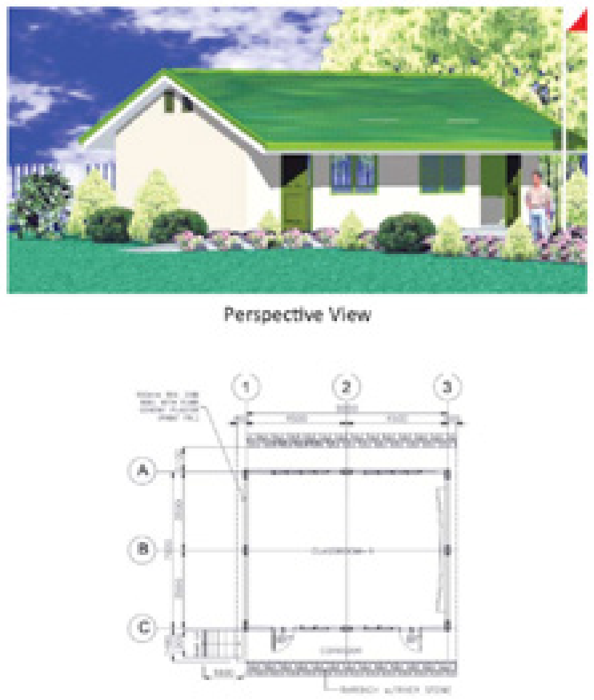


Figure 3 - School module floorplan 1 classroom (DepEd)

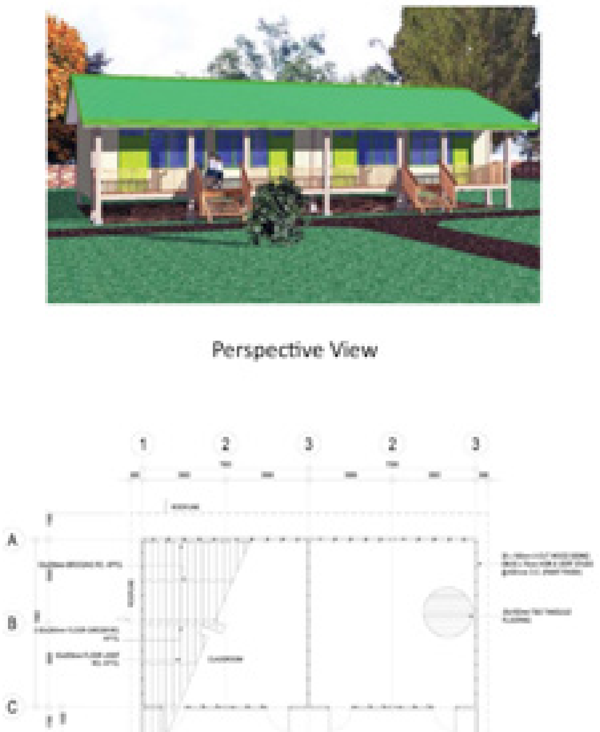


Figure 4 - School module floorplan 1 classroom with wood as main construction material (DepEd)

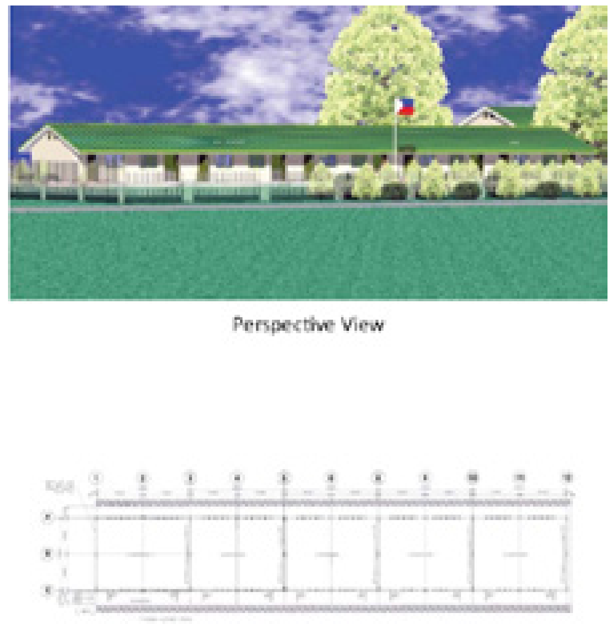


Figure 5 - School module floorplan 5 classrooms (DepEd 2010)

Materialization
The school buildings are constructed out of a basic concrete structure of columns and beams. The walls are built with hollow concrete blocks finished off with a stucco layer. The cable roof is built out of a streel truss connected to the concrete columns. The roofing material consists of corrugated steel sheets. The ceiling hangs on the steel roof frame and consists out an aluminium frame covered by fibre cement board or thick plywood interior ceiling. The windows are filled with shutters.

The major differences between the concrete and wooden school module is that the concrete columns and beams and the steel truss is replaced by wood. The construction of a wooden school building is kept above ground level in order to better protect the wood against natural damage.

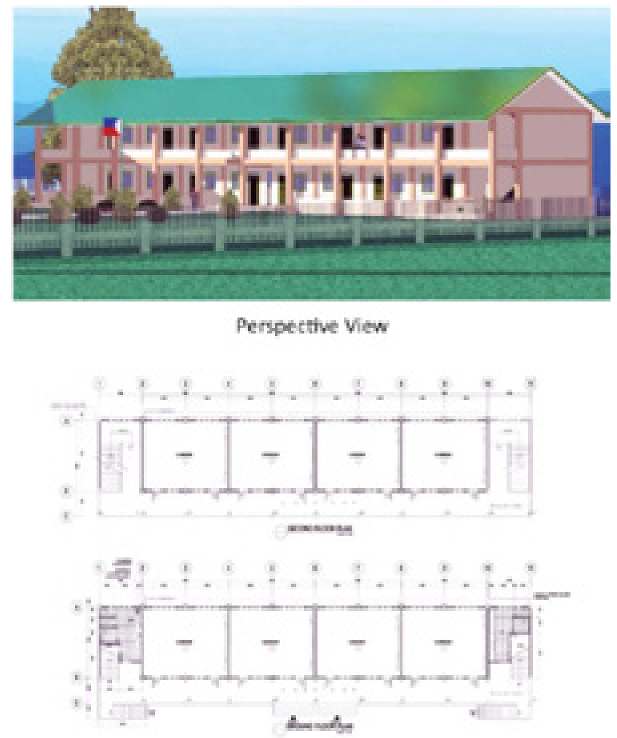


Figure 6 - School module floorplan 2 floors (DepEd 2010)

Figure 7 - Materialization (DepEd 2010)

3.5 Child friendly schools

3.5.1 Principles of a CFS

The approach to child-friendly schools focusses on the student, the primary user of this learning environment, together with the understanding that participating with the community and family, is fundamental for the best results.

Child-friendly schools have much in common with ''good schools" and needs to be conceived as an improvement on the basics of existing good schools. The universal, standard approach does not react with the culture and unique characteristics of a place, and this could result in detachment and estrangement of the community. Therefore an understanding of the child his cultural and environmental background should have prominence in design considerations for a child-friendly school.

When the architecture of the design is a reflection of the community, culture, natural environment and the family, school becomes much more than a physical structure. It becomes an interactive place to learn and teach in which students can learn and explore new possibilities that match their abilities and potential. It is essential that child-friendly schools encourage flexible, participatory approaches and enable innovative teaching and learning methodologies both indoor as outdoor.

School buildings do not only serve as a building they can also serve as a tool for teaching and learning. The school should, together with the school ground be an integral part of the learning process. Overall, spaces should be well proportioned, fit for various learning activities and integrated with outdoor spaces and surrounding. (Unicef, 2009)

Figure 8 - Main principles CFS (Unicef 2019)

3.5.2 Elements for a CFS

Practical experience and theoretical considerations have generated elements which can make the difference between a well-designed school and a child-friendly school. (Unicef, 2009) Various elements can also be interesting for integrating into the design of the floating school.

Flexible spaces Flexible spaces can increase the participation of the student in class and offers teachers the opportunity to provide a more dynamic environment for teaching and learning. The place becomes more suitable for activities, manual projects and easy access to open spaces.

Individual spaces Individual spaces can be divided into two types of individual spaces. The first one is to provide students with individual learning spaces where children can have their own learning styles and time to be on their own to study and reflect. The second one is to create a home base for children, like a storage area in the classroom to store school projects bags, etc.... and students need to have their own lockable storage.

Open spaces Providing easy access from classrooms to open spaces enables children to be in close contact with the environment and to get involved with physical activities. Some examples of open spaces for schools can be play yards, school gardens, decks or verandas for outdoor learning activities, courtyards etc... After opening hours of the school, these open spaces can be allowed for the community to be used for town meetings, local gatherings and other events.

Protective Transparency in the school design so that activities inside the school are visible from the outside and can protect children from abuse. And enclosure of boundaries to protect children from outside elements. In the case of the floating school, it is crucial to protect the children from the water surrounding the school.

Dual function model The dual-function model can reduce the amount of time students are forced to be out of school. During natural disasters, schools are often the safest buildings

Figure 9 shows the transformation of an existing classroom following the CFS guidelines. The main improvements are cross ventilation, two exit doors, gender-separated toilets, multi-activity classroom, veranda for shaded area, and a deck for outdoor activities.

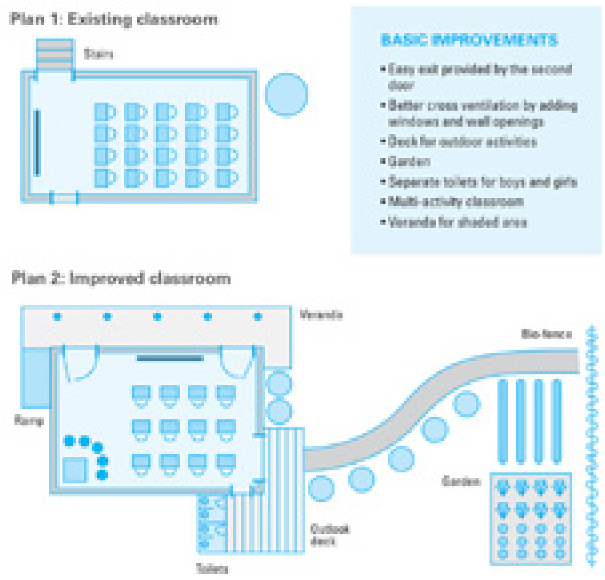


Figure 9 - Floorplan with CFS improvements (Unicef 2019)

Figure 10 shows an example of a dual function model. This model is developed by a school in Maynmar. In this school there is a shortage on teachers. The classroom provides two separate spaces with a nucleus, which allows one teacher to supervise two classrooms. When the school finds a second teacher the layout can stay the same.

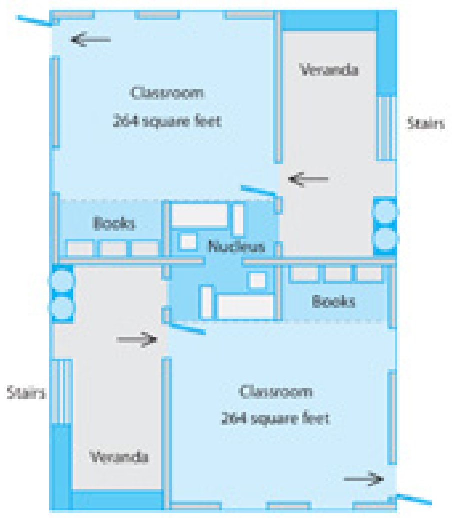


Figure 10 - Dual function floorplan (Unicef 2019)

3.6 Design requirements

The following pertinent requirements prescribed in the National Building Code of the Philippines shall be considered in the design of the school buildings.

Windows Opening of windows shall not be equal to or at least 10% of the floor area of the room. The openings of the window shall not be less than one square meter except those in toilets and baths which shall not be less than 1/20 of the floor area of such rooms, or not less than 240 square millimeter.

Ceiling height The ceilling height of classrooms provided with artificial ventilation shall have ceiling heights not less than 2.40 meters from floor to the ceiling. The ceilling height of classrooms with natural ventilation shall be not less than 2.70 meters.

Floor/Roof Construction All floors and roofs shall be so framed and tied into the framework and supporting walls so as to form an integral part of the whole building.

Exit doors A classroom requires at least two exit doors when the total number of students in the room is over 50. A door shall not be less than 2.10 meters high and 900 milliters wide.

Door shutters Door shutters shall be swing out and must be capable of at least opening for 90 degrees so that the clear way of the exit way is not less than 700 millimeters wide.

Corridor Every corridor shall be not less than 1.10 meters wide and has to be unobstructed.

Stairways Stairways being used by an occupant load of 50 or less must be 1.10 meters wide, those serving more than 50 occupants shall not be less than 1.50 meters. The rise of every step shall not exceed 200 millimeters and the tread shall not be less than 250 millimeters. Handrails shall be provided on each side of the stairway which has more than 4 steps.

Student space According to the DepED to required space for a student in a classroom is 1.4 square meter per place.

Part B: Background

4. Indoor comfort

4.1 Introduction

It is essential that students can work inside a classroom in which they feel comfortable. In a warm and humid climate as in the Philippine's most classroom are cooled by making use of aircon. It is the challenge for the designer of the classroom to make use of passive techniques to make the space comfortable in the sense of the thermal, visual and acoustical aspects.

First, a brief description of the climate in the Philippines is given to get a better understanding of the prevailing environmental circumstances. Paragraph 3 exists out of three chapters. The first chapters explain the relevance of good indoor comfort for students. Secondly, the physiological objectives are described and how they can be achieved. Last, the thermal comfort range is explained and which factor influences this the most. Then paragraph 4 gives multiple design strategies based on the guidelines of the department of education.

Figure 1 - Local house in Santa Rita

4.2 Philippines climate

The climate in the Philippines is tropical and maritime and can be divided into two major seasons, the rainy season, from June to November and the dry season, from December to May. Due to this subtropical climate, the Philippines has one of the richest biodiversities in the world. The geological location near the pacific typhoon belt has a significant impact on the climate and weather conditions of the Philippines. A large part of the rainfall, humidity, and clouds are due to the influence of typhoons. (“PAGASA,” n.d.)

The major climate processes and their impact in the Philippines are the Southwest and Northeast monsoon with rainfall and heavy winds, El Nino that is associated with droughts and the low pressure over the Pacific or south china sea which can lead to tropical cyclones. (GFDRR, 2010)

Temperature - The average temperature of the Philippines normally is between the 21 and 32 degrees with an yearly average of 26,2 degrees. The temperatures can differ in each region and season of the year but overall Janaury is the coolest month and May the warmest. (“Philippines Weather & Climate | Philippines Weather Forecast,” n.d.)

Wind - The north east monsoon brings north east winds from November to February. From March till May there are mostly warm dry winds from the south east direction. The south west monsoon from June untill October brings south west winds. These data are based on the location of Manilla. (Gavieta, 1991)

Humidity - The humidity in the Philippines is high during all seasons, the relative humidity ranges from 68% in April to 86% in September. (Gavieta, 1991)

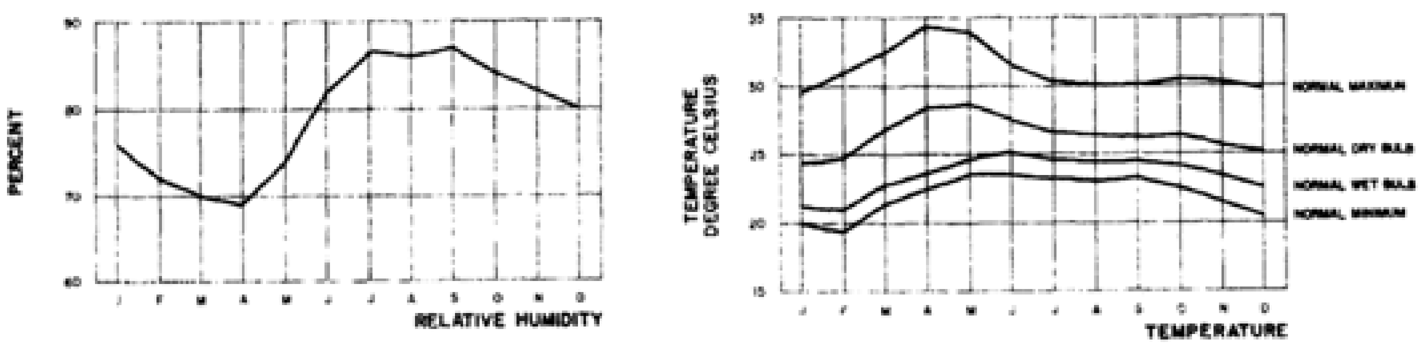


Figure 2 - Yearly relative humidity and temperature, in Manilla, Philippines (Gavieta 1991)

4.3 Indoor comfort for schools

4.3.1 Relevance of a good indoor comfort for students

When designing a school, designers and engineers should take into account that the environmental factors of the building itself play an essential rule in the process of teaching and learning. Environmental comfort represents four main areas: thermal, visual, acoustic and ergonomic comfort. Regarding environmental comfort in the built environment, engineers and architects should primarily focus on the thermal-, visual and acoustical comfort of the building.

Poor acoustic performance of the classroom itself will lead to miscommunication, understanding by the students and can lead to physical stress of the teacher. Poor lighting inside the school will affect the student’s attention and performance. Implementing daylight as an important design parameter can decrease energy consumption and create a pleasant atmosphere for learning and teaching activities.
Thermal discomfort inside classrooms due to overheating or too cold classes can be linked with physical stress which can lead to illnesses and poor performance of the students. (Krü & Zannin, 2004)

4.3.2 Physiological objectives for a school building in a warm and humid climate

The air temperature in a hot and humid climate is almost the same as the skin temperature, bodily heat loss to the surronding air by conduction or convection is negligible. Due to high humidity air, the evaporation of a small quantity of moisture from your body will form a small air envelope around the body, preventing the last option of heat dissipation. Movement of air is the only available relief from heat stress therefore vital for to indoor comfort. (Koenigsberger, 1975) Stimulation of natural air flow through the classroom is an important and one of the main objectives. According to Koenigsberger the cross ventilation is usefull for warm humid climates. This can be achieved with large openings on both side of the building. However, the problems with large openings is the protection from driving rain, insects, smells and noise.

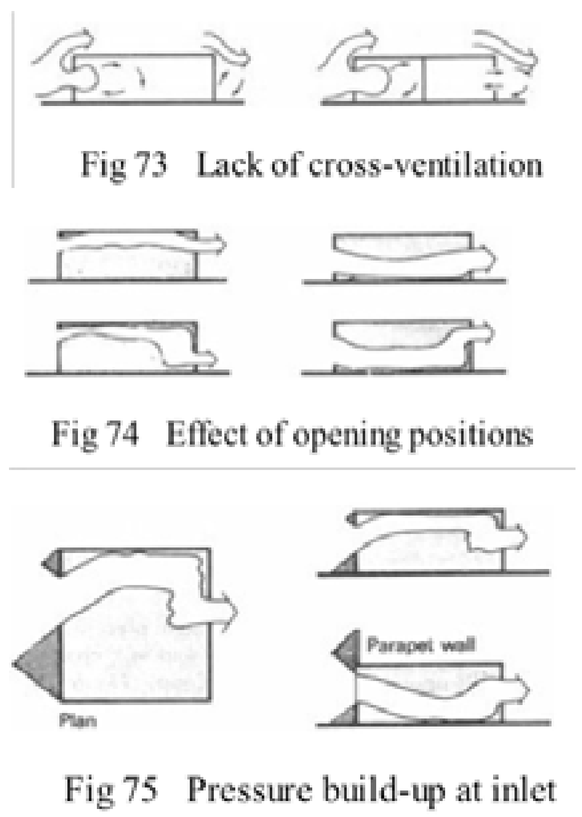


Figure 3 - Cross ventilation principles (Koenigsberger, 1975)

The openness of the building will be one of the dominant characteristics, together with the shading devices. Shading is one of the other objectives for the building design. The shading devices need to prevent heat from entering into the building due to the intensity of radiation. Shading of the walls, surfaces and both openings will be beneficial for the indoor comfort.

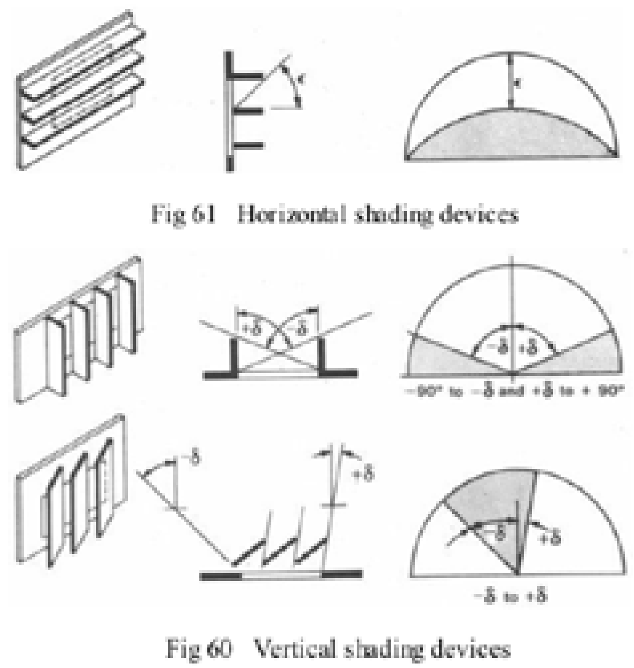


Figure 4 - Example of possible shading devices (Koenigsberger, 1975)

The roof is a component of great importance to control thermal comfort. The roof itself cannot improve the thermal conditions, but it can prevent the indoor temperature increasing above the outside temperature. This can be achieved by a reflective upper layer, double roof construction in which the in-between roof space is ventilated, ceiling with a top surface that is highly reflective and good insulation.
The ceiling and roof should be made out of materials with a low thermal capacity since thermal has no benefits in a warm humid climate.

4.3.3 Thermal comfort

To be able to provide the classroom with a comfortable indoor climate which the occupants will find thermally comfortable, it is essential to understand the basics of the thermal comfort standards. The classroom will be a naturally conditioned building.

Researches have shown that in naturally conditioned buildings, in order to achieve thermal comfort, people can adapt to the temperature changes that may cause thermal discomfort. Therefore, thermal comfort can be achieved in a broader range of indoor temperatures. Adaptive thermal comfort theory considers the adaptability and satisfaction of occupants, which helps to reduce the energy usage (Carlucci et al., 2018).

Toe and Kubota (2013), who have done research on adaptive thermal comfort for hot and humid climate zones, observed that air velocity influences the upper comfort limit of the comfort zone. Hence air movement/cross ventilation is important in the indoor space. According to Figure 4 shows the relation between increase in upper comfort limit with respect to indoor air velocity (Nicol, 2004).

The Adaptive Comfort Model in ASHRAE 55-2010 for the Manila region is used for checking the thermal comfort performance through the program of climate consultant.

The adaptive comfort limits by using natural ventilation with an 80% accaptability is:

Lower comfort limit is 23.3°C
Upper comfort limit is 29.5°C

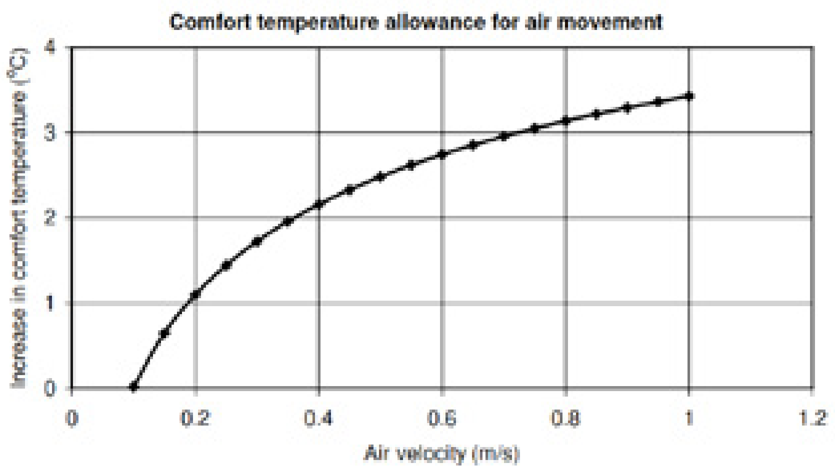


Figure 5 - Comfort temperature allowance for air movement (Nicol, 2004)

For this part of the research, the information about the upper and lower comfort limits provides more insight into the measured temperatures in the classroom. The related questions if they find the classroom thermally comfortable in terms of the temperature can now be related to a specific range which should feel thermally comfortable.

4.4 Design strategies

The educational facilities manual of the Philippines describes specific design strategies to improve the ergonomics of educational facilities. The design strategies given overlap with the same factors as described in 3.2. The design strategies provide more insight into which aspects should be taken into account when analyzing the case studies. (DepEd, 2010)

4.4.1 Thermal comfort

Proper orientation The school building should be adequately orientated to minimalize the amount of solar heat gain, direct sunlight, and to maximize the entrance of breeze of air currents.

Eaves Provide the school from overhanging eaves that provide shadow and promote air motion inside the building.

Floorplan Keep the building as narrow as possible so that breezes can blow easily from one side to the other side of the building.

Fenestration Make sure that the building has enough openings so that wind can blow through.

Planting trees Plant trees around the building to promote air motion inside the building.

4.4.2 Visual comfort

Proper orientation The school building should be adequately orientated to provide adequate indirect daylight in the classrooms.

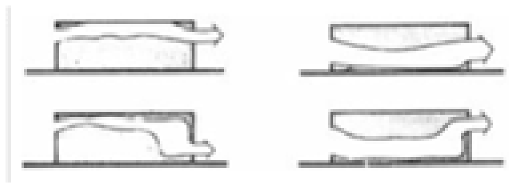
Fenestration Provide the classroom on both sides with fenestration or openings, like windows, to secure daylight all over the school.

Color Use of a correct combination of colors and intensity to provide proper brightness contrast.

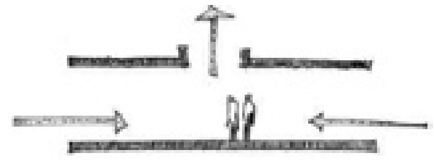
Shading devices Provision of useful shading devices to avoid glare in the classrooms.

4.4.3 Acoustical comfort

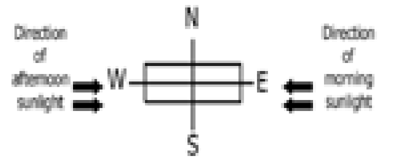
Location Place the school in a relatively quiet area of the neighborhood and a considerable distance from the road.



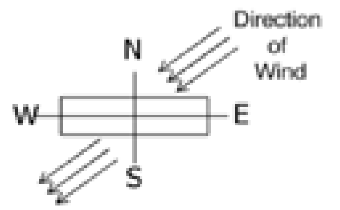
Cross ventilation



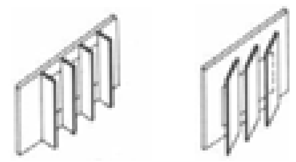
Stack ventilation



Orientated along solar path

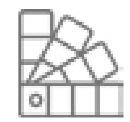


Orientated along wind direction



Louvres and eaves

Location regarding ambient noise



Stimulating color combinations

Icons - Retrieved from (Flaticon.com)

Part B: Background

5. Resilient design

5.1 Introduction

Resilient design is intentional design in order to respond to natural and humanmade disasters. The natural disasters the floating classroom has to overcome are mainly floodings and typhoons. Information on resilience of current buildings to coupe with typhoons and floods was collected to be able to design a resilient floating classroom.

Chapter 2 describes the general theory of the constructional requirement. The first paragraph of chapter 3 explains which parts of buildings are the most vulnerable for high wind speeds. Followed by a section that explains the different failure models of structures and lastly, design strategies are given. Chapter 4 describes how to determine the right wind speeds for typhoon prone area's. Finally, floating behaviour is analysed.

Figure 1 - Local architecure on the island Palawan

5.2 Constructional requirements

The basic requirements of a safe construction have to meet the three basic requirements of strength, stiffness and stability.

Strength - The construction should be strong enough to withstand the stress it will face during its expected lifespan. There are several ways in which a structure can fail to strength; it can break (as a re- sult of bending), crack (as a result of tensile stress) or shatter (as a result of compressive stress). A vital test criterion for strength is the tension in the material. The construction components can be checked against the standard for strength according the Eurocode.

Stiffness - The construction shoud be stiff enough to give a solid impression to the construction. For the deformation of the structural parts, stiffness criteria have been defined for deflection (Eurocode), so that the usability or safety is not compromised. The most important aspects that influence the deflection are the shape of the cross-section and the choice of material.

Stability - The construction should not fall over or lose its position. The construction can withstand horizontal forces due to its stability

The structure must be able to resist the translation and rotation of the building. An important aspect of preventing these movements is the application of stabilization surfaces. The surfaces may not intersect each other in one point to avoid rotation. (see figure 3)

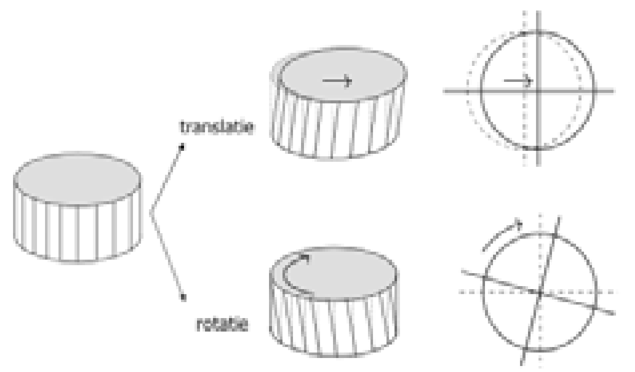


Figure 2 - Movements in buildings (TU Delft, 2008)

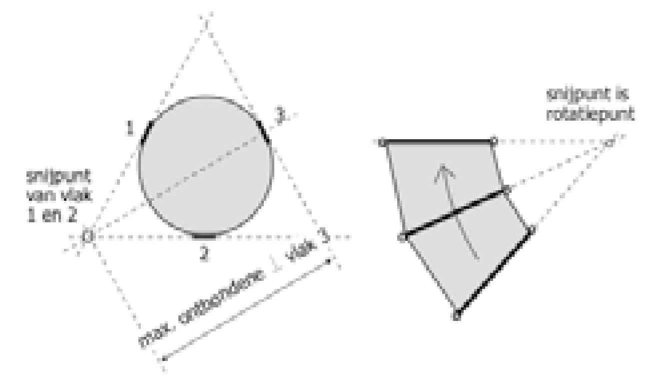


Figure 3 - Correct placement of the stabilization elements (TU Delft 2008)

5.3 Resilient design

5.3.2 Damage by typhoons

In typhoon-prone areas, the vulnerability of buildings is frequently determined by the chance that a cyclone will occur and the degree the structure can be damaged by the cyclone. In general, buildings made of light weight structures, or poorly maintened or unreinforced or poorly made out of hollow concrete blocks are the one that are most vulnerable during the occurence of a cyclone. Houses can be pulled apart due to winds that move swiftly over the building. This lowers the pressure on the outside of the house and creates suction on the roof and walls which can rip the building apart. (Agarwal, 2007).

Damage on houses can come in many variants and mostly depends on the weakest link in the construction. The most common damage are discussed.

Due to the high wind pressure and improper connections of the construction with the foundation the house can be blown away (figure 4).

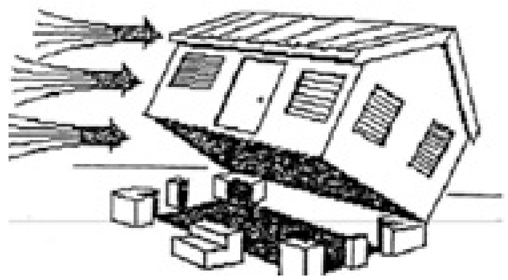


Figure 4 - Improper connection to the foundation (Agarwal, 2007)

Roofing materials that are not properly anchored can be blown away (figure 5).

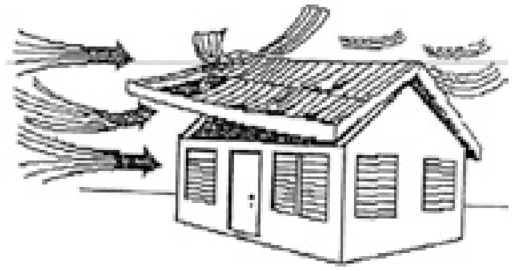


Figure 5 - Improper connection roofing materials (Agarwal, 2007)

Light weight verandas are much more sensitive to damage because of the high wind speeds that can create an uplifting effect under the roof of the veranda (figure 6).

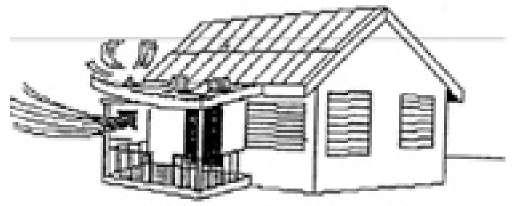


Figure 6 - Sensitivity of verandahs (Agarwal, 2007)

When cyclones are accompanied with heavy rains flooding of the area can occur causing significant damage to the buildings (figure 7)

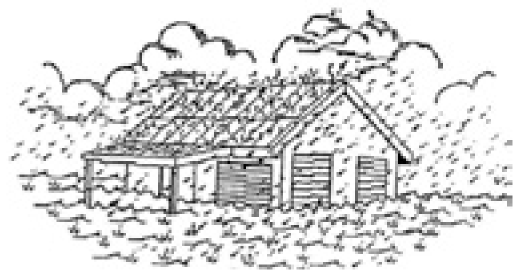


Figure 7 - Damage by flood (Agarwal, 2007)

5.3.3 Wind failure models

A building can collapse under a wind load in several ways. This chapter describes several failure models that can occur as a result of high wind forces. The force of wind pressure is depending on various elements and building components. The aerodynamics of flow around the building, the windward vertical faces that is being subjected to pressure, the leeward and lateral faces that are facing suction effects and the sloping roofs getting pressure or suction effects. Window shades and eaves are facing uplifting wind forces.

Wind entering through a window or door opening can cause the elements to be pushed out from the inside (Figure 8)

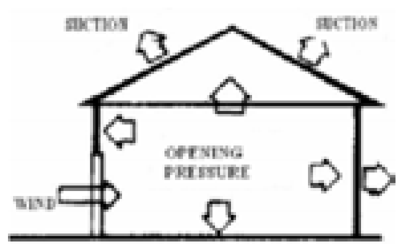


Figure 8 - Opening pressure (Agarwal, 2007)

By creating an opening on the other of counter side of the building, the wind is allowed to escape from the building, so there is no chance of building up pressure inside the building (Figure 9).

Figure 9 - Opposite openings (Agarwal, 2007)

The windward element of side of the building collapses under wind pressure. This occurs when the structural elements cannot withstand the high wind forces and eventually bends so much that it breaks (figure 10).

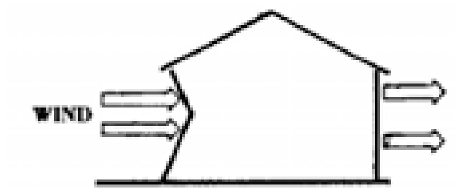


Figure 10 - Failure of windward element (Agarwal, 2007)

When the elements of the structure are not connected firmly together or not correctly attached to the foundation, the nodes can collapse under wind pressure on one plane. (figure 11)

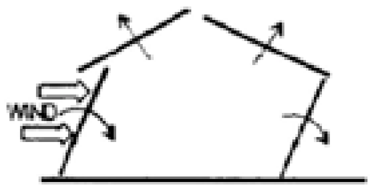


Figure 11 - Nodes colllapsing (Agarwal, 2007)

Wind pressure on a closed building causes pressure from the inside on the walls and roof, pushing them outwards (figure 12)

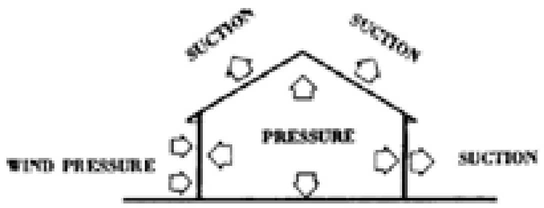


Figure 12 - Innerpressure (Agarwal, 2007)

With light weight constructions, it can occur that the wind lifts the entire building (figure 13).

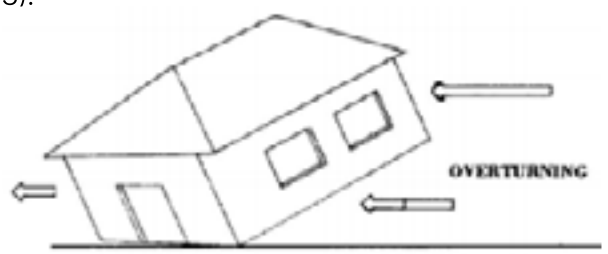


Figure 13 - Overturning (Agarwal, 2007)

5.3.4 Design strategies

Shape of the building

The shape of the building plays a significant role in a design that must be highly resistant to high wind force. The shape of the structure determines to what extent the wind is directed around the building. It is optionable to choose the form of the building based on aerodynamic properties of a particular shape. Agarwal (2007) states in his research that simple, compact and symmetrical shapes are the best to use. The comparison was made between the figures shown in figure 14.

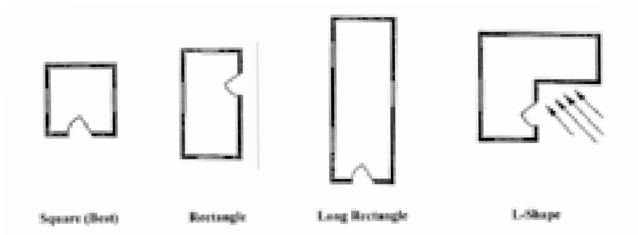


Figure 14 - Shapes that withstand high winds (Agarwal, 2007)

The shapes Agarwal analysed are based on simple and compact shapes. O. Lisowitch (2014) researched the aerodynamic coefficients for multisided cylinders and in particular the drag coefficients by using CFD. The drag coefficient of a shape is used to quantify the resistance of a shape in a fluid environment, such as air.

Figure 15 shows the results of simulation in the CFD (Ansys-CFX) and also the comparison with a real-life wind tunnel test and a design code. Overall the circle performs best, followed by the dodecagon, octagon, hexagon and finally the square.

Drag Coefficients of Multisided Cylinders (Re 100)

	Number of Sides	Wind Tunnel	Design Code [5]	ANSYS-CFX
	Square - 4	2.0 [2]	1.7	1.92
	Hexagon - 6	NA	NA	1.83
	Octagon - 8	1.0 ~ 1.6 [3]	1.2	1.59
	Dodecagon - 12	1.2 ~ 1.6 [2, 3, 4]	1.2	1.33
	Cirlce - 1	1.2 [2,3]	1.1	1.23

Figure 15 - Drag Coefficients (Lisowitch, 2014)

Urban planning

When designing a cluster of buildings, it is important to consider wind as a factor in organizing urban planning. According to (Agarwal, 2007) row planning can create a wind tunnel effect which causes higher wind velocity winds. A way of preventing this is, for example, placing the buildings in a zigzag pattern. (see figure 16)

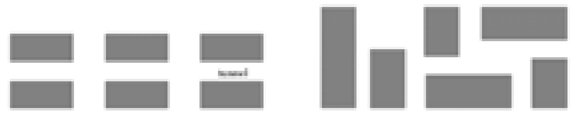


Figure 16 - Patterns in urban planning influencing the wind speed (Agarwal, 2007)

Shape of the roof

One of the most common failures during typhoons is the roof. C.T. Lakshmann (2011) researched three kind of roofs to see which kind of roof faces the highest uplift. The three roofs studied are the gable roof, hipped roof and the pyramidal roof. (see figure 17)

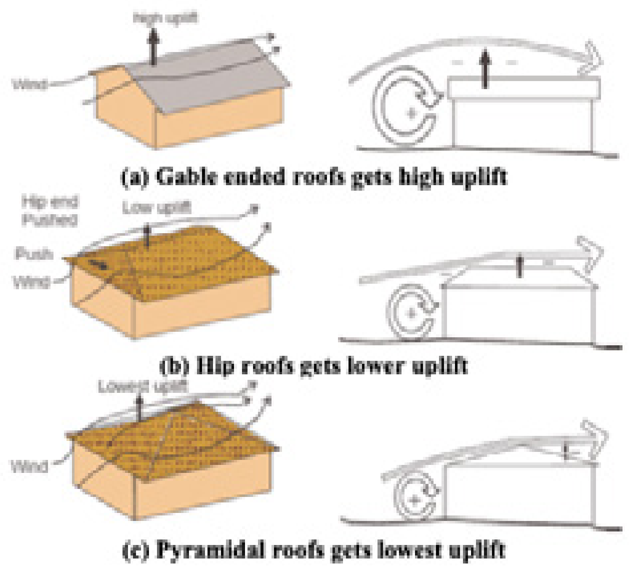


Figure 17 - Roof comparising on uplift forces (Lakshmann, 2011)

The pyrmidal roof gets the lowest uplift. Beside the shape of the roof, overhangs should be avoided and patio roofs / verandas can be built as separate structure from the roof.

5.4 Windloading

5.4.1 Occupancy cattegory

All buildings and other structures in the Philippines are classified based on the nature of occupancy for the purpose of applying wind loads. There are five different categories in which functions of buildings are divided in to.

I: Essential facilities: such as fire and police stations, hospitals, aviation control towers and more.
II: Hazardous facilities: occupancies housing or storing toxic or explosive subtstances.
III: Special occupancy structures: such as museums, libaries, religion facilities, prisons and more.
IV: Standard occupancy structures: all structures housing occupancies not listed in category I,II,III and V.
V: Miscellanous structures: private garages, carports sheds and fences over 1,5m high.
According to table 103-1 of the National Structural Code of the Philippines (NSCP) the design of the floating classroom will fall under category I: essential facilities.

Since 2015 the NSCP departs from prior editions of the national structural codes by providing wind maps that are directly applicable for determining pressures for strength design approaches instead of using a single map with importance factors and a load factor for each building occupancy category.

5.4.2 Wind speed

To determine the wind speeds the NSCP has set up different winds speed maps based on the results from PAGASA. PAGASA is the National Metreological and Hydrological Services agency of the Philippines mandated to provide protection against natural calamities and to insure safety of all people. The different maps are divided in the occupancy categories, the winds speeds set up for category I has the highest values among the other categories.

The NSCP is based on the ASCE7-95 in which wind speed is measured as a 3-second gust speed. In the Eurocode the reference wind velocity is the mean velocity of the wind averaged over a period of 10 minutes, arranged in open terrain exposure at an elevation of 10 meters with a 50 year mean recurrence interval. Conversion of wind velocity is possible by the following formula. (Lungu, 1996)

$$1.05V_{ref}^{1h} = V_{ref}^{10min} = 0.84V_{ref}^{1min} = 0.67V_{ref}^{3sec}$$

Formula: Relation of wind velocities based on time intervals. (Lungu, 1996)

Macabebe is located in the region where a 3-second gust wind speed of 260 km/h is maintained. A 260 km/h 3-second gust factor corresponds to a 10 minute mean velocity or 174.2 km/h. The wind calculations will therefore consistently use a wind speed of 174.2 km/h or 48.4 m/s.

Figure 18 - Basic wind speeds for occupancy category I (NSCP 2015)

5.5 Floating behaviour

In order to assess whether the designed floating platform is safe for use, the underlying theory of establishing the buoyancy and stability of floating structures will be briefly discussed.

5.5.1 States of stability

For the design of the floating classroom two types of stability are researched the static stability and dynamic stability. Static stability, is the behaviour of the floating platform while facing static loading. Static loading can be divided in to dead and live loads.

In addition to static loads, dynamic loads also act on the floating classroom such as wind, waves or people. For this research, static loads and only the dynamic load of wind and people will be considered.

5.5.1.1 Static stability

The static stability can occur in 3 ways.

The vertical equilibrium, in which a floating object will form equilibrium by two resulting forces.

Horizontal equilibrium, this can only be achieved with external influences like a mooring system since there is no resultant hydrostatic force.

Thirdly, there is rotational equilibrium due to external excentric vertical loads, horizontal load or an external moment acting on the floating structure there will be a certain amount of rotation around the centre of buoyancy. This causes the floating structure to tilt. As an effect of the rotation caused by external heeling moment, the form of the sunken part of the structure will change, thus changes the centre of buoyancy. The centre of gravity (g) will also shift. An equilibrium will be obtained when the righting stability moment Mr equals the heeling moment MH. (Ham, 2016)

Ham (2016) mentions in his research multiple options and advice to improve the performance of the static stability of the structure.

- Make use of a lightweight structure in order not to exceed the buoyancy force.

- Increasing the metacentre height (GM), a larger GM means a larger stability arm GZ which results in a higher uplifting moment.

This can be achieved by a low centre of gravity (G) from the structure on top of the foundation. (figure 19)

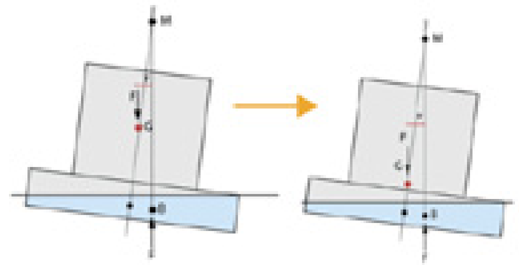


Figure 19 - Lowering centre of gravity (Ham, 2016)

Or/and by making a wide rigid body for the floating foundation, in this case, the centre of buoyancy will shift mostly under a smalled rotation.(figure 20)

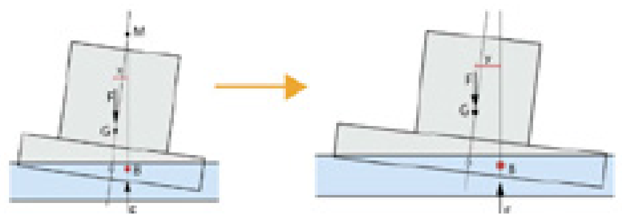


Figure 20 - Difference in width of the floating body (Ham, 2016)

5.5.1.2 Dynamic stability

Ham (2016) describes four different scenarios in which a floating object can move freely. The scenarios described are based on a floating structure that is moored. For this research, the dynamic heave oscillation is not taken into account because it is mainly caused by waves and is not taken into account in this study.

- Surge and sway

Surge and sway will be prevented by the mooring piles.

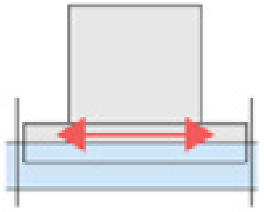


Figure 21 - Surge and sway (Ham, 2016)

- Dynamic roll and pitch

Rolling and pitching can occur in both static and dynamic ways. The static roll can be called heeling or tilting and can occur by external static moments or horizontal and vertical forces.

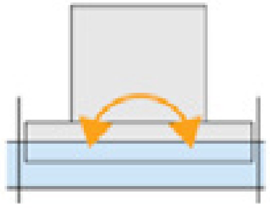


Figure 22 - Dynamic roll and pitch (Ham, 2016)

- Yaw

Rotation of the structure around the z-axis will be prevented by the mooring piles.

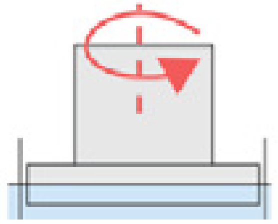


Figure 23 - Yaw (Ham, 2016)

5.5.2 Eccentric load

After the building has been taken into use, in addition to the wind, eccentric loads may also arise from the users. If a large number of people are on the floating structure, and they would concentrate on one side of the structure, a turning moment arises.

For structures where fewer than 40 people are allowed, the NTA describes a simplified method based on live loads. In this method, as shown in figure x, one side of the structure is fully loaded with live load, and for the other side, the live load is set to 0.

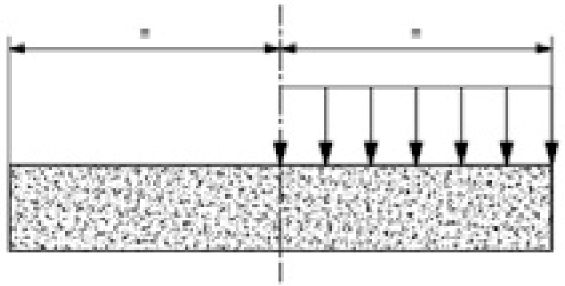


Figure 24 - Simplified method of eccentric load caused by the occupants (NTA, 2011)

In the classroom, there is a high chance that all the students will be on one side of the classroom. Therefore the floating module of the classroom will also be tested on the described eccentric load.

5.5.3 Tilting of platform

The turning points that arise as described in the stability scenarios can lead to tilting of the platform. The NTA states that the maximum slope may not exceed over 4 degrees. However, this value arose from a practical choice because of up to 4 degrees the metacentre will remain approximately in the same place.

Also, for the user-friendliness, the comfort of the structure is an important aspect. With the maximum slope of 4 degrees, the chance of shifting the interior is low.

Part C: Location visit

6. Location analysis

6.1 Introduction

The Macabebe project site is located in the province of Pampanga. Outside the project location, there are many fish ponds in the province that are no longer being used today, and these are potential future locations for a floating school. In particular, the increase in population density in the province is a development that demands more classrooms in the future. With an expected increase in floods, classrooms resistant to flooding will be favourable.

The first chapter (6.2) describes the Pampanga region and the problems of the Pampanga delta. In the second chapter (6.3), local schools are being analyzed to evaluate how they respond to floods and overcrowded classrooms. Finally, the location for the pilot project is analyzed.

Figure 1 - Flooded schoolyard Macabe High School

6.2 Pampanga

Pampanga is a province in the central luzon region of the Philippines. Pampanga lies on the northern shore of the Manila Bay.

The region has a population of around 6.6 million inhabitants and has a density of 630 persons/km2, which is more than twice the national average as per the year 2010 according to the National Statistics Office (Shrestha et al., 2016).

Agricultural fields comprise the majority of area with built-up area scattered across the region. San Fernando, Angeles and Cabanatuan are the most urbanized areas in the province. Figure 2 shows the land cover and conditions of the region.

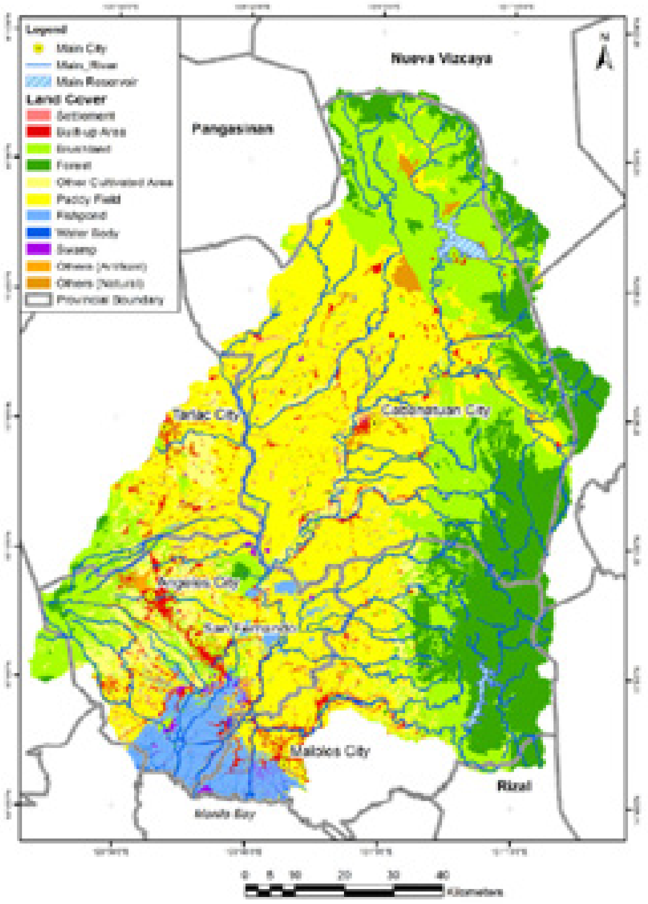


Figure 2 - Landcover map Pampanga province (Shrestha et al., 2016)

The Pampanga delta where Macabebe is situated, faces serious flood problems. It has one of the most important river basins in the Philippines, the Pampanga river basin and it experiences at least one flood event a year (Shrestha et al., 2016). The excessive groundwater extraction causes the land to sink by an average of 5 cm/year (Rodolofo & Siringan, 2006). The land subsidence combined with tidal and fluvial flood causes flood in low lying areas of the Pampanga delta.

Locally, the municipalities in Pampanga region have implemented several strategies to lessen the impact of flood by increasing the height of roads for uninterrupted road networks. This however, worsens the situation as it blocks the outflow of the water (Ham, 2016). The flood causes damage to the buildings, agricultural fields and also submerge fish ponds.

Figures - Local circumstances in the province of Pampange

6.3 Local research

6.3.1 Schools

During the field research, multiple schools in and around Macabebe were visited. The goal of these visitations was to study the current situations of the schools and to see how they operate on a daily basis.
By analysing the classrooms, more information was gathered on aspects that are useful for the design of the floating classroom, both technically and architectonically.

In addition to our own findings, interviews with teachers provided information on how current classroom are perceived and as well as ideas for improvement. Some of the students also received questionnaires in which they could rate their current classrooms in terms of comfort and indicate what they think is still missing in the classrooms.

Four schools have been visited Colegio de San Lorenzo, Macabebe High School, Macabebe Elementary School and the San Vincente - San Fransico High School. The schools vary from each other with regard to primary and secondary education and whether the school is public or private. Each school had unique classrooms relative to each other, which will give research into the current classrooms more diversity except for the newly built classrooms according to the DepEd method.

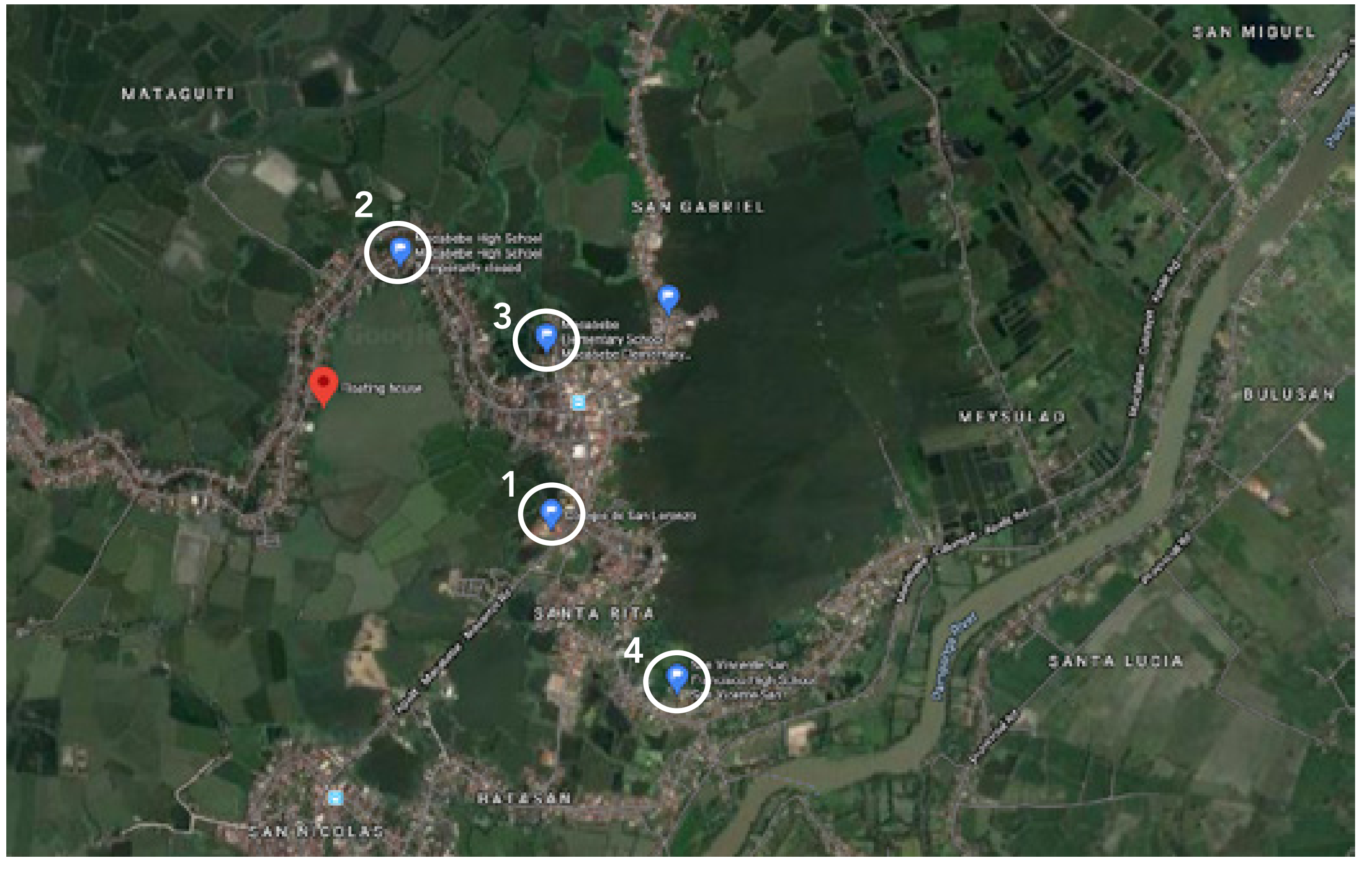


Figure 3 - Location of the visited schools

1. Colegio de San Lorenzo
private school

2. Macabebe High school
public school

3. Macabebe elementary school
public school

4. San Vincente - San Francisco - High School
public school

6.3.2 Effect of ground subsidence and floodings

An overview of the consequences of flooding is presented below.

Damage to materials

- Rotting of wooden structures, furnitures etc.
- Moisture in the building materials
- Molds, fungus etc. affects healt of the students

Buildings and spaces not being used or unusable

- Various classrooms are not used, because of damage or they cannot be reached as there is no safe pathway to the buildings.

- Various toilets are damaged and can not be used with the consequence that not enough toilets are available for the number of students.

Outdoor spaces are still under water and unuseable

- Potential spaces for out-door activities for the students are not available, lack of playgrounds.

- Limited walking space between the classrooms. Everybody is confined to move along the pathways.

Stagnant water

- Unsafe environment for students
- Stagnant water brings a unpleasant smell which is uncomfortable to stay.
- Breeding spaces for mosquitous and other unwanted organisms








Figures - The effects of floods and ground subsidence on local schools

6.3.3 Response of the schools

Raised floors, curbs and pathways

- Due to raising of the floors the height of classrooms are reduced each time the floor is raised with a new concrete slap.. This makes the classrooms unpleasant regarding daylight and temperature.
- To reach the classrooms pathways are raised using sandbags, tires or concrete platforms.
- Toilets have to be raised due to broken drains to the septic tanks.

Crowded classrooms

- Due to unavailability of classrooms, classes of the same grade have to sit together.

Construction of new school blocks

- The school can apply for new classrooms only when the old classrooms are no longer sufficient/ qualified to use. The downside of this relative late renewal is merger of classes resulting inoverpopulated classrooms.
- Now a days, new school buildings has a one meter raised floor above plane to coupe with settlement of soil for the next 20 years. After this period the new building will face the same problems due to subsidence.

Vegetation

- Schools are planting vegetation and gardens to absorb the water faster.

Wall art and signs

- The students are made aware on how to act during an natural disaster.
- Evacuation maps.

Figures - Responses of the schools on floods and ground subsidence

6.3.4 Questionnaires and interviews

In addition to findings during the field visit, interviews with teachers were conducted to find out what they think about the current classrooms and what they would like to see differently and students received questionnaires in which they could rate their current classrooms in terms of comfort and indicate what they think is still missing in the classrooms.

6.3.4.1 Questionnaires

The purpose of the questionnaires was to gather the perspective of the students of their current classroom in terms of temperature, light, sound and space. Questionnaires were taken from students at each school. The students that filled in the questionnaires contained girls and boys, from grade 6 to grade 10. The questionnaires provided information about what a student finds a pleasant learning environment in terms of comfort.

Hobo measuring equipment was used to measure the temperature in the classrooms. The dimensions of the classroom were documented to determine the number of square meters per student.

The indoor temperature and air velocity were measured while the students were filling in the questionnaire. The results of the questionnaire is shown in figure 4.

Temperature:

Majority of the students and teachers felt slightly cold in the classrooms with air conditioning, and they preferred the passive methods for thermal comfort.

Light:

Most of the students and teachers prefer natural light instead of using artificial light.

Acoustic:

Teachers and students had concerns regarding noises from other classrooms and outdoor activities.

Space:

Most of the students were pleased with the amount of space they have in the classrooms.

In chapter 9, design solutions will be described how the preferences of the students and teachers can be implemented into the design.

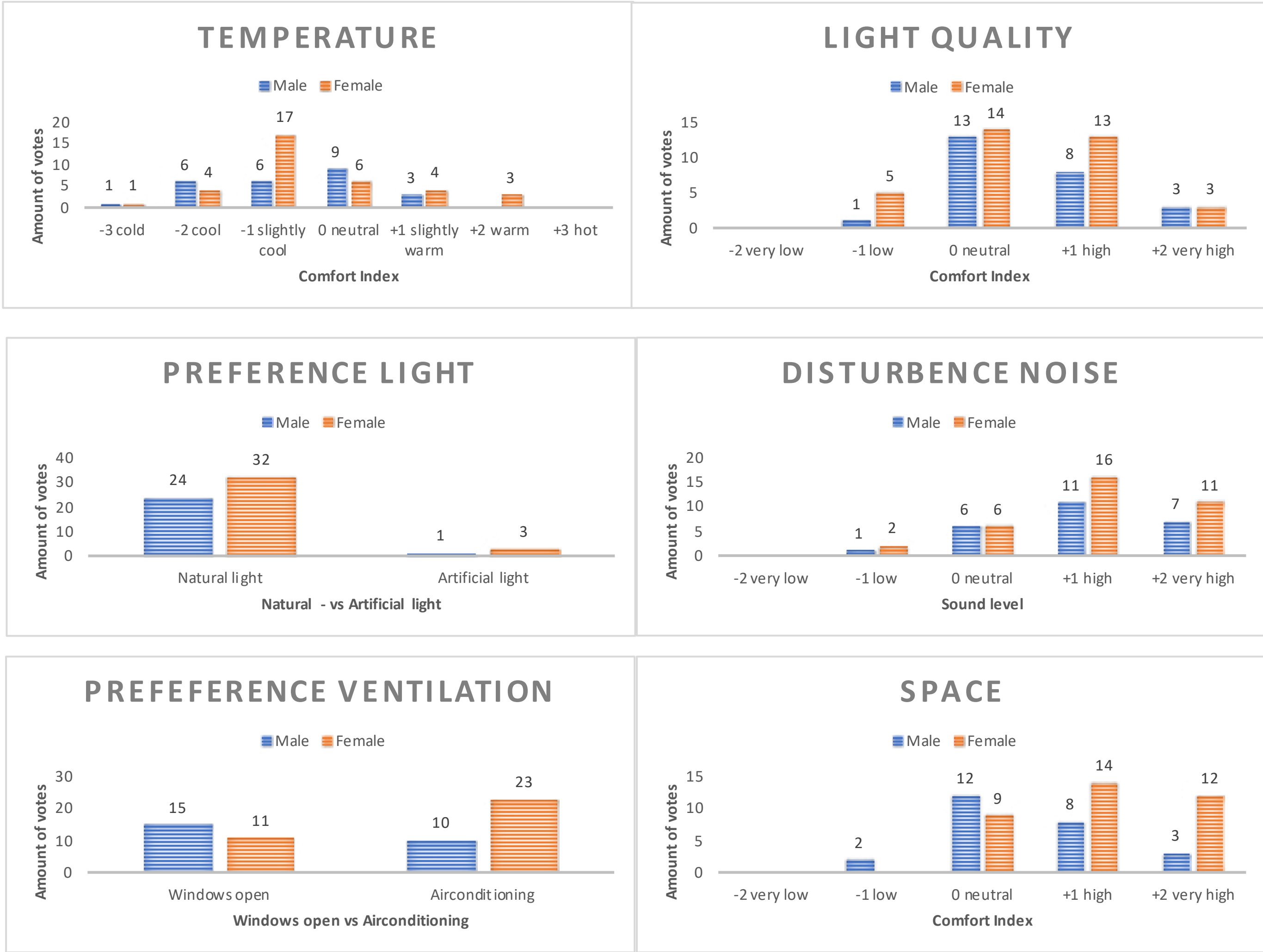


Figure 4 - Results of questionnaires

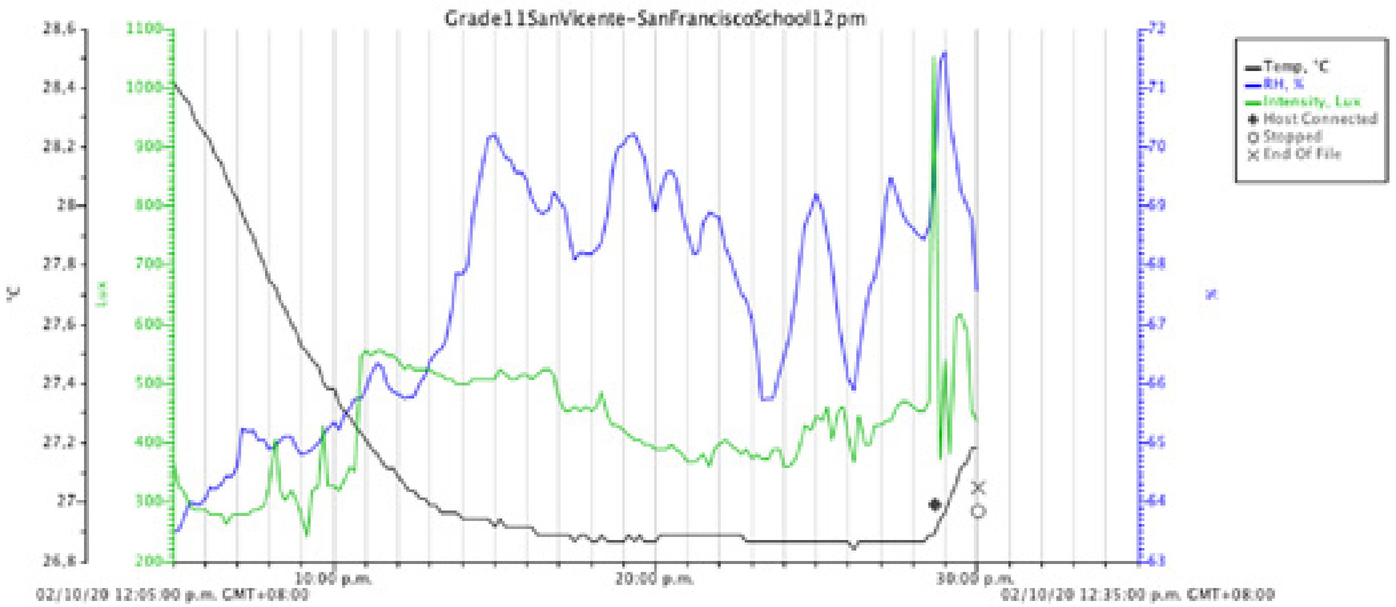


Figure 5 - Hobo measurement classroom of San Fransisco school

6.3.4.1 Interviews

The purpose of the interviews was to understand how teachers think a classroom should be designed. The teachers were asked to indicate what they are currently missing in their current classrooms and what can be improved. At least three teachers from each school were interviewed. The interviews were recorded, the interview and of the results can be found in the appendix.

The questions asked in the interview arose from specific topics. The topics on which the questions were asked were: general, school design, indoor comfort and flooding.

Based on the answers of the teachers, the following describes the most critical answers per topic that can serve as input for the design.

General:

Teachers speak about the influence of the western world on the design of the classrooms. The classrooms are designed according to the western standards based on designs with much concrete made for four different seasons. They would like to see more traditional based designs with the use of local materials as for example, the Bahay Kubo. The school should be the cultural identity in which the students learn about their cultural background, so do the identity of the region does not go away.

School design:

The new classrooms work well for learning because they're wider and safe for students in use. In terms of flexibility, teachers mention they have a lot of demonstrations and presentations in the classroom so they prefer a spacious classroom in which the furniture is not fixed so they can create their own setting. The colours in the classroom are set by the DepED; teachers mention they would like to influence the colour schemes because they think this will affect the children, especially the younger ones.
Most of the classrooms now are designed with windows towards the corridors; the teachers mention that this distracts the students, and as a solution, they close the curtains. Most teachers are enthusiastic about the creation of outdoor spaces and greenery in and around the classroom, this would promote learning diversity, and the students come into contact with the environment.

Indoor comfort:

Most of the teachers mention that the ventilation in the classroom is not sufficient enough. Most of the classrooms are using electrical vans only or in combination with air conditioning. Some teachers mention they would prefer to use natural ventilation but note that there is almost no wind in the summer. To block out the direct sunlight, the teachers like to close the curtains, which leads to poor lighting inside the classrooms. Most of the teachers prefer to make use of natural light.

Regarding the acoustical quality in and around the classrooms, teachers mention that when there is to much noise from the outside, they prefer to close the windows, which makes it hotter inside the classrooms itself.

For some schools, the remaining floodwater was a problem in terms of fresh air. When the flood goes away, the classroom still keeps the smell of the floodwater, creating an unpleasant learning environment.

Flood:

Many classrooms on the ground floor have already had to raise the floor several times. The teachers indicate that this makes the classrooms very compact and a lot warmer than before, the classrooms are getting darker, which affects the students.

The teachers would like to have a good drainage system in and around the classrooms to drain the water as quickly as possible.

The floods also have an impact on the lessons; many classes are cancelled. One of the principals indicated that they continue giving classes even in the occurrence of a flood by looking at which classrooms are available and then create an adjusted schedule with the classrooms to be used.

Figure 6 - Conducting the interviews

6.4 Project location

The project location concerns the school Colegio de San Lorenzo. The school suffers from flooding abd experience daily the consequences as described in the previous chapters. In most classrooms, the floor has already been raised four times and the classrooms are becoming less comfortable. Since raising the floors is only a temporary solution, the director Bembong has the ambition to build six floating classrooms.

6.4.1 Depth of the pond

Behind the school is a former fish pond that has been made available as a location for the floating classrooms. The pound has a length of 144 meters and a width of 42 meters.

The depth of the pound was mapped during the field research. Because the barrels of the floating foundation can sink for a maximum of 1 meter, which is equal to the height of the barrels, a minimum depth of 1.2 meter is required. The lowest point measured in the pound was 1.45 meters, which is suitable for what is required for the floating foundation.

These measurements were taken in February 2020 during the dry season in the Philippines. The expectation is that the level of the water will increase by approximately. X meter in the rainy season.

6.4.2 Orientation and wind

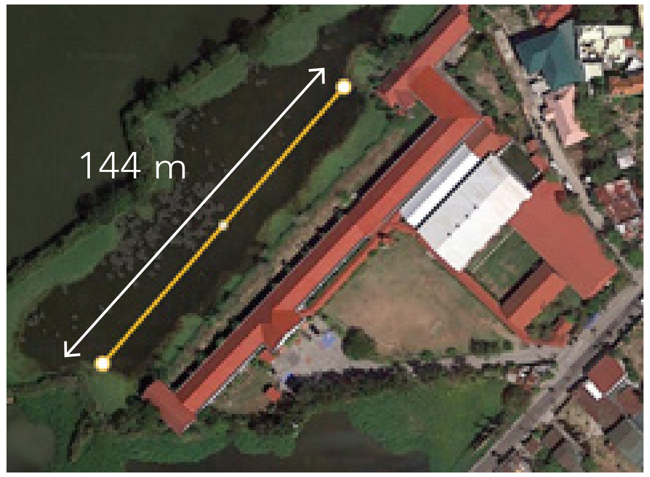
The pond is located behind the school building the main direction of the pond is from south-west to north-east. Based on chapter 4.2, the wind is expected to come from the north-east during the period from March to May and from the south-west during the period from June to October. The orientation of the pond fits well with the expected wind directions in order to provide the classrooms with natural ventilation.

6.4.3 Waves

The wave action that can occur in the figure will mainly come from wind. This aspect will have to be further investigated to check how much impact this has on the stability of the floating greenhouse buildings and what kind of wave action can occur.

6.4.4 Accessibility

The accesibilty to the floating classrooms is further described in chapter 10.



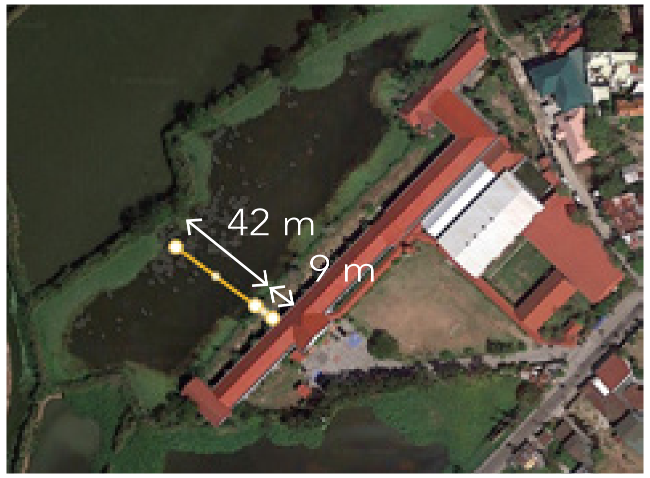
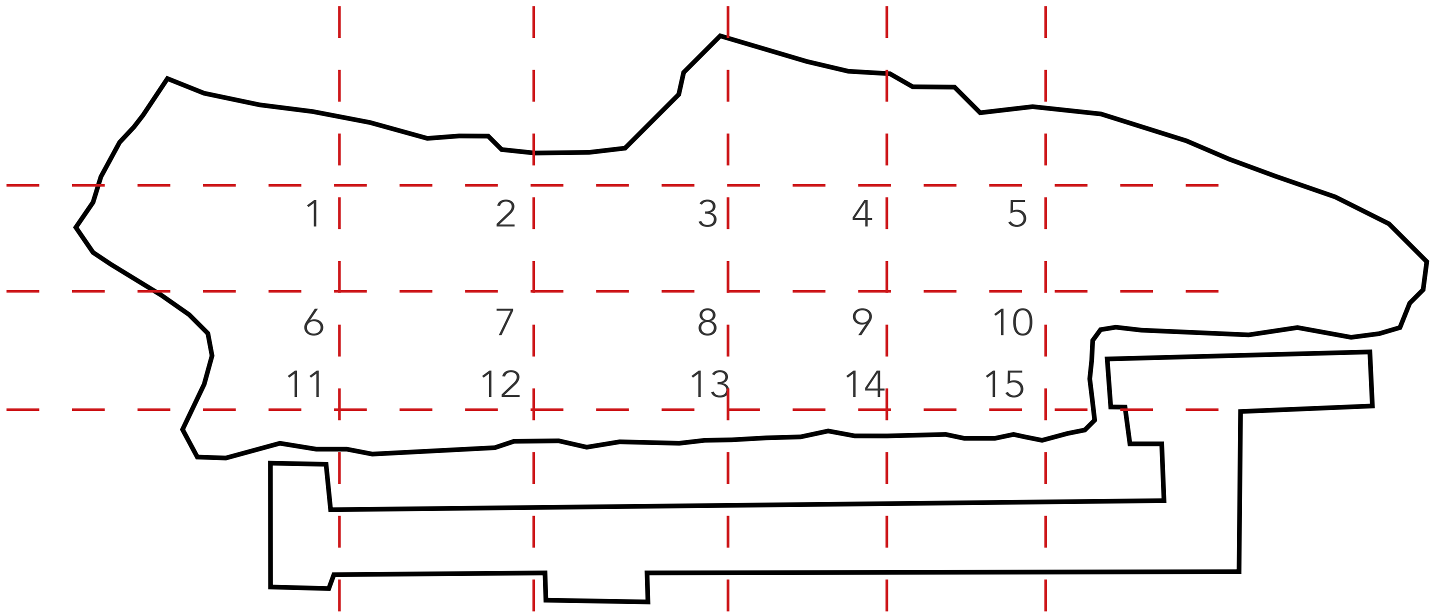


Figure 7&8 - Size of the pond behind Collegio de San Loreno



1	1.7 m	2	1.9 m	3	1.55 m	4	1.9 m	5	1.9 m
6	1.9 m	7	2.05 m	8	1.65 m	9	2.2 m	10	2.2 m
11	1.75 m	12	1.75 m	13	1.8 m	14	1.8 m	15	1.45 m

Figures - Water depth of the pond behind the San Lorenzo School

Part D: Design framework

7. Design analysis

7.1 Introduction

The analysing the Finch Floating Home and the conducted field research in the Philippines already identified certain aspects that should be taken into account when designing the classroom. This chapter will describe which challenges came across by analysing the Finch Floating Home and during the field research and what solutions can be found which provides input for the classroom design.

Chapter 2, goes deeper into the local materials, in particular the challenges they entail and how they can be solved. Chapter 3 discusses why this building shape has been chosen for this design. Chapter 4 describes the improvements for the floating foundation and the design. Chapter 5 describes the structural framing of the classroom. Finally, chapter 6 illustrates the building sequence of the classroom.

Figure 1 - Photo of a classroom of the Macabebe Elementary School

7.2 Materials

The design principles describe certain criteria to guarantee the sustainability of the project, including the choice of materials used. J. van Schaik (2016) researched which material meets the design principles. The research looked primarily at the different materials and a comparison was made of the four most common building materials in terms of sustainability. The comparison showed that wood is the most sustainable choice and also locally present, which promotes the local economy. In this research the choice of the type of wood that was used is based on the types of wood encountered during the field visit.

Wood has many advantages, such as high strength, easy shapeable by simple tools and suitable for prefabrication. However, the use of wood comes with some challenges. In this chapter the challenges of wood and workability are decribed so that the right solutions can be found and be included in the design.

Fire

One of the biggest challenges of working with wood as a construction material is its flammability. In the event of a fire, an insulating charcoal layer is formed the surface that delays spread of the fire. An advantage of wood is that it does not lose its strength in a fire like steel does.
Solutions to increase fire safety is to increase the dimensions of the essential structural components so that it still has the correct structural dimensions in the event of a fire, including the charred layer. Applying a fire- resistant coating is an altyernative option. However, compatibility of coatings with the local wood species has been researched as well as the environmental burden of these products are.

Weathering & decay by funghi

To be able to use wood for a certain lifespan, it must be protected against fungi. Fungi break down wood with a type of digestive juices: enzymes. These only work in an aqueous environment. Without water, the action of enzymes stops and the attack of fungi's is not possible. Wood contains sufficient water for fungi from a moisture content of approximately 22% fungi then still grow slowly. Only under higher wood moisture contents, fungi spread faster. Fungi can only affect wood if it remains moist for a long time. In addition, some types of wood have a certain naturally resistance against fungi. As a result, damage does not occur, or only after years of moisture exposure. Wood that regularly comes into contact with water and is not allowed to dry completely, is more likely to be affected by fungi than wood that is permanently underwater or cannot come into contact with moisture. (RDMZ, 2001)

Logban Policy

As of February 1, 2011, the Philippines has started the wood ban policy, as a result of the masses of felled forests and the additional problems such as landslides and floods. This policy forced the land to import construction wood from elsewhere in the world. This ensures that the range of types of wood is very different per supplier. (Eco-business)

The NGP is working on a reforestation program. Tree species planted under the NGP include mangroves; fuelwood, to supply the country's fuelwood requirement; as well as wood to feed the country's wood industry for raw materials.

Local suppliers
During the field research multiple local construction material suppliers were visited. The main purpose of these visitations was to see what type of wood and at what dimensions are locally available. The main purpose of these visitations was to see what kind of wood and at what dimensions was the wood available.

All local suppliers do not deliver or store goods like in Europe. They do not work with standard dimensions. This is due to the lack of local demand and partly to the orientation of the industry to export contracts (van Schaik. J, 2016)

The dimensions offered by the local suppliers were mainly dimensions that are not large enough for the main supporting structure, but can instead be used for facade cladding, floor parts, etc. Almost all types of wood went up to a maximum length of 3 to 4 meters, but it was noticeable that this often leads to a slight skew in the beams. The wood that was present at the local suppliers were red meranti, yellow meranti, pine wood from ukraine and pine wood from new zealand.

Since both the two pine woods are imported products and dont fit to the according design principles of using locally produced materials the Yellow meranti is used as wood type for the construction of the floating classroom. Yellow meranti can be easily produced with hand tooling and machines withouth any problems (Centrum-hout).

Figure 2 - Locally available wood

Figure 3 - Skew in the beams

7.3 Shape

In terms of the shape of buildings there is chosen for a octagonally building shape. The decision to choose for an octogan shape was based on the studied literature in the background section. The criteria for the shape are aerodynamics, expandability and orientation.

7.3.1 Aerodynamics

In chapter 5.3.4. a study described the aerodynamic efficiency of different building shapes. (figure 5) Looking at the outcome of this study, the shape that performed best in terms of aerodynamics is a circle followed op by a dodecagon, and then followed up by an octagonal shape.

The circle and dodecagon perform better in the field of aerodynamics, but it is also essential to consider the consequences of choosing one of these shapes in terms of marketability. The circle and dodecagon cause more problems in terms of making the construction elements of the classroom. A circle has a lack of corners, so it requires curved elements which are not offered as standard elements in the building industry. The dodecagon has four more sides than an octagonal, which in turn yields to more connections that have to be made and have a chance of collapsing during a typhoon.

Chapter 5.3.4 also describes the effect of row-planning of buildings. Row planning should be avoided not to create wind tunnel effects between the different shapes. Looking at an octagonal shape in terms of row planning, this can easily be avoided due to the eight different sides; a new classroom can be connected.

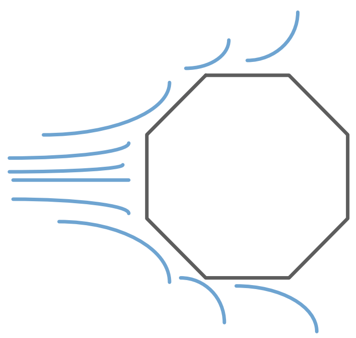


Figure 4 - Aerodynamic shape octagonal

	Drag Coefficients of Multisided Cylinders (Re 10K)			
	Number of Sides	Wind Tunnel	Design Code [1]	ANSYS-CFX
	Square - 4	2.0 [2]	1.7	1.92
	Hexagon - 6	NA	NA	1.83
	Octagon - 8	1.0 ~ 1.6 [3]	1.2	1.59
	Dodecagon - 12	1.2 ~ 1.6 [2, 3, 4]	1.2	1.33
	Cirkle - 1	1.2 [2,3]	1.1	1.23

Figure 5 - Drag Coefficients (Lisowitch, 2014)

7.3.2 Expandability

When a school desires more than one classroom, the octagonal shape offers eight sides to which the next classroom can be connected. This ensures that there are many possibilities when it comes to expanding the classrooms and the desired paths that can be formed with them.

Figure 6 and 8 show examples of the options available to grow a cluster of classrooms in different ways. Also, looking at these clustering, it can be seen that the described wind tunnel effect mentioned in 7.3.1. is prevented.

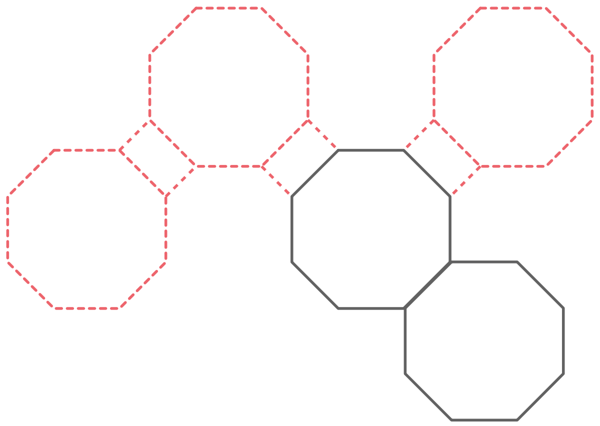


Figure 6 - Expandability of an octagonally shape

7.3.4 Flexibility in orientation

One of the design strategies in chapter 4.4 states that the classroom should be adequately orientated to minimalize the amount of solar heat gain, direct sunlight, and to maximize the entrance of breeze of air currents.

The advantage of an octagonal shape is that there is no dominant facade side, for example in comparison with a rectangular shape. Figure 6 illustrates the orientation of two different shaped buildings, one octagonally shaped and one rectangular shaped. The rectangular-shaped building is orientated in such a way that the longest sides of the building are as less exposed to direct sunlight as possible. Looking at the octagonally shaped building, all the sides of the building are of the same size meaning there is no dominant face side which provides flexibility in orientating the building on the location.

The same applies to the orientation based on the wind direction. In chapter 4.2 it is mentioned that in the Philippines there are two monsoons which mostly brings the wind from a specific direction during these seasons the northeast wind during the northeast monsoon and the south-east winds during the south-west monsoon. The wind direction, in combination with the sun orientation, could be the dominant factor for placing a building with a rectangular shape with the result of having less flexibility in orientation.

With both the wind and sun orientation, the placement and orientation of an octagonally shaped building are freely divisible.

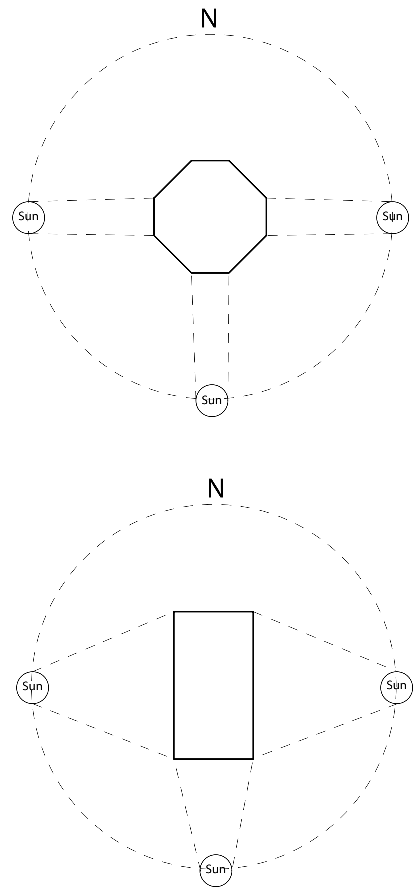


Figure 7 - Orientation based on the sun

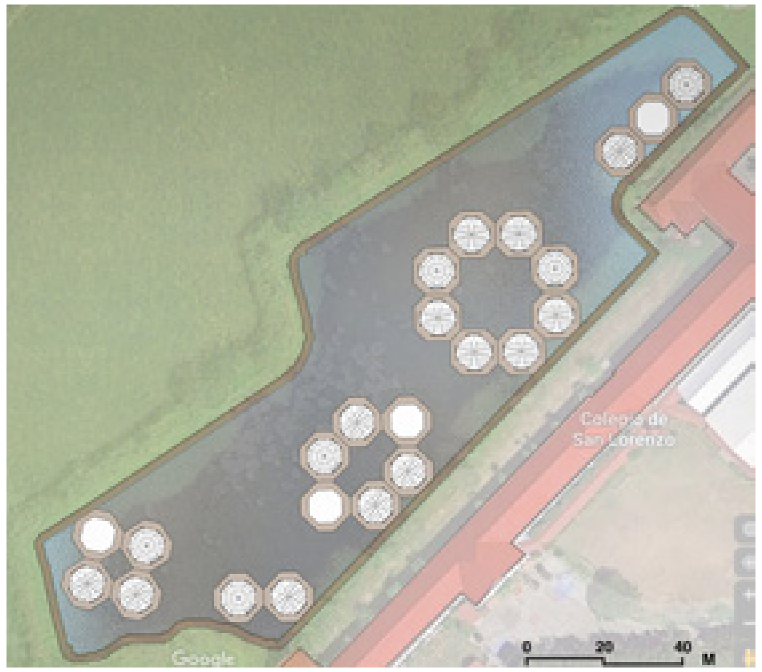


Figure 8 - Possibilities of clustering

7.4 Foundation

For the design of the foundation modules, an analysis is made of the current foundation modules that are used in the Floating house. The analysis considered which aspects of the design can be used and which aspects can be improved. An interview with desginers/ buiders of the Floating home was part of the analysis

7.4.1 Floating modules floating house

For the floating house prefabricated floating modules are used. Every module consists of 16 barrels that are kept together in a wooden frame with the standard dimensions of 2.5 x 2.5 x 0.6 meters. Because each module has the same dimensions and building method, the construction speed will increase considerably as more modules are built.

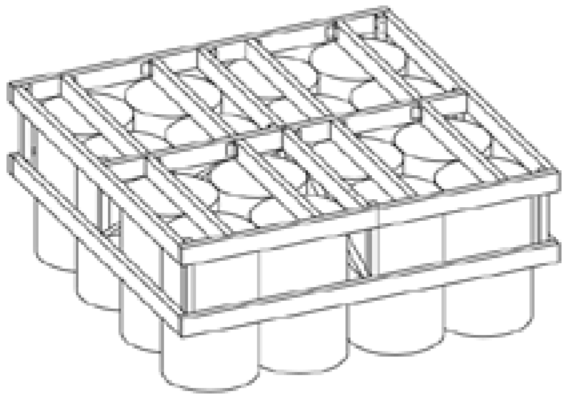


Figure 9 - Floating module of the floating house (Ham, 2018)

The modules and barrels were transported separately from the construction site to the project location. The barrels were connected to the module by means of ropes on site. Ultimately, the modules were lifted into the water, and the various modules were connected to each other on the water by means of bolted connections

The standard module of the floating home also offers certain flexibility. The module can be used for other functions besides homes.The simple connection between the modules gives the possibility to expand buildings or to connect different buildings together.

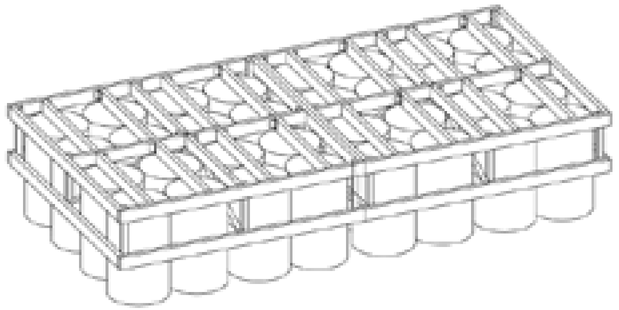


Figure 10 - Floating modules connected (Ham, 2018)

During an interview with Joran and Pieter, several questions were asked about the floating modules and what problems they encountered while building the floating module.

Problems encountered during the realisation were:

- Weight of the floating module, eight men were needed to lift a module woth 16 barrels.

- Oversizing of the trusses, double profiles emerge add merging of modules.

Chapter 7.2 describes that wood lasts best if it has as little contact with water as possible. In the current design of the floating modules, the barrels are surrounded by the 0.6-meter high frame. The barrels used have a height of 1 meter, which means that there is a height difference of 40 centimetres between the bottom of the barrels to the beginning of the wooden frame. Due to the weight of the building and the number of people in the building, there is a high possibility that the 40 centimetres get exceeded this causes that the wood has a great chance of getting exposed to water. In the longer term, this can have an impact on the life span of the wood.

During the field trip, it was noticeable that many barrels were out of position in the frame. (See figure 12) Besides the fact that this gives a less attractive appearance aesthetically, this can also pose a problem for the barrels in the longer term. Figure 12 shows that due to movement of the barrels, one of the barrels has deformed because it is pushed against the wooden frame. For now, this barrel was still intact, and it retains its buoyancy; however, practice will have to show what effect this will have on the barrel in the long term.

Design input

Analysis of the floating modules of the Floating house provided the following input for the design;

- Standard prefabricated floating module, which is easy to prefabricate.

- Bolted connection which makes it easy to connect the differen modules on site.

Figure 11 - Connection of barrels and dubbel truss beams (photo by P.Ham)

Design improvements

In addition to design input, design criteria can also be derived from the analysis. The design criteria are the mean points that could be improved while creating a new floating module.

- Reducing the weight of the floating module.

- Increasing the height between the bottom of the barrel and the wooden frame.

- Avoid over-dimensioning of the trusses.

- Prevent the movement of the barrels.

Figure 12 - Displacemet of barrels after 1,5 years

7.4.2 Improvements

The design input and observations from 7.3.1 are used for the design of the floating module. The floating module of the floating house was used as a starting point.

Size of the module

The size of a module has a significant impact on the total weight of a module. One of the criteria is to reduce the weight of a module so transportation and moving of the modules requir less effort. In the current design, a module consists of 4 segments with 4 barrels per segment with the dimensions of 2.5 x 2.5 meters. The options can be to divide the module into two parts or even into four parts (see figure x)

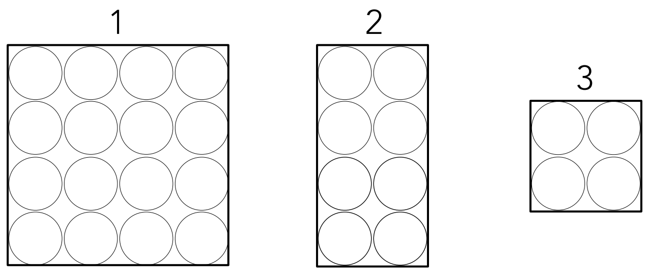


Figure 13 - Floating module of the floating house (Ham, 2018)

However, by reducing the size of the modules, more connections will be created between the modules to obtain the same desired surface area. The goal is to make as few connections as possible on the construction site itself. By increasing the amount of modules, the amount of connections is also increased.(see figure 14) Option 2 is chosen to reduce weight significantly and to keep the number of connections limited in practice.

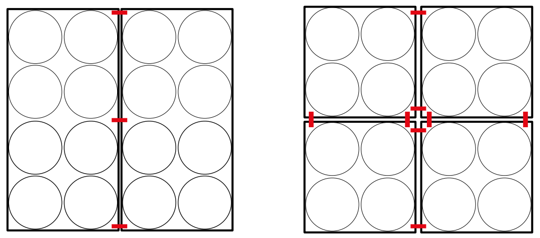


Figure 14 - Floating module of the floating house (Ham, 2018)

Securing the barrels

To secure the barrels from movements it's important to fix the barrels at at least two places. The university of waterloo developed a method to secure the barrels that are used for the foundation of the NRC research pavilion.

These barrels are fixed in the top of the frame. There is a small offset in the diameter of the barrel, between the body and the lid which can be used to fill in to secure the barrel.

In addition to securing the barrels at the top of the frame, a cable is also stretched around the barrels to secure the barrels together in the middle/bottom part. (figure 15)

Figure 15 - Barrels secured in the frame of the NRC Pavillion (Buoyantfoundation offcial site)

Trusses of the foundation

The foundation trusses play an essential role in making the floating foundation act as a whole and distribute the forces equally. The criteria is to avoid over-dimensioning of the trusses and to diminish contact with water.

In the floating house, the truss beams are also used to keep the barrels in place. By securing the barrels as is done at the NRC research pavilion, it is no longer necessary to hold the barrels in place with the frame.

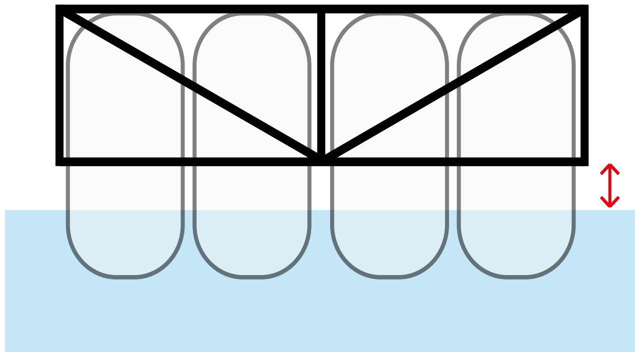


Figure 16 - Barrels placed inside the frame

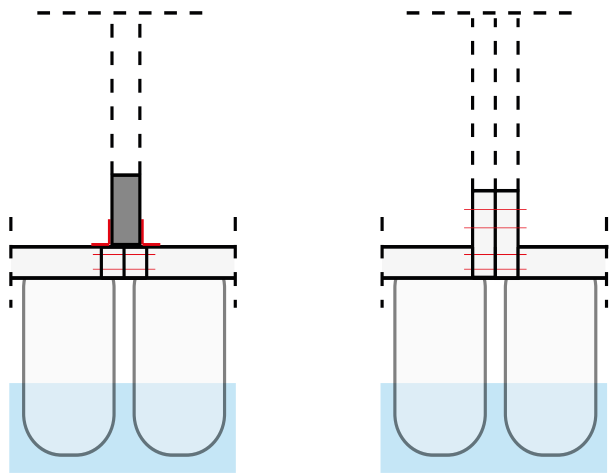


Figure 17 - Options for designing the truss

Instead, the framework can be mirrored so that the frame will be placed on top of the barrels. Placing the frame on top of the barrels reduces the chance of wood of the frame is being exposed to water alternately.

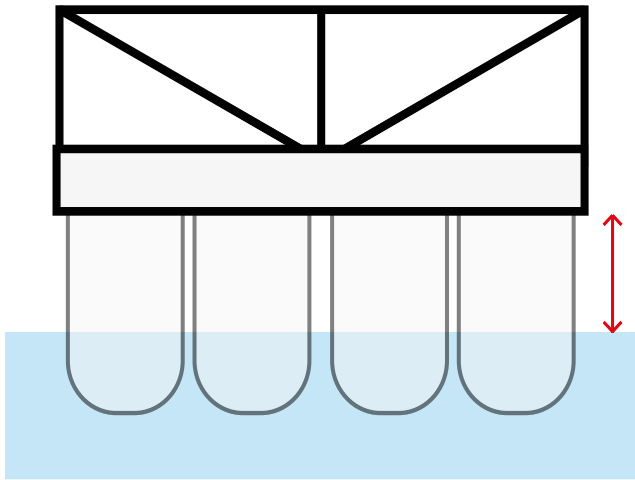


Figure 18 - Framed placed on top of the frame

7.4.1 described that the modules of the floating house is constructed in such a way that each module has its own frame and that the connecting of the modules creates double beamed frames. In order to prevent this, two options are considered to prevent material from being overused.

The first way is to reduce the size of the dimensions of the frames so that when the frames are linked together, a composed frame is formed that is able to meet the requirements set for strength and stiffness. The other option is to create floating modules without integrating a frame. In that case, the floating modules are first placed into the water and connected and later on the trusses will be placed and connected to the modules.

For this design, the trusses are constructed as separate prefabricated parts and installed after the platform of floating modules has been completed.

7.4.3 Design of the floating module

The design of the floating modules focusses on prefabrication, easy connections and to be able to replace a barrel while the modules are in use. These points will be briefly described in a short description, followed by order of placement when building the floating foundation.

7.4.3.1 Prefabrication

The floating module has a size of 1,5 x 3 meter and exists out of 8 barrels of 200 litres. Figure 20 shows the prefabrication process of prefabricating the floating modules.

The different parts are numbered from number 1 to number 7 which indicates the construction sequence. Now it is shown that they make the foundation supported on trestles, but in practice, this can vary. Part 1 is the composite beams that lie transversely in the frame; these are first temporarily supported by two beams. After placing component 1, component 2 will be screwed on the middle of component 1. Component 2 serves to keep the barrels in place.

After this, the barrel is placed on either side of number 2. By placing the barrel with the lid on number 2 and then connecting it through component 4, which is then also screwed to number 1. Now the barrels are clamped between the frames and can no longer fall out. Then the frame is covered on both sides by number 5, which is also screwed on. Finally component 6, the angle brackets are placed on both sides so component 7 can be connected to the brackets making use of bolts. The function of component 7 is to absorb the upward force from the barrel. After the placement of component 7, there will be a stainless steel cable stretched around and through the barrels, holding the barrels together at the bottom.

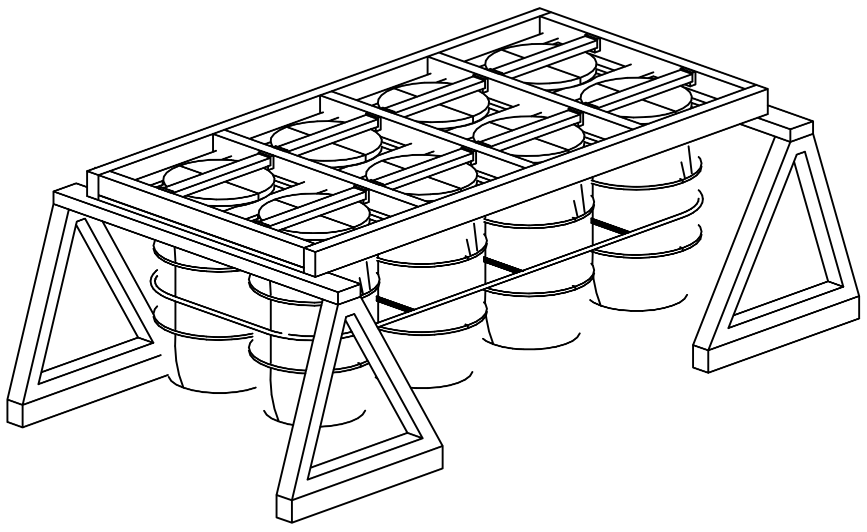


Figure 19 - Prefabricated module

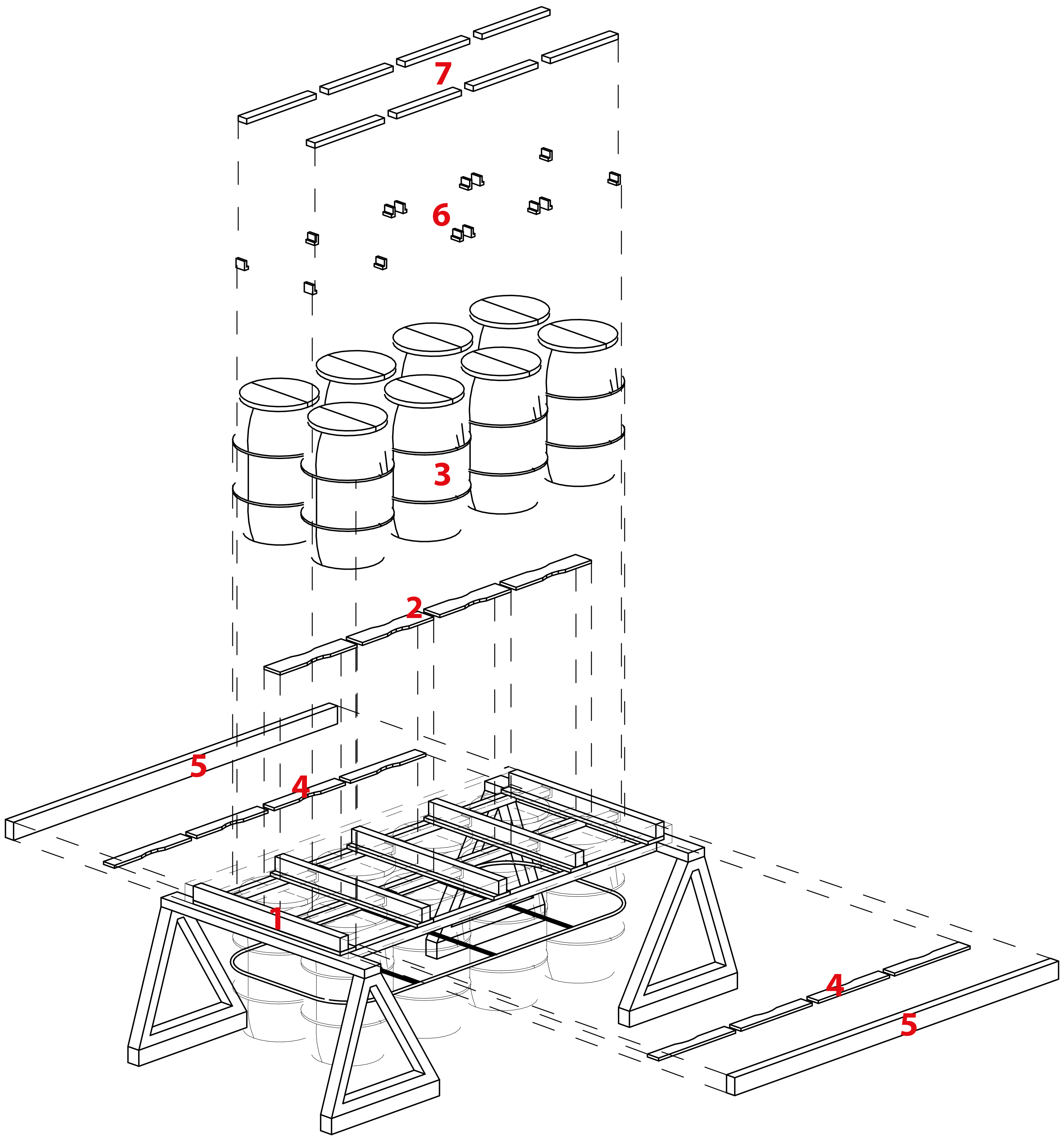


Figure 20 - Prefabricarting process of the floating modules

7.4.3.2 Connections

The different floating modules can be connected on the water by means of a simple bolted connection indication with red lines in figure 21. The amount of bolts required has to be further researched.

In total there are 24 modules of 8 barrels that are getting connected, what brings the total amount of barrels used at 192 barrels.

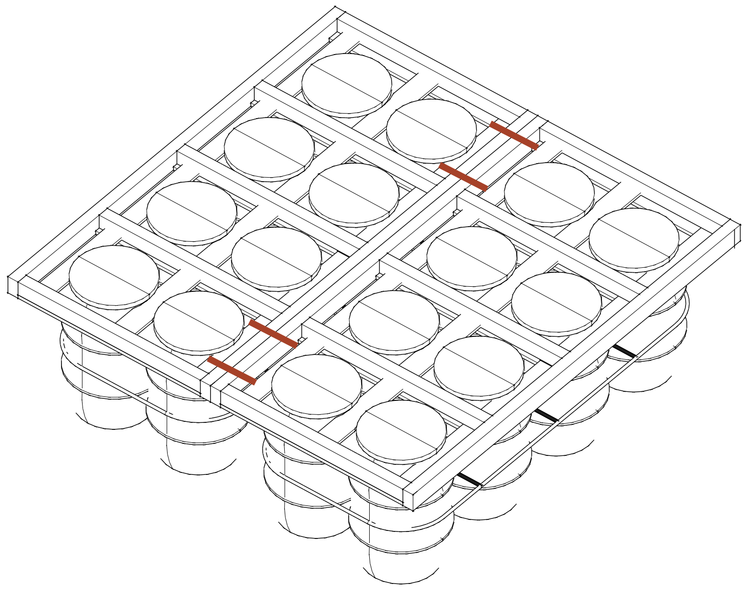


Figure 21 - Connection between the module

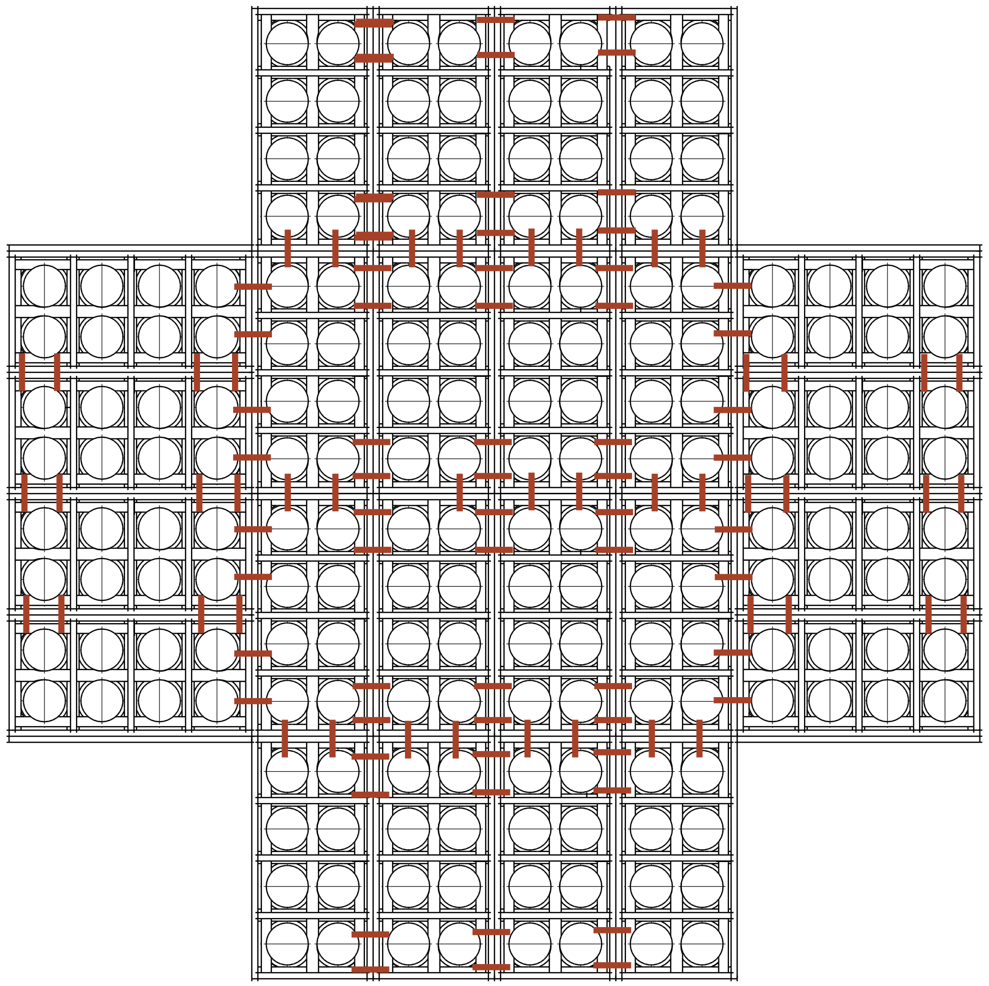
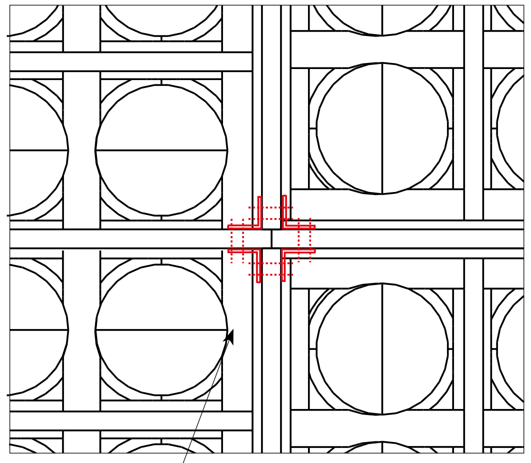


Figure 22 - Overview of all the floating modules connected

7.4.3.3 Trusses

After all the floating modules are succesfully connected the prefabricated trusses can fixed to the floating modules. Figure 23 shows the placement of the trusses on the floating foundation and the connection between the trusses. The highlighted zones in figure 18 indicates the spaces which are intentionally left open to save on the number of drums used.

The trusses must provide the foundation of the floating platform stiffness to distribute the forces evenly over the floating modules.



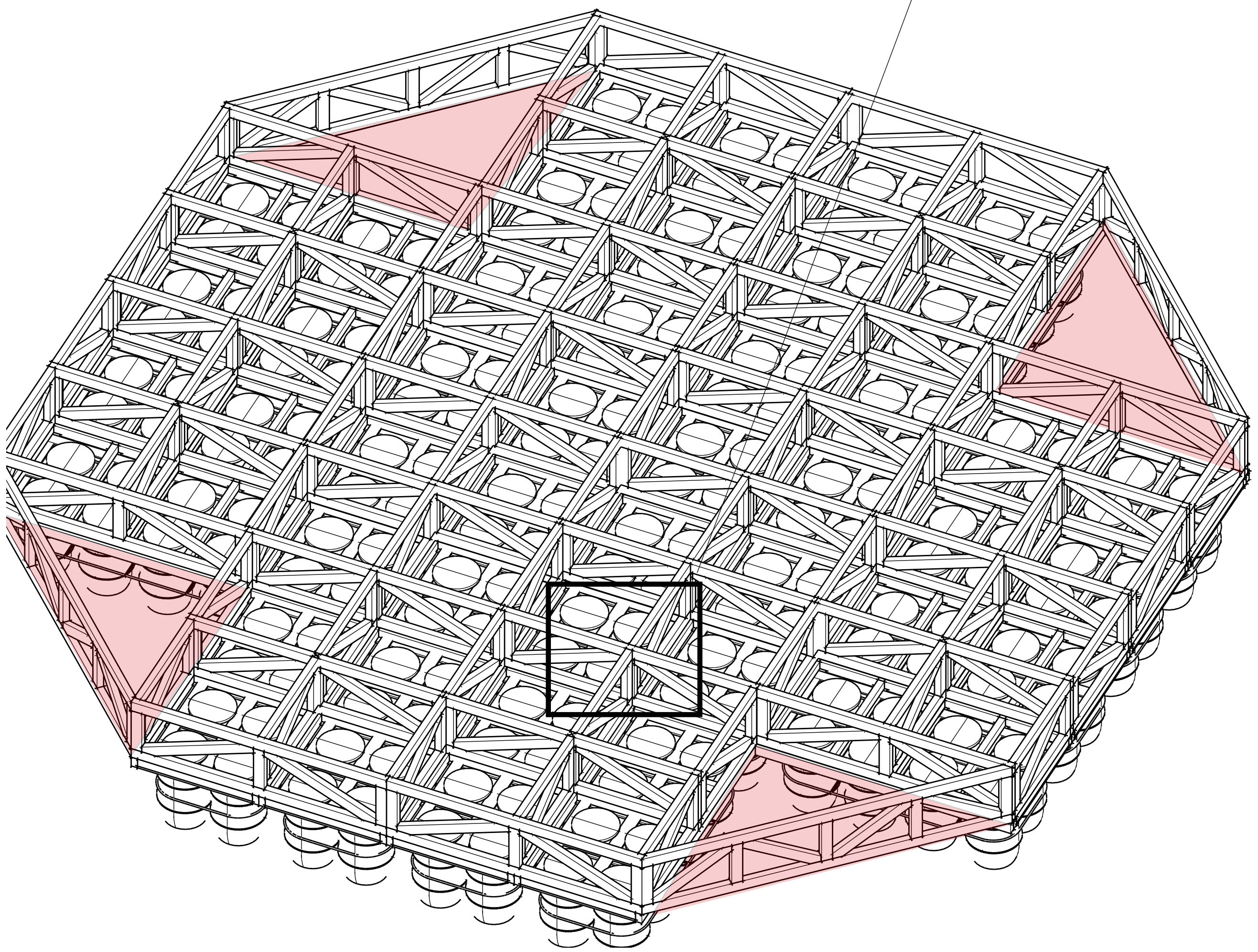


Figure 23 - Overview the trusses connected to the foundation

7.5 Structural framing

This chapter will further examine how the design of the structural framing is set up and what design decisions have been made.

Firstly there is a brief description of the principles that are the basis of why this particular type of structural framing is chosen. Secondly, it will be discussed which challenges there are in terms of workability and feasibility due to local circumstances and available materials followed by solutions that are based on case studies and references from the field trip. Lastly, an overall impression is given of the final design and in which order the structural frame can be made.

7.5.1 Type of load bearing elements

When building with timber, a distinction is often made between either a frame structure as a load-bearing construction or load-bearing timber-walls. A difference between the two supporting structures is that load-bearing frames mainly consist of line elements, so columns and beams and load-bearing walls are often composed of line and plate elements.

It is the challenge of the designer to determine whether the function of the building influences the choice of the load-bearing structure. For example, with the floating house, load-bearing timber frame walls are used. Here the load-bearing walls can be used to offer the privacy that is required in some cases for the function of residential housing. However, looking at the function of a school building the previously described principles for child-friendly school aim to provide classrooms with open spaces and transparency.

For the design of the classroom, there is chosen to use load-bearing frames as the main structure in order to provide flexibility in designing the building elements like the facade and offer flexibility in terms of the transparency of the building.

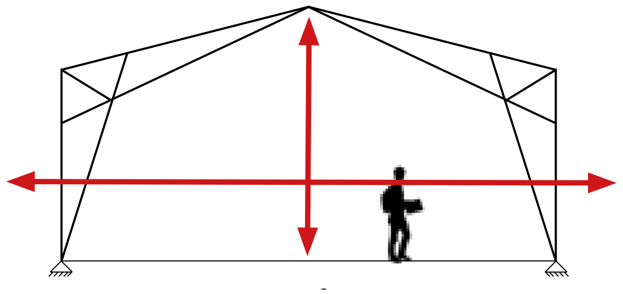


Figure 24 - Providing transparancy in- and outside the classroom

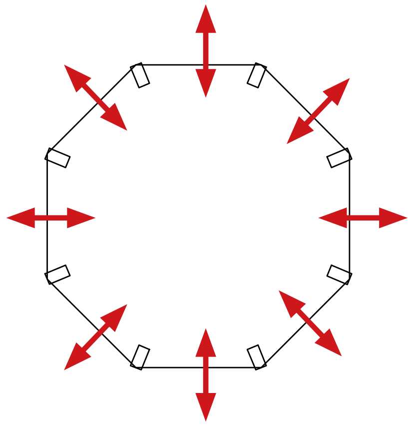


Figure 25 - Flexibility in the layout of the facade

Figure 26 - Different sizes of wood used

7.5.2 Challenges and solutions

Challenges

During the field research many buildings were visited that are constructed from wood. Figure 26 and figure 27 show two buildings that are visited. The building in figure 26 used to be an open-air classroom, but the DepEd did not allow the school to keep using it due to the lack of maintenance. The picture on the right is a storage building.

The similarity between the two buildings is that they both cover a large span through the use of a truss. Using a truss allows covering a considerable span through the joining of smaller construction parts that can also be prefabricated.

By analyzing the construction of the buildings and the visitation of the local suppliers some challenges emerged:

- The use of many different types of wood and dimensions that are used, which may indicate that local contractors use whatever they have in stock.

- Small dimensions and sizes of the wood profiles

- Skew in the profiles, which gets worse as the dimensions increase

- Poor quality of the connections

Figure 27 - Skews in longer beams

Solutions

After analyzing the case studies and buildings from the field research, some solutions are found on how to tackle these challlenges.

Figure 28 shows a detail of the Makoko floating school. They have created a double profile by connecting two individual beams through connecting them with spools of wood on some places fixed with bolts. Instead of wooden spools, this could also be done using steel plates in between the wooden profiles. Figure 29 shows the interior construction of the floating home. By making use of glue and screws, the two individual beams are fixed together and forms one of the main constructional beams for the floating house.

- Making of bigger spans by using triangular-shaped construction elements that are connected through hinged connections.

- the use of double profiles by gluing, screwing or connecting them together using spools of wood

Figure 28 - Connection details Makoko School

Figure 29 - Glued and screwed beams together

7.5.3 Design of the structural framing

Shape

To create a three-hinged frame without using any fixed connections, the corners of the frame are strengthened by creating triangular patterns in the corner.

Figure 30 illustrates a three-hinged frame with fixed corners and a three-hinged frame with strengthened corners. All connections of the elements in the frame are hinged; these hinged connections can transfer normal- and shear forces. By creating the triangular shapes in the corner of the frame, a rigid corner is created. The effect of this rigid corner will be similar to the effect of a moment fixed corner used in three-hinged frames. The frame covers a span of 4,25 meters and is 4.,2 meters high at the highest point.

Elements and connections

In figure 31, the final design of the structural frame is shown. The same principle of using double beamed profiles is used as in the Makoko floating school.

The space in between the profiles is on some places filled with connecting pieces between the different elements. The elements are connected through bolted connections.

Flexibility

The design of the frame is now used for an octagonal shaped building, but it could also be used for other shaped buildings, for example, a building with a rectangular floorplan.

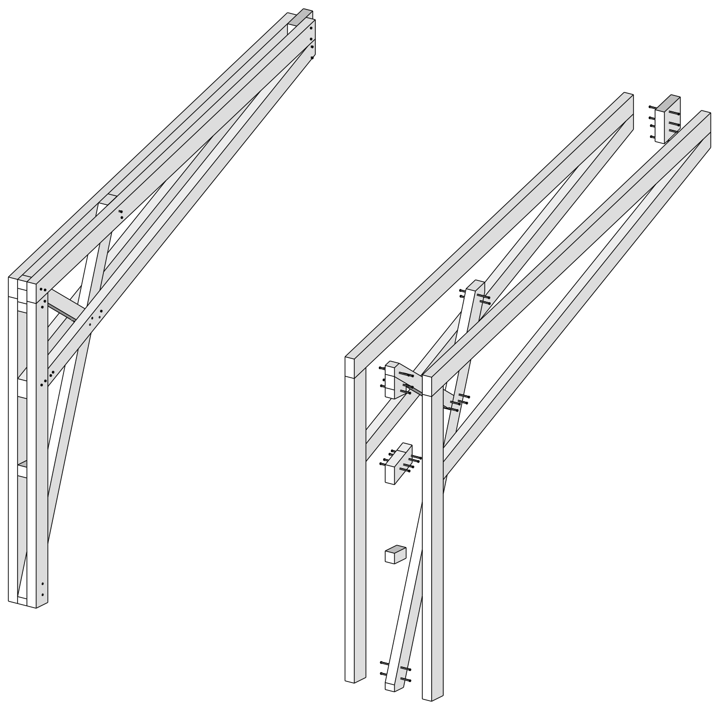


Figure 31 - Prefabrication of the frame

Prefabrication

The frames will be prefabricated and transporter to the building site. Once the frame arrives on site, it only needs to be connected to the pressure ring on top and to the steel plate, which is fixed on the foundation trusses. (figure 32)

All the frames are connected in the middle by a wooding octagonal. (figure 33) The ring is inspired by the construction of a traditional Yurt building. The construction of the pressure ring will be more explained in chapter 8.6.2.

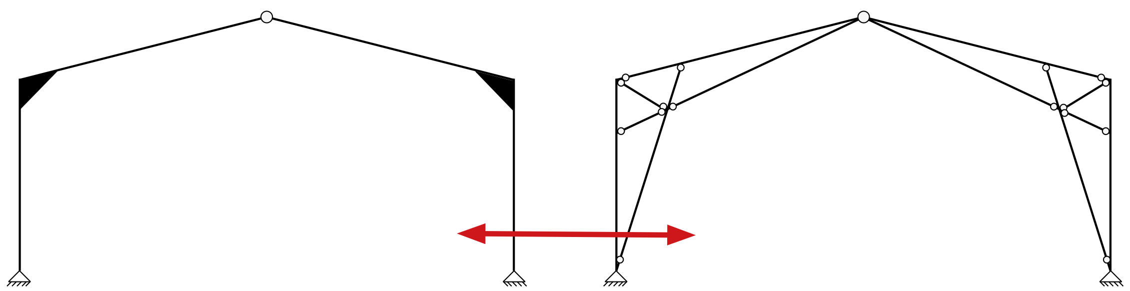


Figure 30 - Left a three hinged frame with fixed corners, right a three hinged frame with strengthened corners.

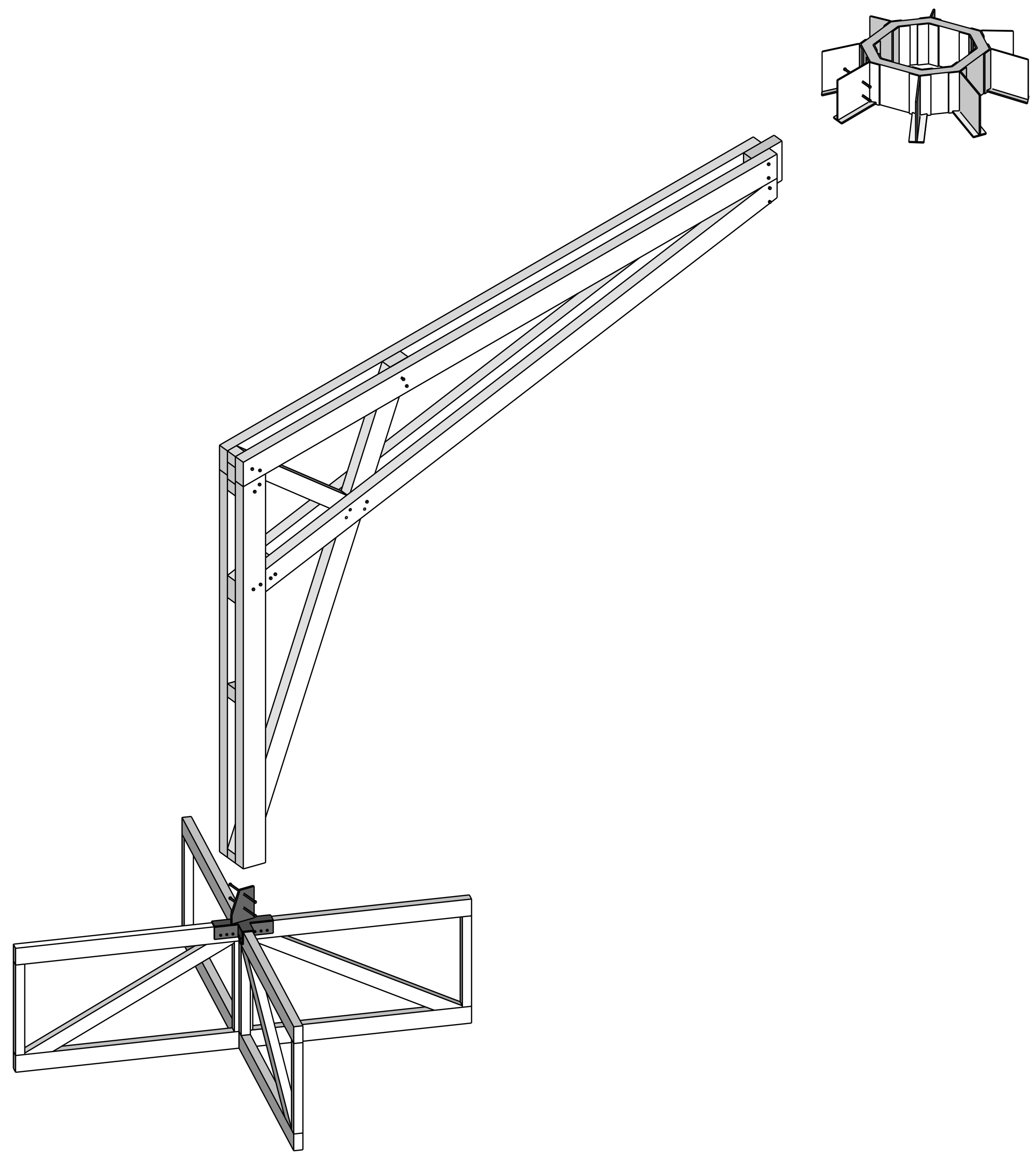


Figure 32 - Connectitng of the frame on site

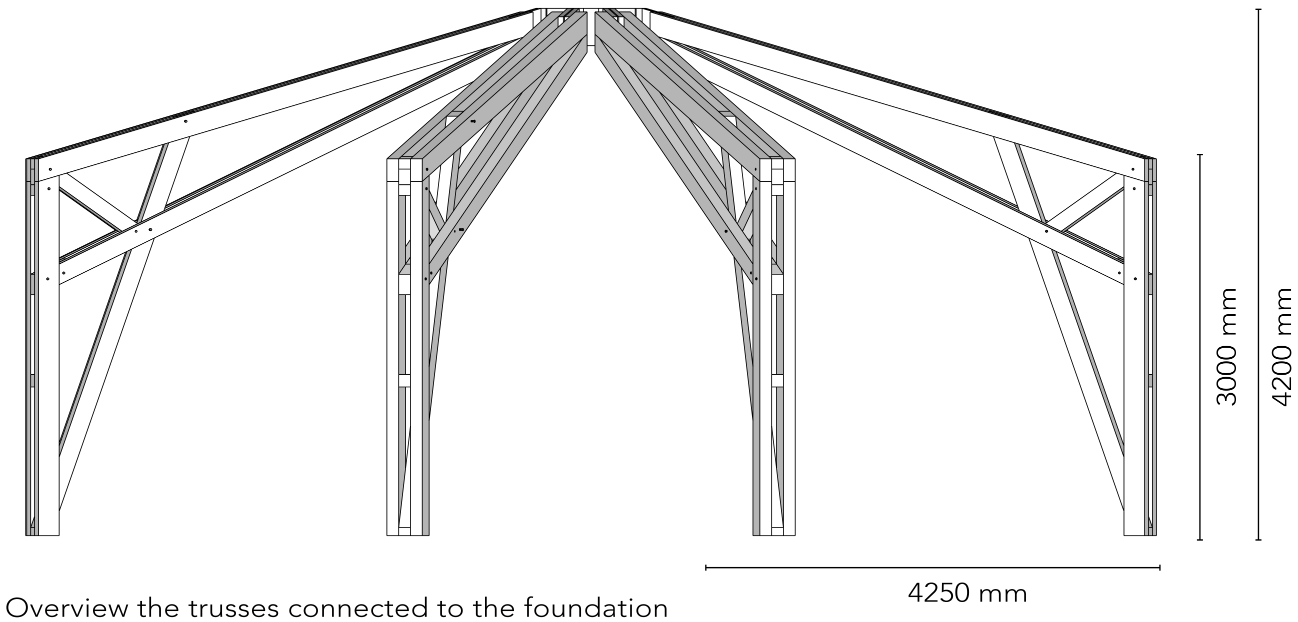
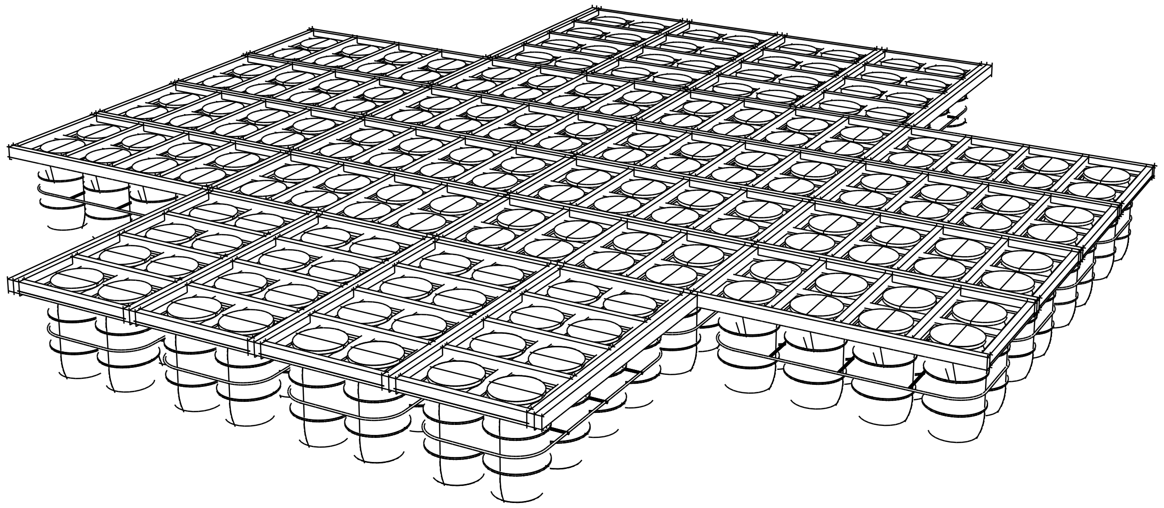


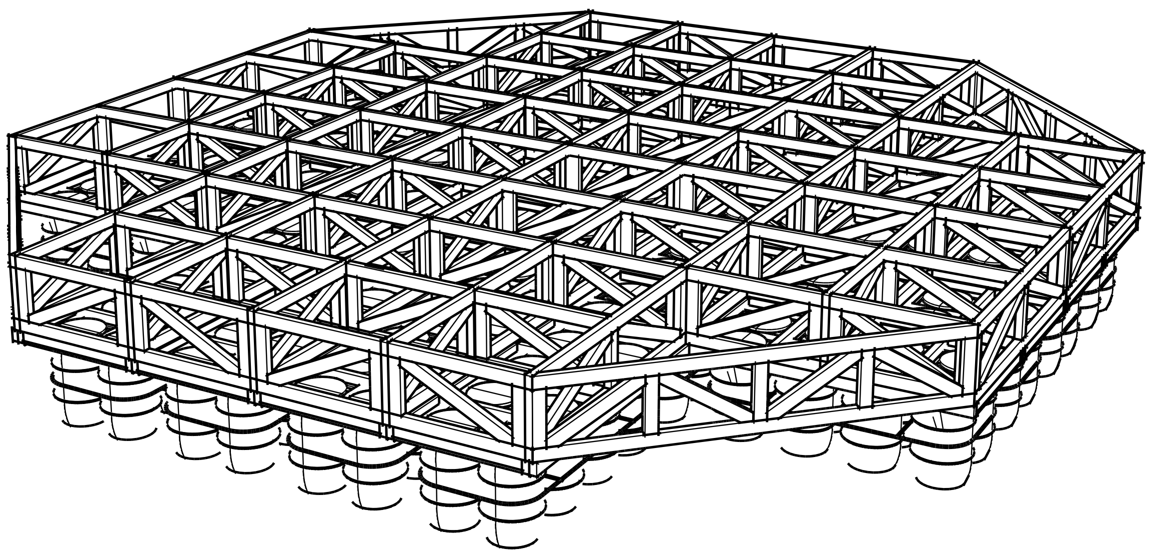
Figure 33- Overview the trusses connected to the foundation

7.6 Building sequence

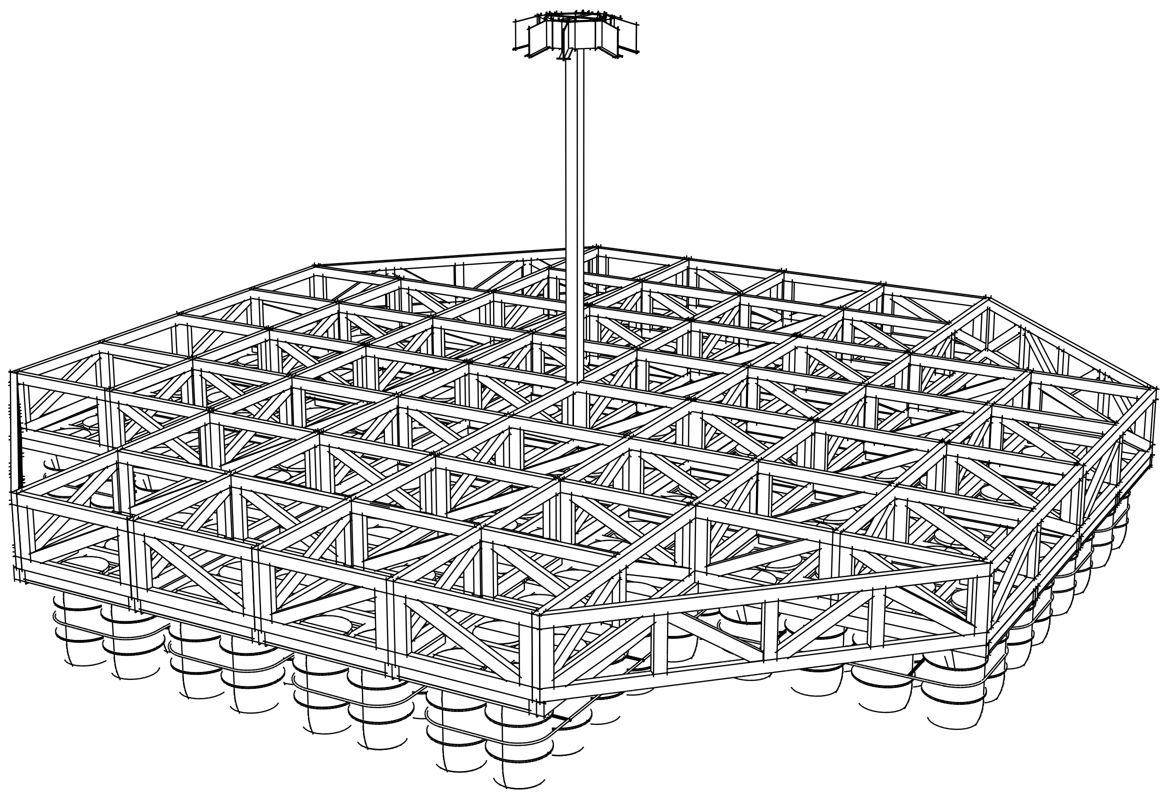
Step 1 - Connecting the floating modules on the water



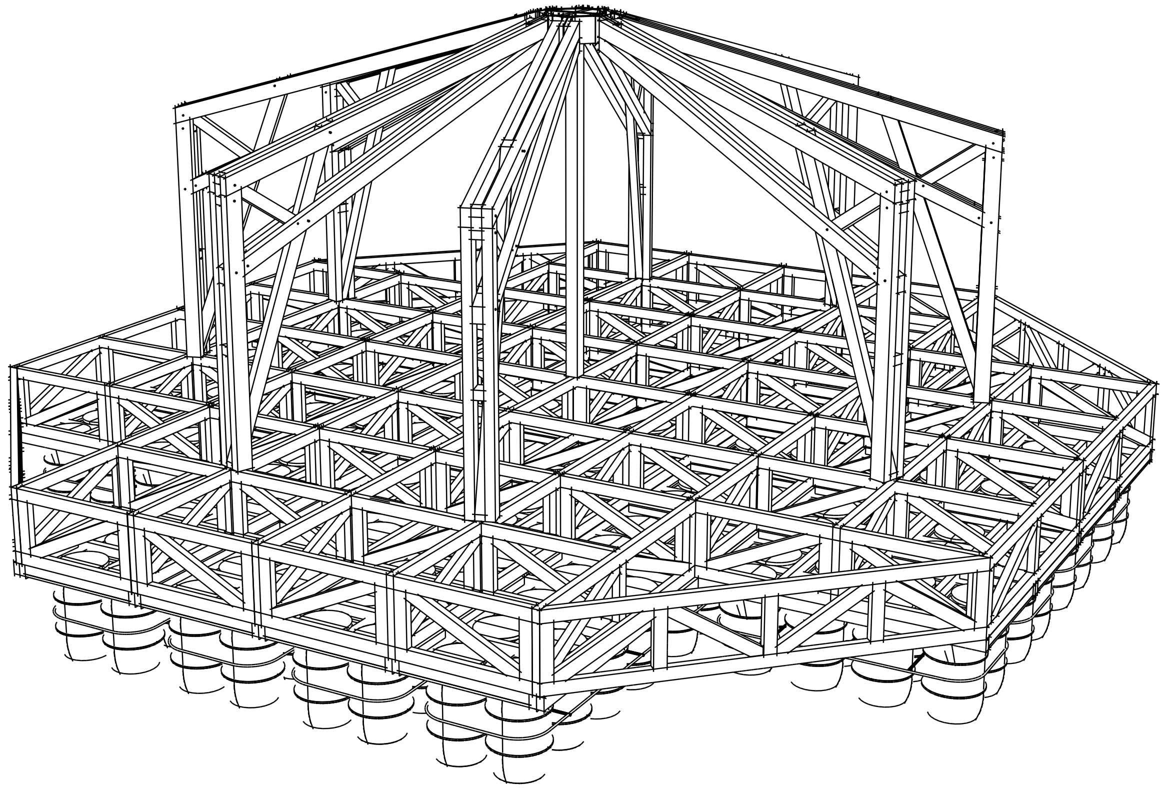
Step 2 - Connecting the prefabricated trusses on to the floating modules



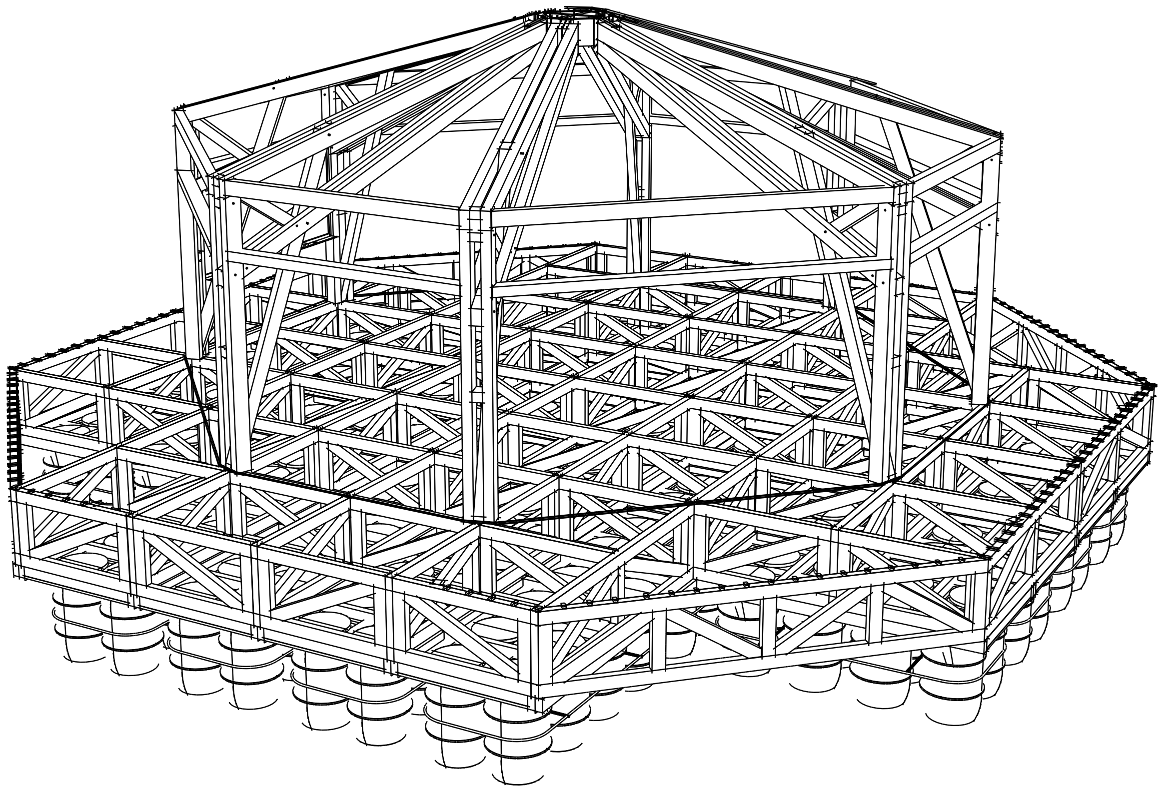
Step 3 - Placement of the pressure ring on a temporary column



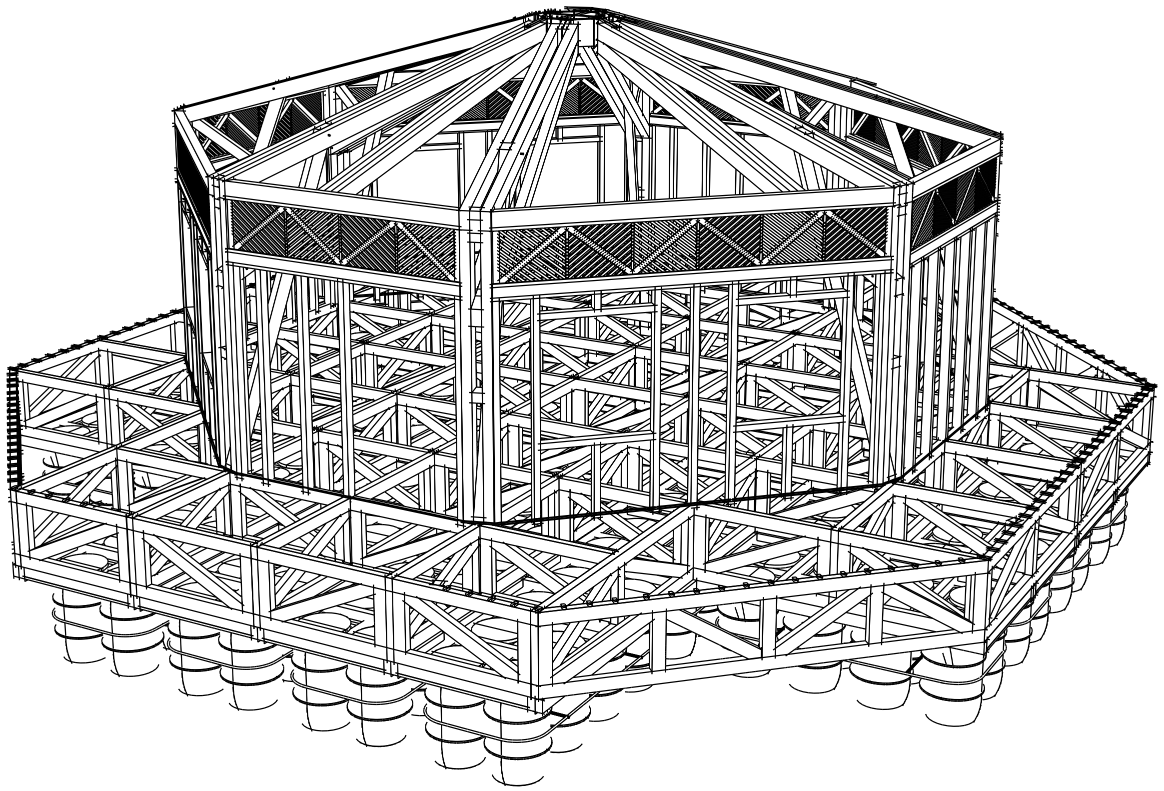
Step 4 - Connecting the prefabricated frames to the foundation and the pressure ring, after all frames are connected the column can be removed



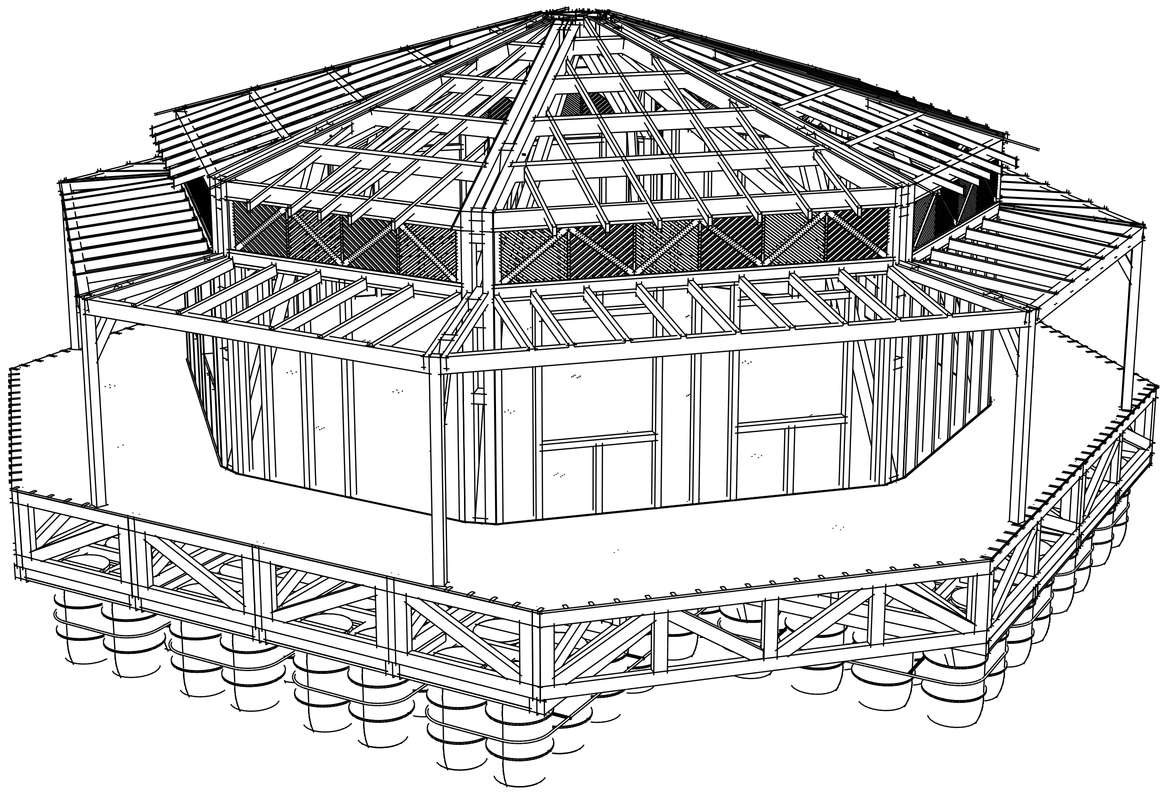
Step 5 - Connecting the beams between the frames to which the prefabricated facade elements are connected



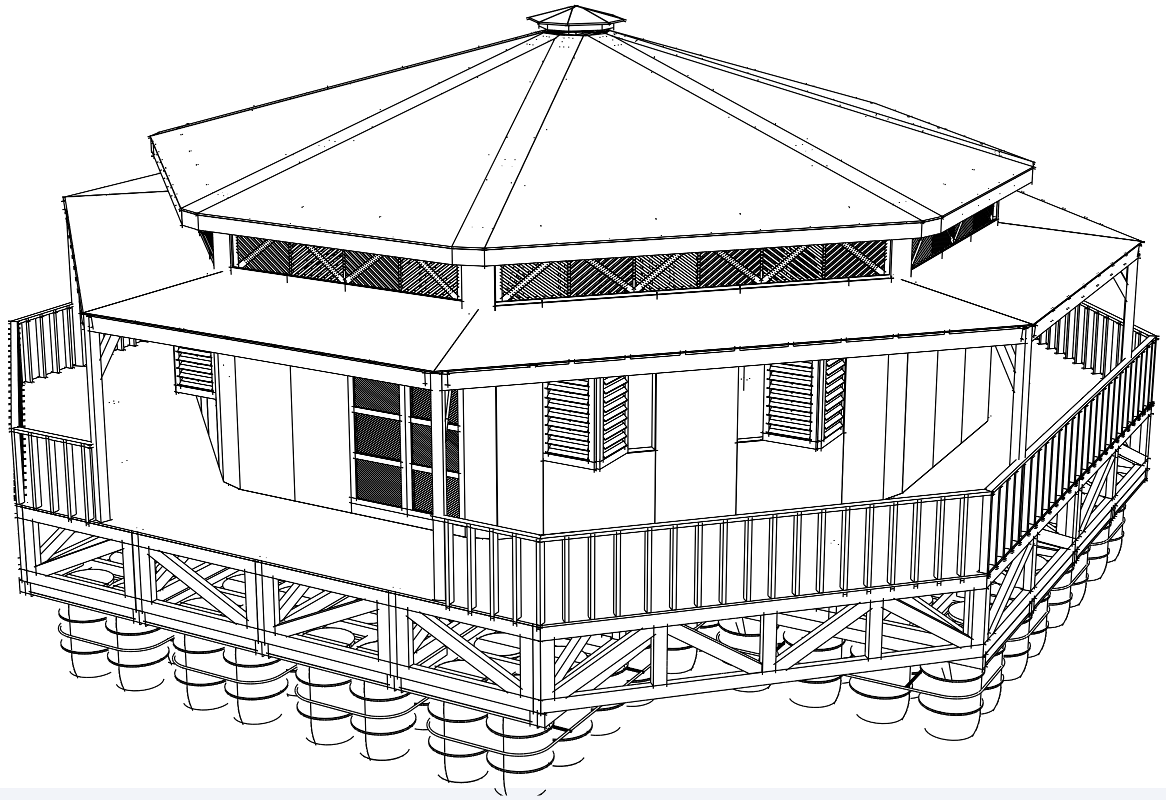
Step 6 - Placing the prefabricated facade elements



Step 7 - Placing the rafters, the eaves and flooring



Step 8 - Finishing of the roof, the facade panels and placing the fence around the classroom



Part D: Design

8. Structural analysis

8.1 Introduction

One of the most important aspects of the design of the classroom is to ensure the safety of the students through a solid construction. That is why the design is tested for structural safety in this chapter. Safety must be guaranteed for the floating capacity of the whole structure as well as stiffness and strength of all buildings elements against the heavy wind loads.

Chapter 2 will discuss how the different structural models are set up and what goal should be achieved with this model.Chapter 3 will discuss the dimensioning of the building elements. Chapter 4 concludes whether the floating platform and the structural framing meet the stability requirements. Chapter 8.5 shows the validation of the computer model calculations and in Chapter 6, several connections of these elements will be elaborated.

Figure 1: Timber from a local wood retailer

8.2 Structural models

This chapter introduces the different structural models of the foundation and structure of the classroom.
It describes how the different models were constructed, which loads and load combinations will be used and presents the results of the structural calculations. The results of structural calculations were used to design all elements and connections on a structural level.

8.2.1 Structural models

The purpose of a structural model is to produce three mathematical models, a structural model, a material model and a load model. The structural model consists of the essential elements, the nodes and the supports. In practise, the nodes and supports should correspond to the design as accurately as possible so that they react the same as the computer-controlled model.
The floating school is divided into two related structural models, one for the structural framing and one for the floating foundation. Both structural models have their unique loads and load combinations.

For both components, the programs Technosoft Frames and AxisVM X5 was used. Technosoft Frames is a structural calculation program specially designed for frames and truss constructions in 2D. The input in Technosoft is the geometry with the correct member connections, supports, loads and load combinations, material properties and the correct boundary conditions. AxisVM is a structural calculation program that, in contrast to Technosoft, can make linear and non-linear structural calculations in 3D. The input is the same as in Technosoft except that the design can be checked a.long 3 axes.

8.2.1.1 Workflow

A workflow was compiled for both components to set up a method in a structured manner that leads to structural models that simulate reality as much as possible with the right associated results. The workflow indicates the assumptions, preconditions and structural codes used to set up the models. It also describes which information from the results can be used to achieve the aim of the model.

Workflow Structural Framing Classroom

The workflow of the structural framing of the classroom in steps, see Table 1. Behind each step it is indicated which program or which source was used. The 2D model was used to determine which dimensions of the elements can provide a solid structure in terms of strength and stiffness, for a more detail see Table 1. The 3D model was used to schematically test the total stability of the classroom for displacement in the x, y, z-direction.

Workflow Floating Foundation

The workflow of the floating foundation is presented in Table 2.. The 2D model supported the setup for the 3D model. The goal of the 2D model was to determine global dimensions for the structural trusses used for the 3D model. The goal of the 3D model was to check the overall stability of the floating foundation under the different load combinations and to determine the right dimensions of the structural trusses.

Workflow - Structural Framing Classroom		
1) Set up structural model (2D) to determine dimensions of the structural framing	Set up geometry and materials according to the design	technosoft
	Set up loads and load combinations	eurocode / NSCP
	Determine dimensions with structural calculations according to the internal forces	eurocode
	Check the maximum displacement in both the x and z direction of the structural members	eurocode
2) Set up a 3D model to validate the theory about the stability of the building	Set up geometry and materials according to the design	AxisVM
	Set up loads and load combinations	eurocode / NSCP
	Check the overall stability of the structure and the deformation in the x,y,z direction	eurocode

Table 1: Workflow structural framing classroom

Workflow - Floating Foundation		
1) Set up simplified structural model (2D) to determine first dimensions of the truss	Set up geometry and materials according to design	technosoft
	Set up loads and load combinations	eurocode / NSCP / NTA811
	Determine spring constant of the supports (floating capacity of a barrel)	
	Determine dimensions with structural calculations according to the internal forces	eurocode
2) Set up a 3D model to assess the maximum subsidence and internal forces of the foundation when the floating modules interact with each other by means of truss structures	Set up geometry and materials according to pre-design	AxisVM
	Set up loads and load combinations	eurocode / NSCP / NTA811
	Determine the subsidence of the floating foundation according to the different load combinations	NTA811
	Determine dimensions with structural calculations according to the internal forces	eurocode

Table 2: Workflow floating foundation

8.2.1.2 Structural model - framing classroom

The structural framing of the classroom is made up of several elements. The main supporting structure consists of wooden elements that together span a length of 9.5 meters. Figure 4 shows the schematization of the structural model. All connections of the elements in the frame are hinged; these hinged connections can transfer normal- and shear forces and allow rotation between the elements. By creating the triangular shapes in the corner of the frame, a rigid corner is created. The effect of this rigid corner will be similar to the effect of a moment fixed corner used in three-hinged frames.
The columns of the frame and the ridge of the classroom are connected through double beams. These beams will be subjected to tensile and compressive forces depending on the wind direction. Due to the distance between both beams, the moment in the frame will be decomposed into a pressure and tension component divided by the two beams.
The forces are transferred downwards through the columns to the truss of the foundation by means of a hinged connection. This connection must be able to transfer the normal and shear forces into the foundation.

The ridge of the structural frame consists of an octagonal line element, in which all rafters come together. This octagonal line element can be made out of steel or wood. All rafters that come together in the ridge are connected through hinged connections; these ensure that no moment can be transferred into the ridge so that only transfer takes place between pressure and tensile forces.

In the 2D model, the pressure ring was neglected and simplified to a model in which the roof trusses connect directly to each other in the ridge. The simplification is done because the model could not find stability in the Y-direction when the compression ring with hinged connections would be included in the model. The problem could be solved using a 3D model in which there is a frame connected to the pressure orientated in the y-direction.

As described in the workflow of the structural framing, the 3D model was set up to control the overall stability of the structure. In the model, three main elements should ensure the stability of the classroom.

The main elements that provide stability are the frames as described in the 2D model. The second element are the stabilisation walls. In real life, these walls are made out of wooden rails and posts finished with fibre cement boards. In the 3D model, the stiffness of these walls is simulated by applying diagonals in the shape of a cross. The diagonals are fixed with hinges to the columns of the frames. (see figure 6 and 7).

The third stabilisation element is the roof, in real life, the roof exists out of beam that is connected with hinges to the frames (see figure 5) and finished by a layer of plywood. In the model, the same principle as with the walls is used. In figure 7, the roof is coloured grey, but in the model, there are crosses between the beams and the frame.

For both models, hinged supports are used able to transfers normal and shear forces but not capable of transferring moment forces.

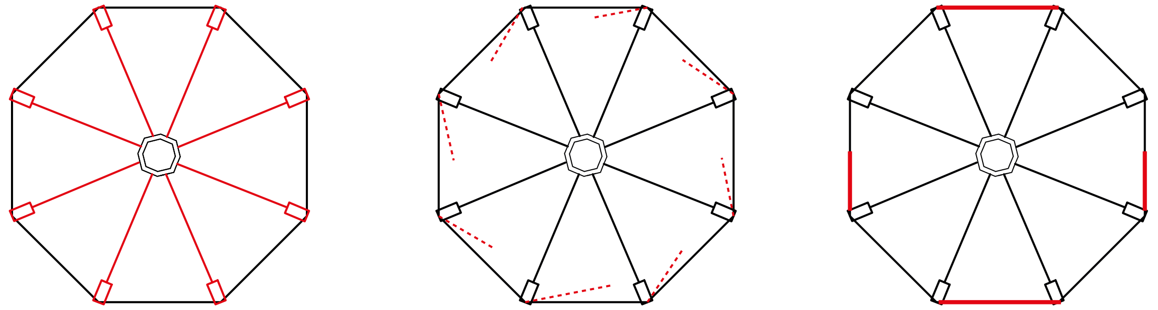


Figure 2 - Preventing rotation of the structural frames by placing the stabilization walls.

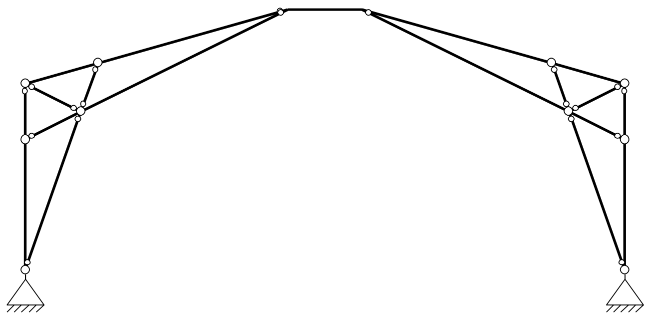


Figure 3- 2D structural model with pressure ring

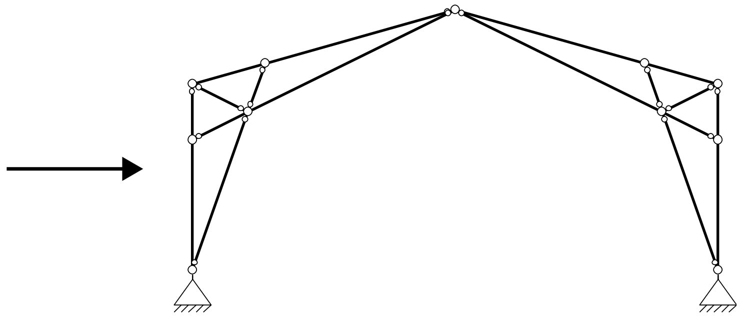


Figure 4 - 2D structural model simplified

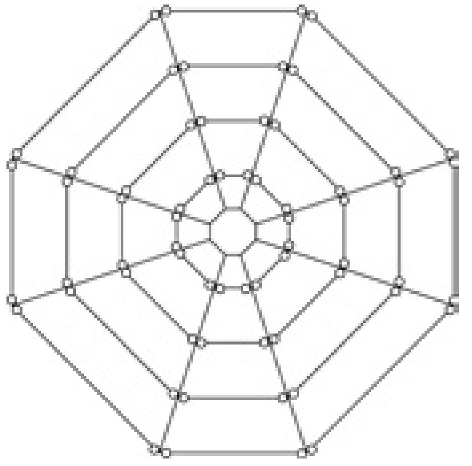


Figure 5 - Structural of the roof

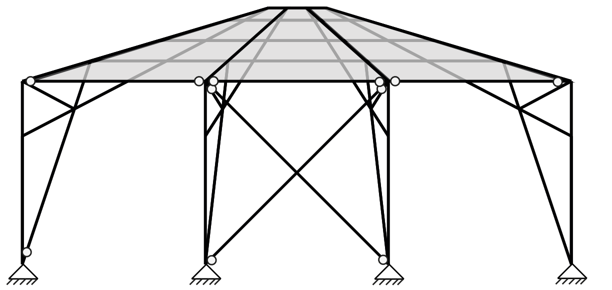


Figure 6 - side view 3D structural model

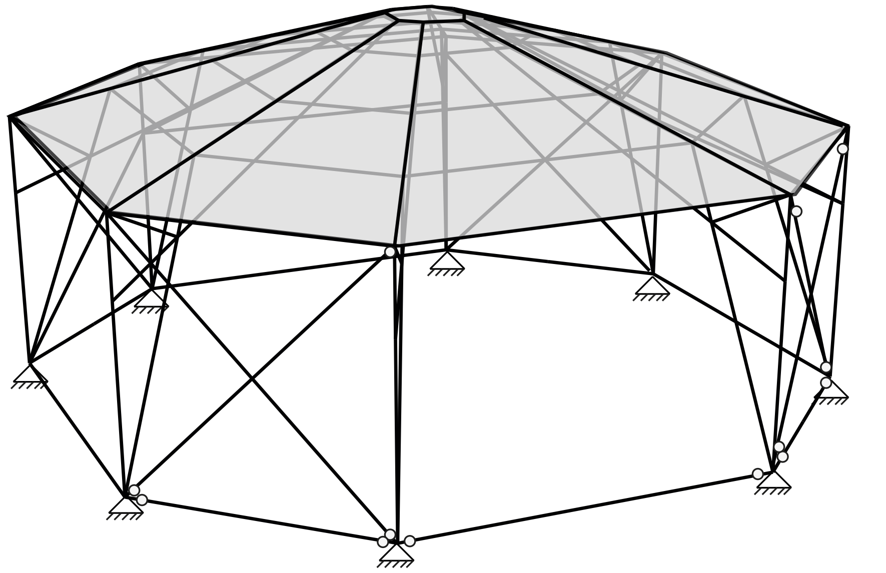


Figure 7 - 3D structural model

8.2.1.3 Structural model - foundation

For the floating foundation, there were two structural models made. The first structural model is a 2D model made in Technosoft and is a simplification of the real-life scenario. The second model is a 3D model set up in Axisvm to determine the overall displacements of the floating foundation and maximum internal forces that can occur in the trusses.

Figure 9 indicates the truss, which is used to set up the 2D model. The goal of the 2D model was to determine what maximum forces occur according to the load combinations placed on the model. From the maximum forces, the first dimensions of the trusses was determined, which in turn serve as input for the 3D model.

The beam shown in figure 8 is a simplification of the truss described above. The rigidity of a truss is simulated in the model by choosing a profile with a high rigidity value. The self-weight of the beam must be entered into the program not to influence the results. The beam is supported by spring supports based on the buoyancy of the barrels.

On the left side of the structural model in figure 8, there is a roll-support. This support acts as an ''anchor'' to absorb horizontal loads, in real life to prevent the structure from floating away from its place. Since this is a simplified model, there are no horizontal loads in the load cases, but the support is still to prevent the program of giving an instability warning.

The benefit of the 3D model in relation to the 2D model is the option to see the cooperation between the different elements because the geometry can be set up in the x-, y- and z-axis. The floorplan of the floating foundation is presented in figure 9. The length of the truss determines the length of the line-element put into the model. The connection between the different trusses is through hinged connections. Looking at the truss itself (see figure 8) the connections of the diagonals and upright beams are hinged to the top and bottom beams.

The overall 3D model is presented in Figure 10. The value of the spring support depends on the number of barrels located around the truss. There were two different values used for the spring support in the model. One of 2 kN/m which is equal to the buoyancy of 1 barrel and one of 4 kN/m which is equal to the buoyancy of 2 barrels.

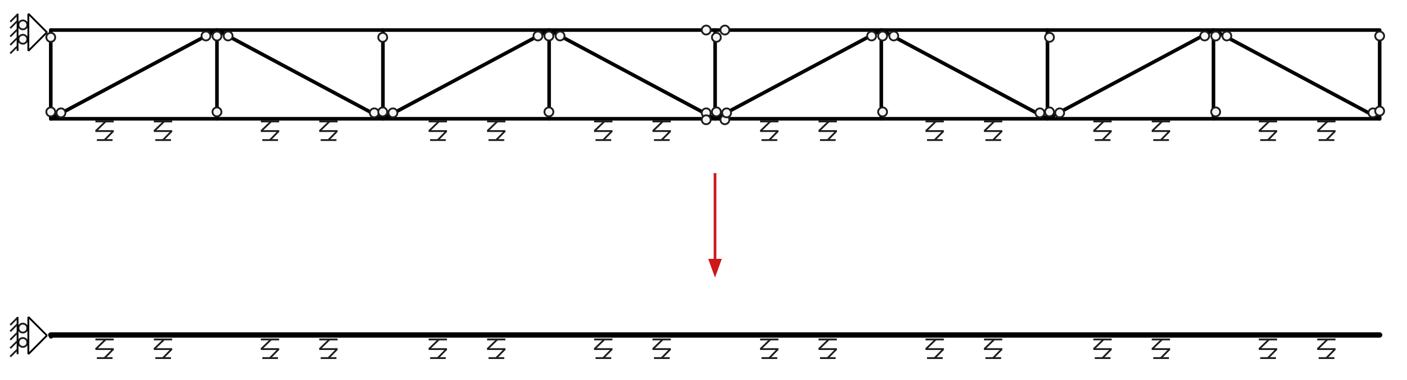


Figure 8 - real situation simplified as 2D model

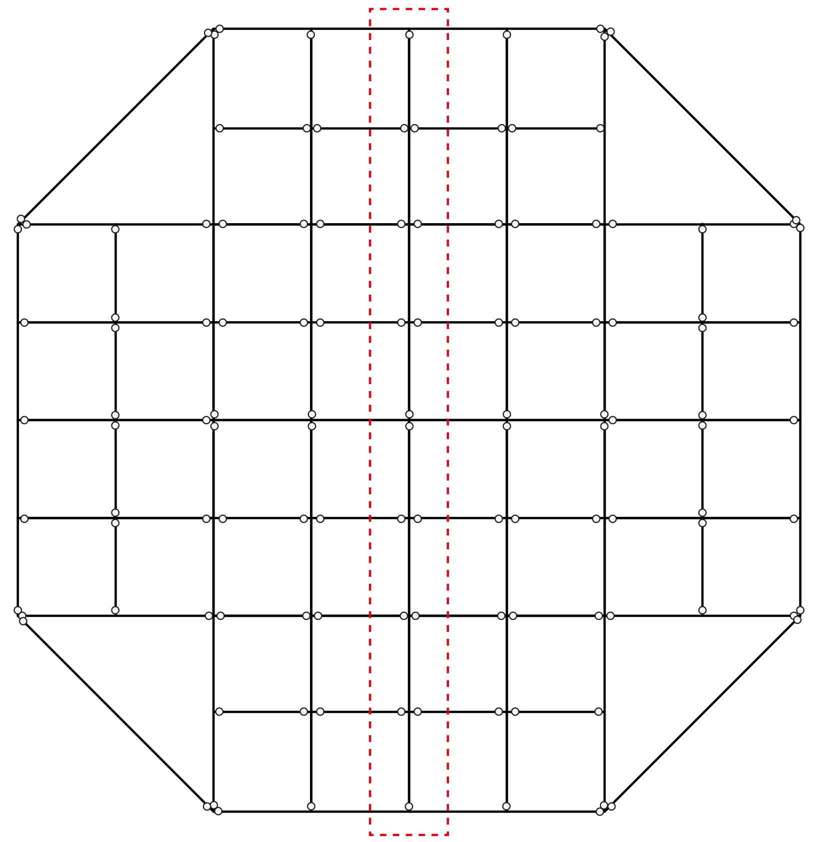


Figure 9 - Floorplan of the foundation

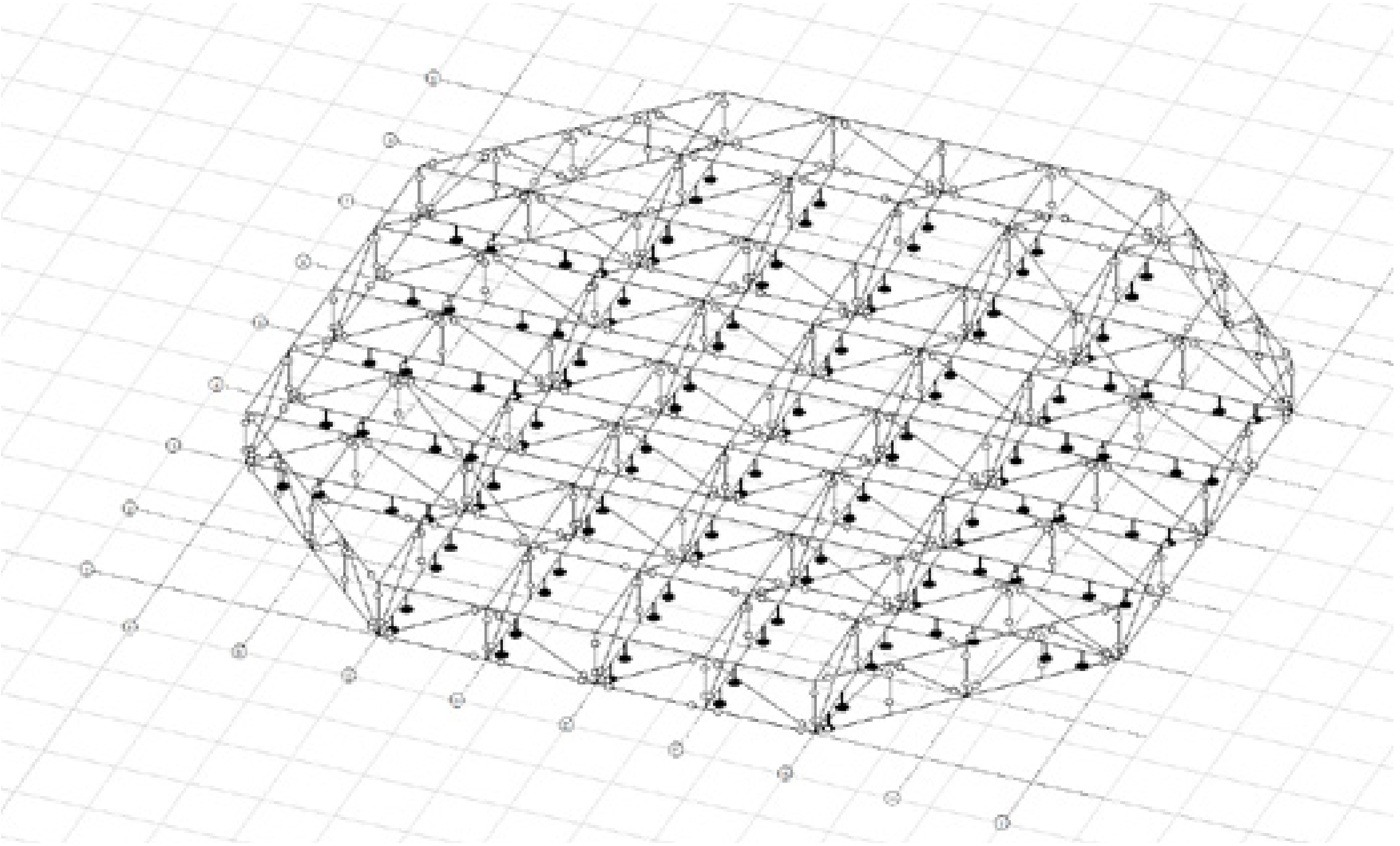


Figure 10 - 3D model set up in Axis VM

8.2.2 Load assumptions

Loads are critical information to set up the models correctly. This chapter explains which load assumptions were made and which sources were used in order to set up these load assumptions.

To determine the load-assumptions it is important to know the type and amount of material for each part of the building.

The loads were divided into dead loads, live loads and winds loads. The wind loads usually are a subject to live load but will be described separately to form a clearer picture of the loads.

The NSCP was used to set up the weight assumptions and the Eurocode to set up the wind load and load combinations.

8.2.2.1 Dead loads

In general, the dead loads consist of the weight of all the materials of the construction including walls, floors roofs, ceilings etc. Loads of materials are based on the density given by the Eurocode, NSCP and information of suppliers of the specific material.

Roof - The roof exists out of a wooden support structure of main support beams and side beams that are connected to the frames. Plywood plates are hammered onto these beams and finished with a layer of insulation and steel roof plates.

Assumptions have been made for the weight of the beam support structure 0,3 kN/m^2.

The NSCP describes a load of 0,0060 kN/m2 for every mm of plywood, looking at the floating home a plywood panel of 18 mm is assumed which gives a weight of 0,1 kN/m^2.

For insulation, the NSCP gives an average value of 0,0015 kN/m2 assuming a layer of insulation of 20 mm gives a weight of 0,03 kN/m^2 rounded to 0,05 kN/m^2.

For metal deck roof plates of 18 gage, the NSCP subscribes a weight of 0,10 kN/m^2.

The total weight of the roof is 0,6 kN/m^2.

Classroom floor - The floor of the classroom exists out of a wooden framing which is finished by bamboo beams covered with bamboo mats. Later on, there is a small calculation of the bamboo beams plus the covering mats showing a weight of 0,2 kN/m^2. For the wooden framing (this is not including the weight of the structural trusses of the foundation but it is including the wood of the floating modules) a weight of 0,3 kN/m^2 is assumed.

This brings the total weight of the floor of the classroom up to 0,5 kN/m^2.

Walkway - The floor of the walkway exists out of a wooden framing which is finished by wooden floorboards. The weight of these floorboards is assumed as 0,2 kN/m^2. For the wooden framing (this is not including the weight of the structural trusses of the foundation but it is including the wood of the floating modules) a weight of 0,3 kN/m^2 is assumed.

This brings the total weight of the floor of the walkway up to 0,5 kN/m^2.

8.2.2.2 Live loads

Variable loads are the maximum loads that can occur with the intended use of the structure and occupancy rate.

Live load classroom - The NSCP 2015 describes for each use of occupancy of a building / construction which minimum uniform and concentrated live load can be applied. A uniform load of 1.9 kPa is used for schools, which equals 1.9 kN/m^2 and a concentrated load of 4.5 kN.

Live load roof - The uniform load of the roof depends on the angle of the roof. The roof of the classroom is at an angle of 15 degrees. An angle of 15 degrees is divided into category 1 in the NSCP: roofs between 0 and 33 degrees. The associated uniform load with a roof surface smaller than 20 m2 is 1 kPa or 1 kN/m^2.

	G [kN/m²]	Q [kN/m²]	
1 Classroom floor			
bamboo flooring + bamboo mats	0,2		
wooden framing	0,3		
school load		1,9	+
	0,5	**1,9**	[kN/m²]
2 Roofing			
wooden framing	0,3		
steel roof sheets	0,1		
plywood sheets	0,1		
insulation	0,05		
roof load		1	+
	0,55	**1**	[kN/m²]
3 Walkway floor			
wooden framing + deck planks	0,5		
school load		1,9	+
	0,5	**1,9**	[kN/m²]

Table 3 - Overview of the load assumptions

8.2.2.3 Wind loads

The wind loads used were determined according to the NEN-EN 1991-1-1-4 general wind load loads.

The wind speed and pear pressure are composed of an average and a fluctuating component. The average windspeed v_m is determinedby the basic wind speed v_b , the roughness factor c_r and the orography factor c_o.

Basic wind speed - Chapter 4.3 already explained the different wind zones and occupancy categories which are used in the Philippines to determine the basic wind speeds, which are used for structural calculations. A school falls under-occupancy category 1, this is the highest class in terms of the magnitude of wind speeds. Macabebe is located in the region where a 3-second gust wind speed of 260 km / h is maintained. A 260 km/h 3-second gust factor corresponds to a 10 minute mean velocity or 174.2 km/h. The wind calculations were consistently done with a wind speed of 174.2 km/h or 48.4 m/s. For the directional factor and the seasonal factor, we can assume for both that this 1.

Mean wind velocity - The roughness factor is influenced by the height above ground level, which is 4.2 meters in the design (see table 3). The category in which the terrain falls also influences the roughness factor, in this case, terrain category one has been chosen. The choice of category 1 is also partly based on the possibility of making the same design suitable if the site concerns a lake or large area of open water. The orography factor is equal to 1. The final mean wind velocity is 49.6 m / s.

Terrain category		Zo	Zmin
		m	m
0	Sea or coastal area exposed to the open sea	0,0003	1
I	Lakes or flat and horizontal area with negligible vegetation and without obstacles	0,01	1
II	Area with low vegetation such as grass and isolated obstacles with separations of at least 20 obstacle heights	0,05	2
III	Areas with regular cover or vegetation or buildings with isolated obstacles with separations of maximum 20 obstacle heights	0,3	5
IV	Area in which at least 15% of the surface is covered with buildings and their average height exceeds 15 meters.	1,0	10

Table 4 - Terrain categories

Turbulence intensity - The turbulence intensity is depending on the of the height z, which is determined as the standard deviation of the turbulence divided by the mean wind speed. The standard deviation depends on the turbulence factor, which is 1, the orography factor, which is also 1 and the roughness factor 1.03. This brings the standard deviation to 8.21. With the standard deviation of 8.21 and a mean velocity of 49.6 m/s, the turbulence intensity will be 0.17.

Peak pressure - The peak velocity pressure at height z is determined by the density of air, the turbulence intensity and the mean wind velocity which brings the peak pressure at 3322 N/mm2 or 3,32 kN/m2.

fundamental value of the basic wind velocity	v_bo	48,4 m/s		
directional factor	c_dir	1,0		
seasonal factor	c_season	1,0		
basic wind velocity	v_b	48,4 m/s		
	Terrain category :	1		
minimum height	z_min	1 m		
maximum height	z_max	200 m		
	z_0	0,01 m		
	z_0,II	0,05 m		
height	z	4,2 m		
terrain factor	k_r	0,17 -		
roughness factor	c_r(z)	1,03 -		
orography factor	c_o(z)	1 -		
mean wind velocity	v_m(z)	49,6 m/s		
turbulence factor	k_I	1 -		
	σ_v	8,21 -		
turbulence intensity	I_v(z)	0,17 -		
air density	ρ	1,25 kg/m3		
peak pressure	q_p(z)	3321,7 N/m2	→	3,32 kN/m2

Table 5 - wind pressure

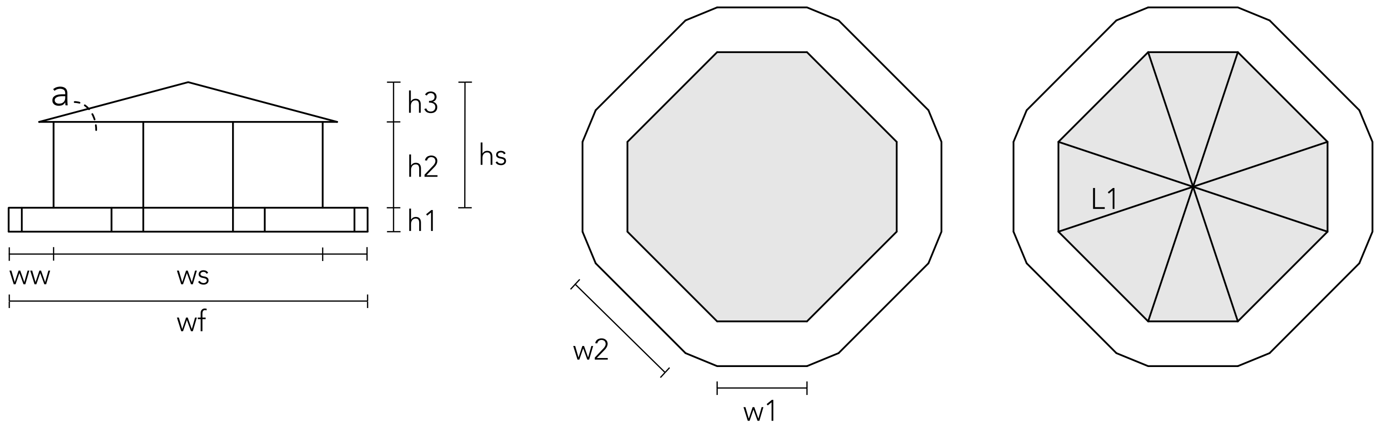


Figure 11 - Design dimensions

8.2.2.4 Wind factors

The wind factors are determined according to the NEN-EN 1991-1-1-4 general wind load loads.

The Eurocode describes several models to determine the wind shape factors for the zones of the building based on the building shape. However, this is not the case for a building with an octagonal shape, so a simplified model is set up based on the rectangular model from the Eurocode that tries to establish the wind loads as accurately as possible.
Figure 12 shows the wind zones of a rectangular building with a hipped roof. Figure 13 is the simplified model set up for an octagonal shape.

Each zone of the roof has its own wind form factor that determines whether pressure or suction is created on the roof surface due to the wind load. Zones G, L, J, and K are the zones at edges where higher loads are applied than on the roof surface zones H, M, and I. In addition to the wind forces on the roof, the facades also play an important role. Figure 13 shows a wind direction coming from the left. As a result, the facade on the windward side falls under zone D and the facade at the leeward side under zone E.

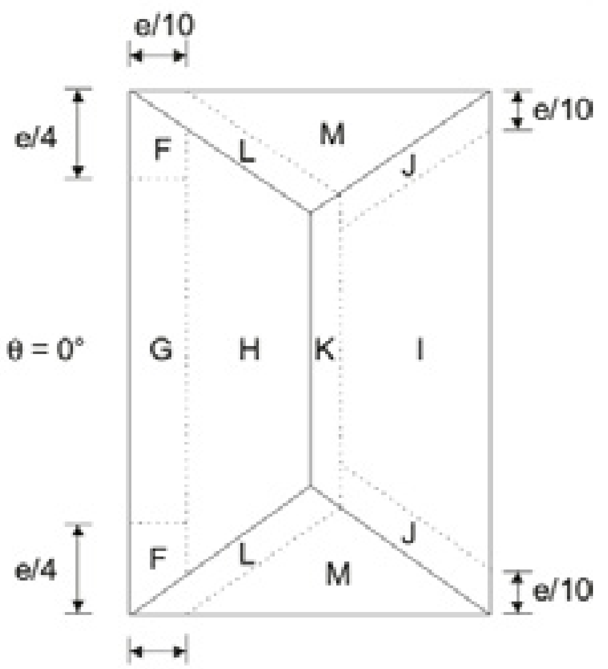


Figure 12 - Wind zones hipped roof

On the right the different wind load scenario's are illustrated based on the windform factors related to the associated zones. In the appendix the zones with the related windformfactors are shown.

For the internal pressure Cpe 0,2 is used and a Cpe of 0,3 is used for the overpressure in the building.

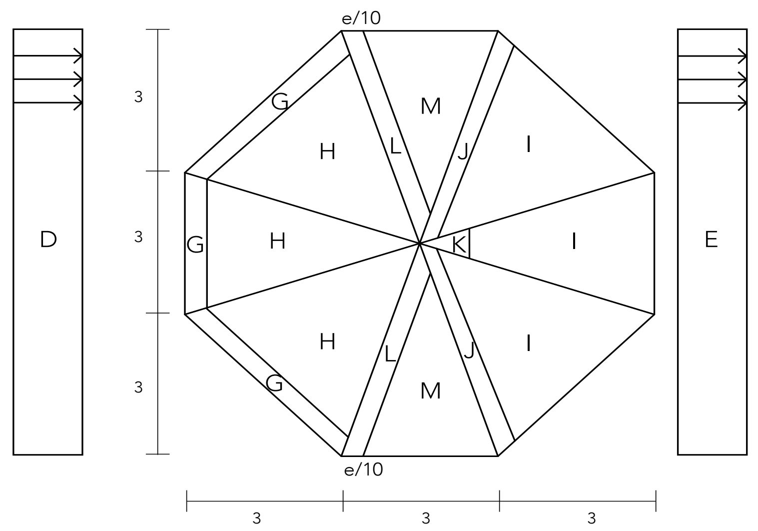


Figure 13 - Wind zones octagonal shape used for 2D model

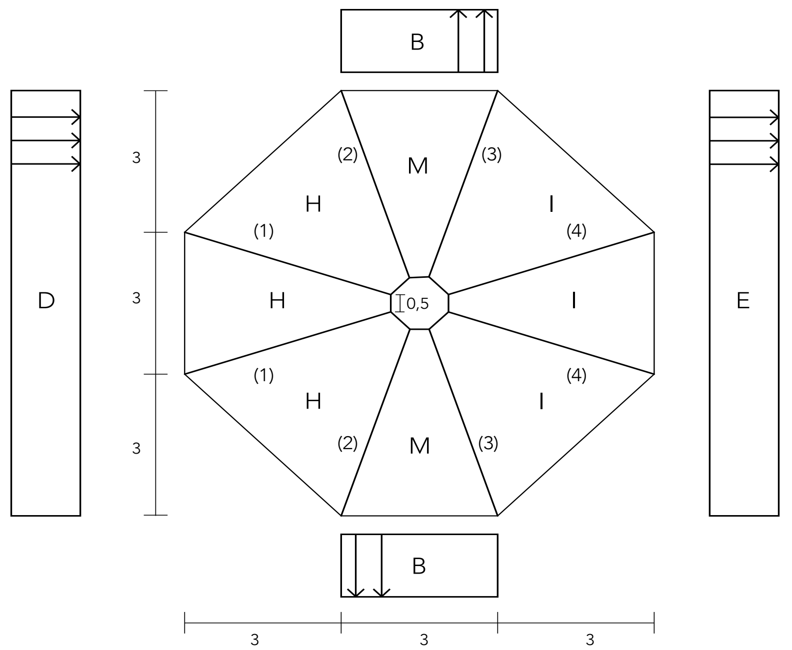
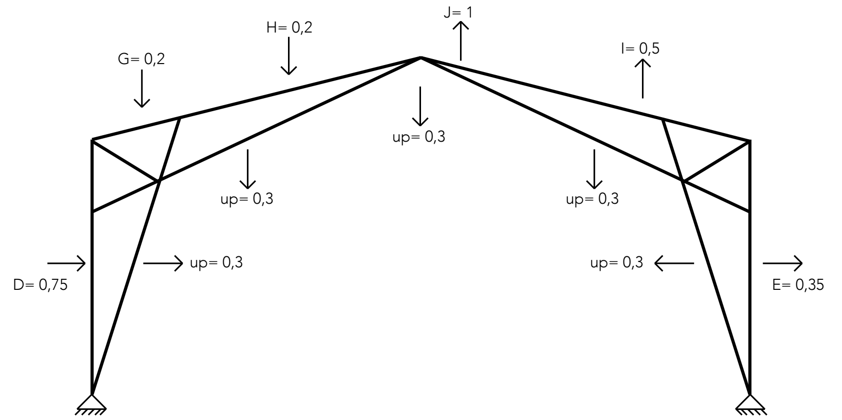


Figure 14 - Wind zones octagonal shape used for 3D model

Wind load scenarios 2D model

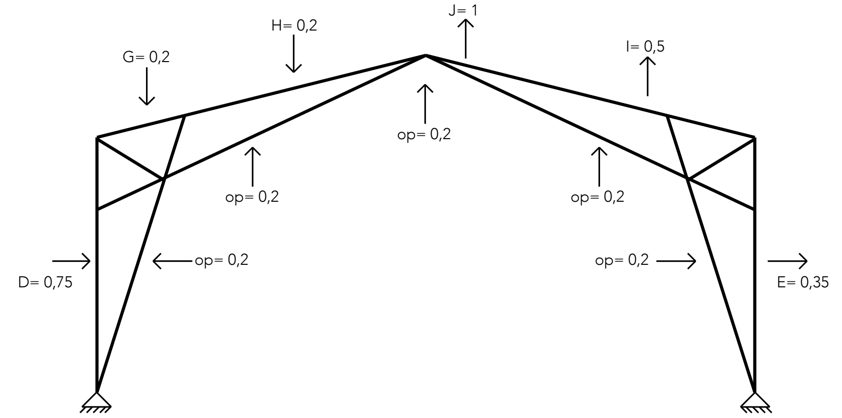
Wind load scenario 1

- wind from the left
- pressure front side of the roof
- suction back side of the roof
- internal underpressure



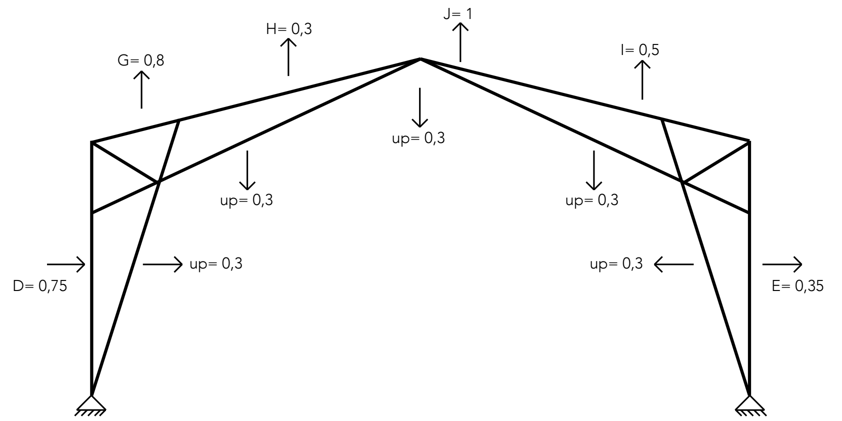
Wind load scenario 2

- wind from the left
- pressure front side of the roof
- suction back side of the roof
- internal overpressure



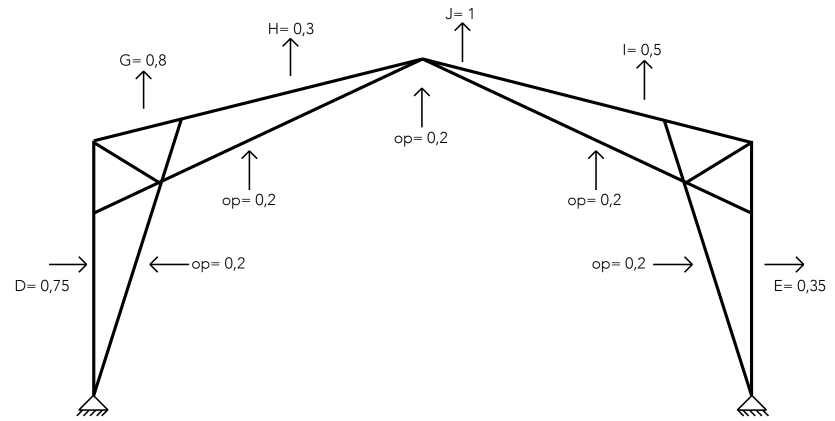
Wind load scenario 3

- wind from the left
- suction front side of the roof
- suction back side of the roof
- internal underpressure



Wind load scenario 4

- wind from the left
- suction front side of the roof
- suction back side of the roof
- internal overpressure



8.2.3 Load cases and combinations

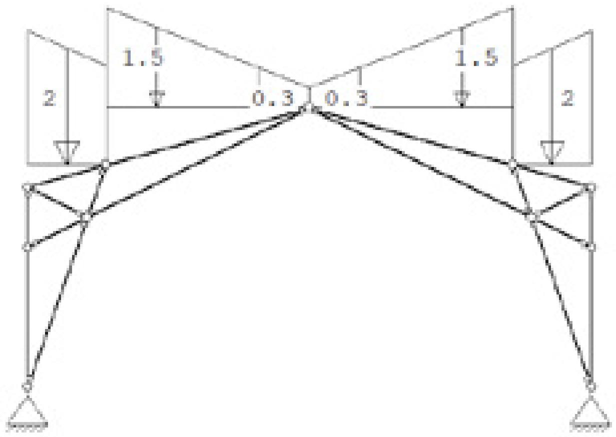
In order to design a structure that is safe and can resist all actions that they are likely to face during their service life, the eurocode prescribe load factors and combinations. Load factors are developed to achieve the desired level of reliability of a structure.
The load factors are based on the user category, safety class and reference live of the building. The floating school is placed in user category C, gathering building with a reference period of 50 years and safety class 2.

For this study, two conditions were tested, each with their own load combinations and factors. The ultimate limit state (ULS) which is used to determine the needed dimensions of the structural elements and to see if they meet the strength requirements the elements for strength. The load factors associated with this are, unfavourably 1.2 for dead load and 1.5 for the live load. The other condition to be tested is the service limit state (SLS) to the check on the stiffness of the elements. The load factors of the SLS is 1 for both dead and live load.

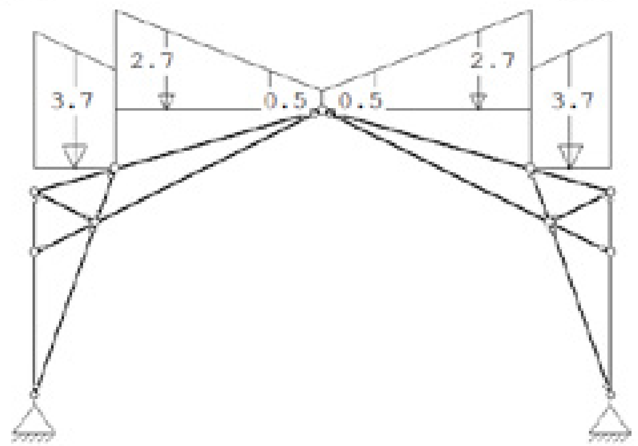
Load combination	LC1 - Dead load	LC2 - Live load	LC3 - Wind 1	LC4 - Wind 2	LC5 - Wind 3	LC6 - Wind 4
C1 - ULS 1:	1,35	-	-	-	-	-
C2 - ULS 2:	1,2	1,5	-	-	-	-
C3 - ULS 3:	1,2	-	1,5	-	-	-
C4 - ULS 4:	1,2	-	-	1,5	-	-
C5 - ULS 5:	1,2	-	-	-	1,5	-
C6 - ULS 6:	1,2	-	-	-	-	1,5
C7 - SLS 1:	1	-	-	-	-	-
C8 - SLS 2:	1	1	-	-	-	-
C9 - SLS 3:	1	-	1	-	-	-
C10 - SLS 4:	1	-	-	1	-	-
C11 - SLS 5:	1	-	-	-	1	-
C12 - SLS 6:	1	-	-	-	-	1

Table 6 - load combinations

Load case 1 - dead load

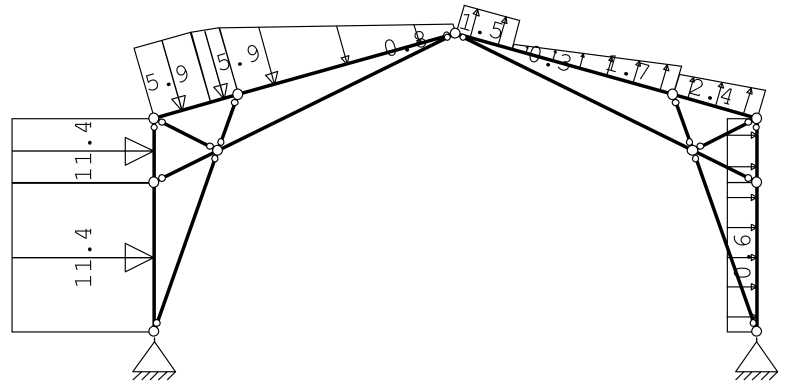


Load case 2 - live load



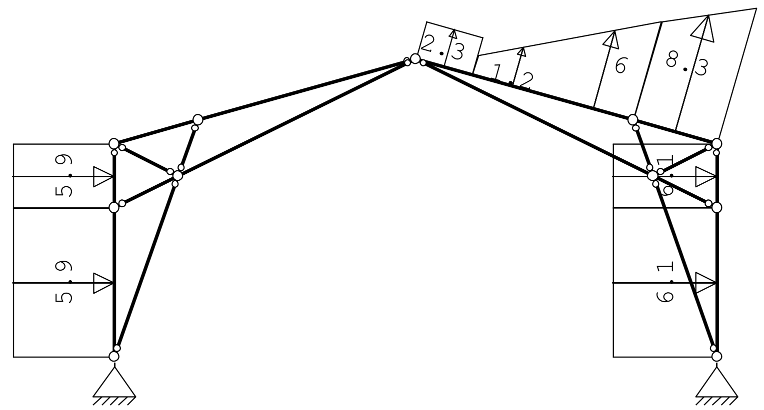
Load case 3 - wind 1

- wind from the left
- pressure front side of the roof
- suction back side of the roof
- internal underpressure



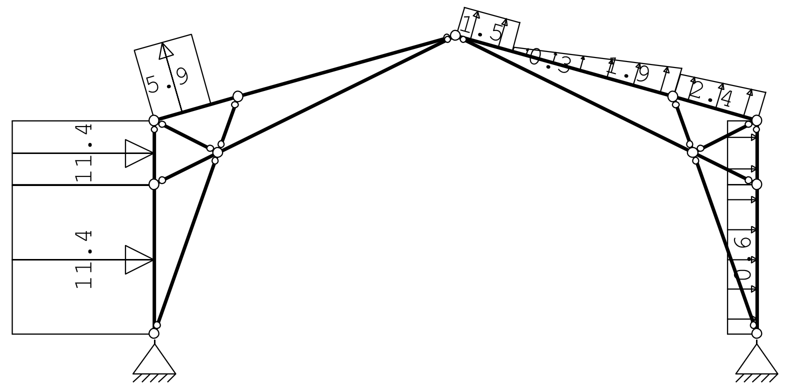
Load case 4 - wind 2

- wind from the left
- pressure front side of the roof
- suction back side of the roof
- internal overpressure



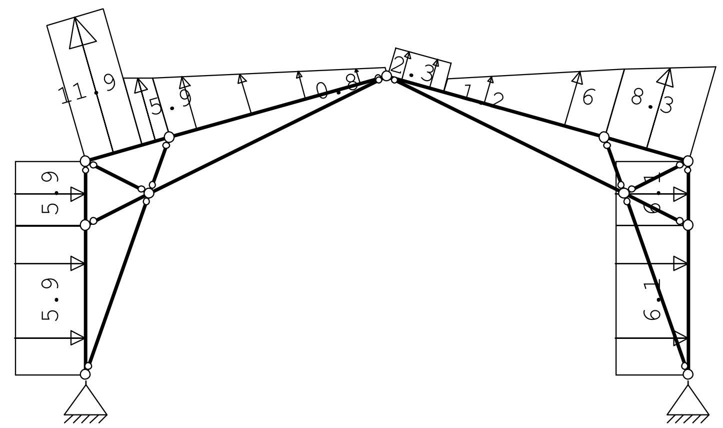
Load case 5 - wind 3

- wind from the left
- suction front side of the roof
- suction back side of the roof
- internal underpressure



Load case 6 - wind 4

- wind from the left
- suction front side of the roof
- suction back side of the roof
- internal overpressure

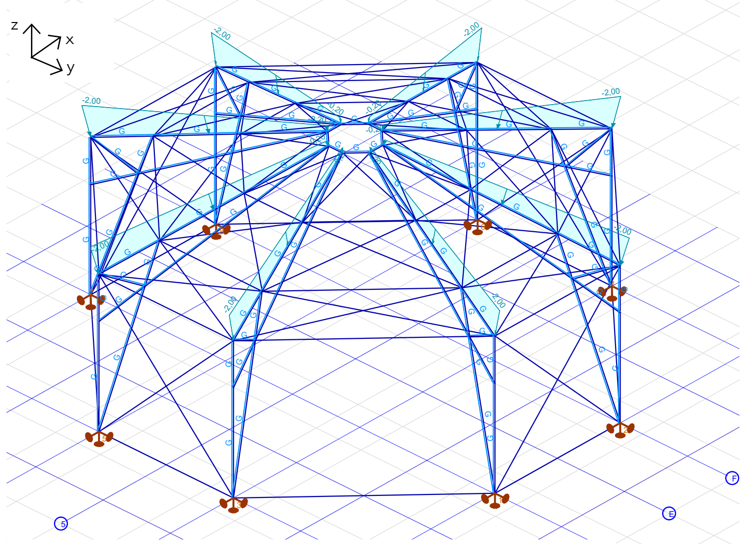


8.2.3.2 Framing classroom 3D

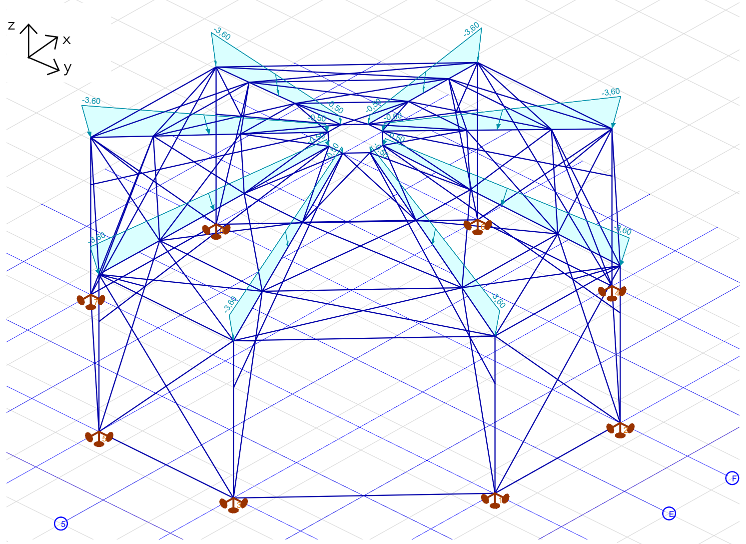
The difference between the 3D and 2D model for the structural framing is that in the 3D model, the wind loads in the y-axis can be entered. In the appendix, more information can be found on how the loads are set up with the corresponding values.

Load combination	LC1 - Dead load	LC2 - Live load	LC3 - Wind 1	LC4 - Wind 2	LC5 - Wind 3	LC6 - Wind 4
C1 - ULS 1:	1,35	-	-	-	-	-
C2 - ULS 2:	1,2	1,5	-	-	-	-
C3 - ULS 3:	1,2	-	1,5	-	-	-
C4 - ULS 4:	1,2	-	-	1,5	-	-
C5 - ULS 5:	1,2	-	-	-	1,5	-
C6 - ULS 6:	1,2	-	-	-	-	1,5
C7 - SLS 1:	1	-	-	-	-	-
C8 - SLS 2:	1	1	-	-	-	-
C9 - SLS 3:	1	-	1	-	-	-
C10 - SLS 4:	1	-	-	1	-	-
C11 - SLS 5:	1	-	-	-	1	-
C12 - SLS 6:	1	-	-	-	-	1

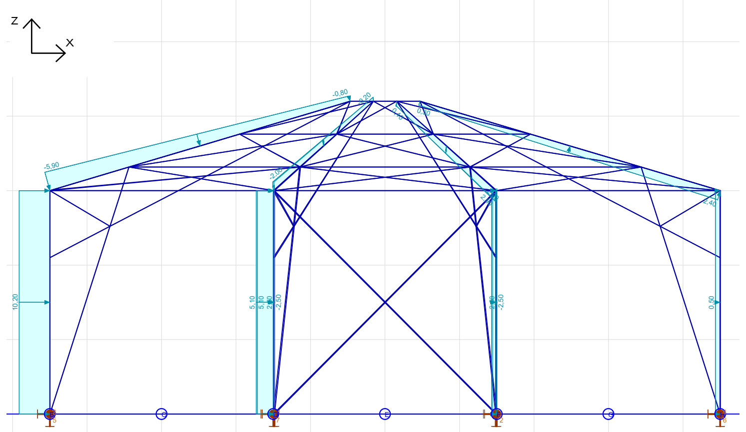
Table 7 - load combinations



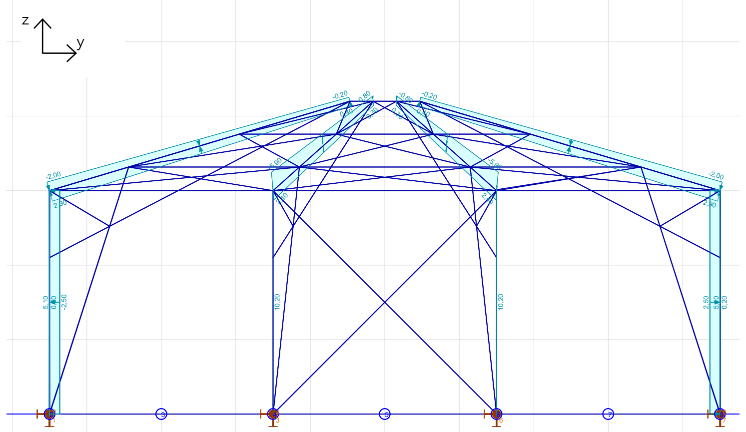
Load case 1 - dead load



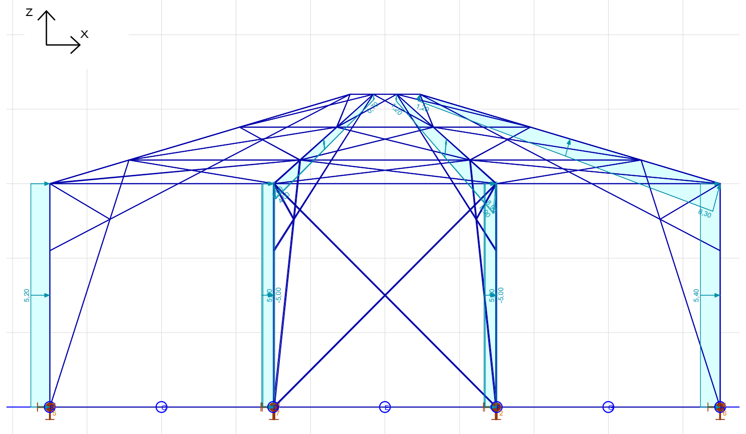
Load case 2 - live load



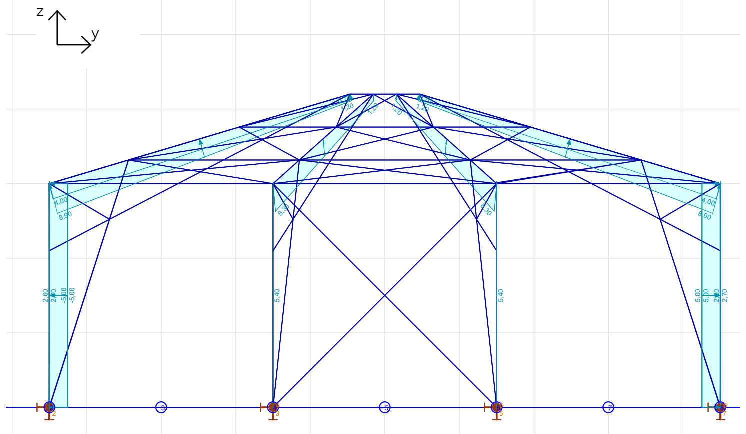
Load case 3 - wind 1, front view



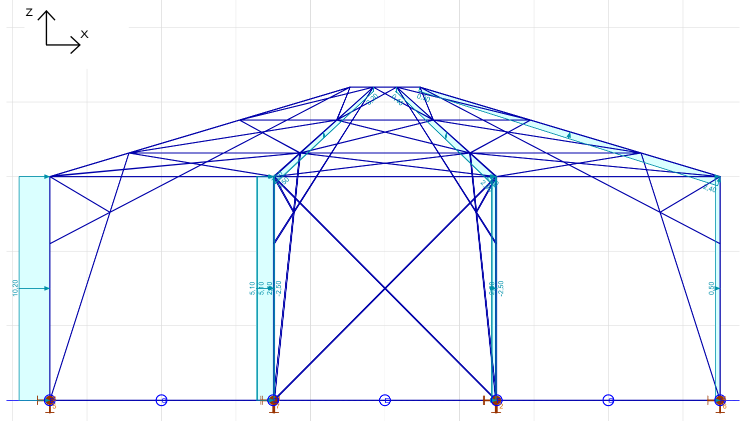
Load case 3 - wind 1, side view



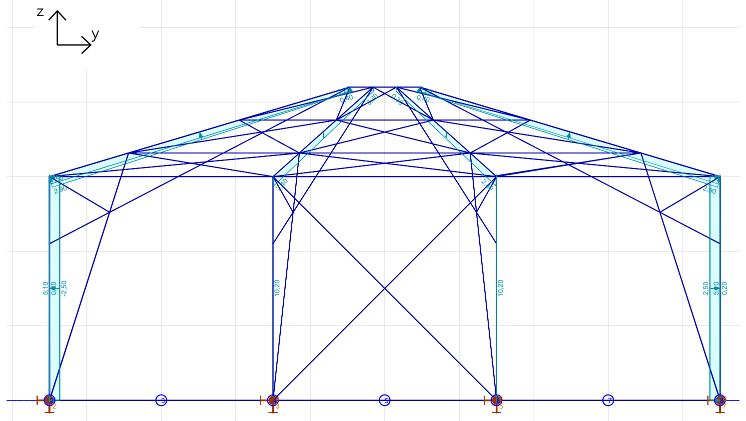
Load case 4 - wind 2, front view



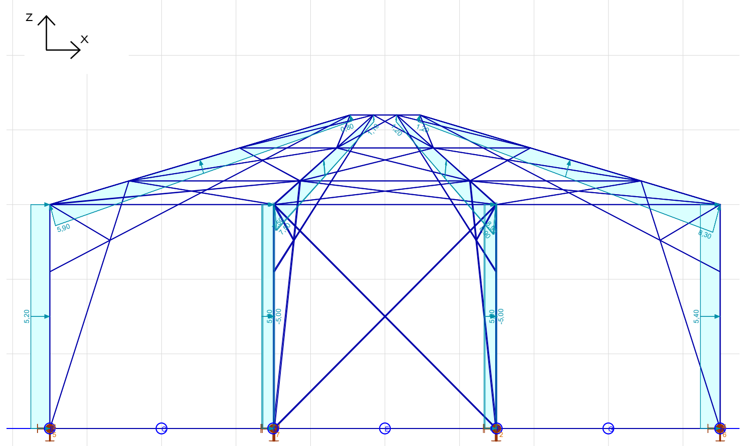
Load case 4 - wind 2, side view



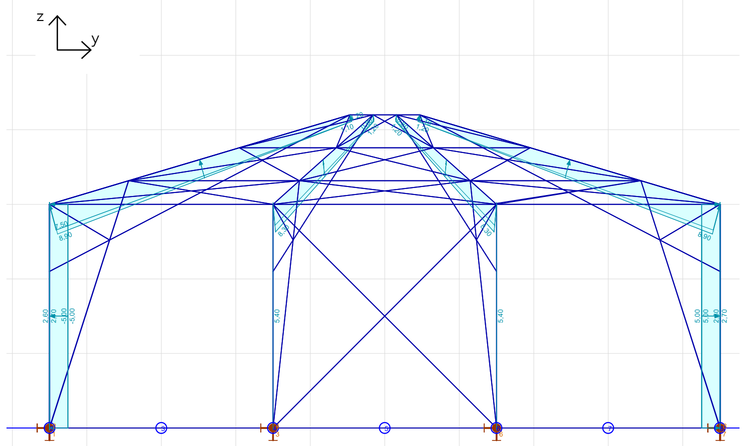
Load case 5 - wind 3, front view



Load case 5 - wind 3, side view



Load case 6 - wind 4, front view



Load case 6 - wind 4, side view

8.2.3.3 Floating foundation 3D

The load cases illustrated are simplified illustrations based on the load cases that are used in the 3D model (in the appendix an overview of the load cases can be found combined with the load values). There is a distinction made between loads illustrated in a black colour and a red colour. The black coloured loads are the loads that apply directly on the floating platform and the red coloured loads are the reaction forces out of the columns from the frame.

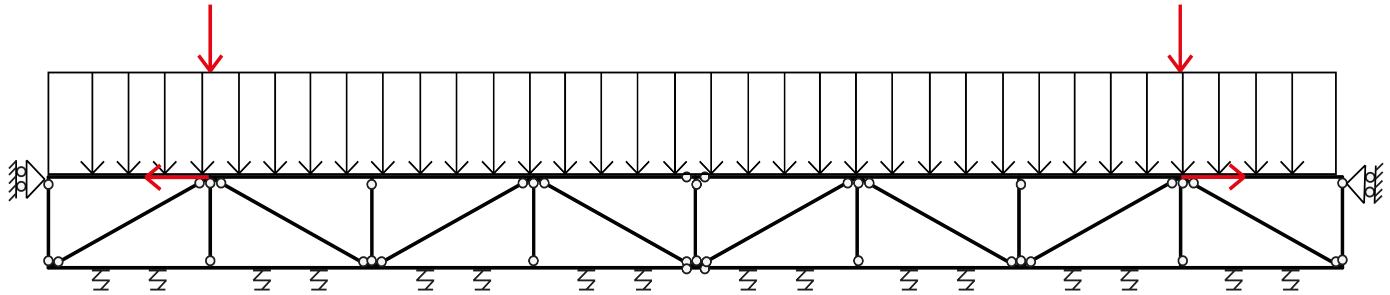
In addition to vertical loads coming from the columns, horizontal loads will also have to be absorbed by the foundation. The horizontal forces arise from the resistance that construction offers to deformation and displacement. Especially the load combinations which contain wind loads will have greater horizontal forces. The loads that are entered on the floating platform come from the 3D model of the structural framing. The support reactions are extracted from the 3D model of the structural framing and entered as loads at the location of the columns.

Load combination	LC1 - Dead load	LC2 - Live load classsroom	LC3 - Live load roof	.C4 - Eccentric load classroom	LC5 - Wind 1	LC6 - Wind 2	LC7 - Wind 3	LC8 - Wind 4
C1 - ULS 1:	1,35	-	-	-	-	-	-	-
C2 - ULS 2:	1,2	1,5	-	-	-	-	-	-
C3 - ULS 3:	1,2	-	1,5	-	-	-	-	-
C4 - ULS 4:	1,2	-	-	1,5	-	-	-	-
C5 - ULS 5:	1,2	-	-	-	1,5	-	-	-
C6 - ULS 6:	1,2	-	-	-	-	1,5	-	-
C7 - ULS 7:	1,2	-	-	-	-	-	1,5	-
C8 - ULS 8:	1,2	-	-	-	-	-	-	1,5
C9 - SLS 1:	1	-	-	-	-	-	-	-
C10 - SLS 2:	1	1	-	-	-	-	-	-
C11 - SLS 3:	1	-	1	-	-	-	-	-
C12 - SLS 4:	1	-	-	1	-	-	-	-
C13 - SLS 4:	1	-	-	-	1	-	-	-
C14 - SLS 5:	1	-	-	-	-	1	-	-
C15 - SLS 6:	1	-	-	-	-	-	1	-
C16 - SLS 7:	1	-	-	-	-	-	-	-
C17 - SLS 8:	1	-	-	0,7	-	-	-	1

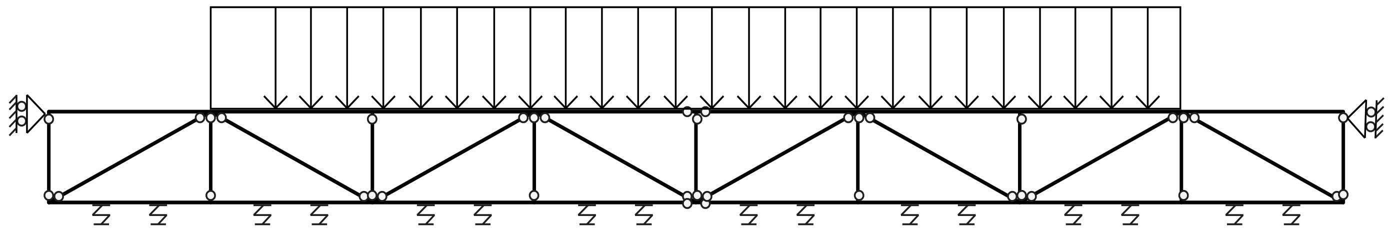
Table 8 - load combinations

Load combination 1 until 9 are ULS load combinations and will be used to determine the maximum tensions that occur in the floating foundation.

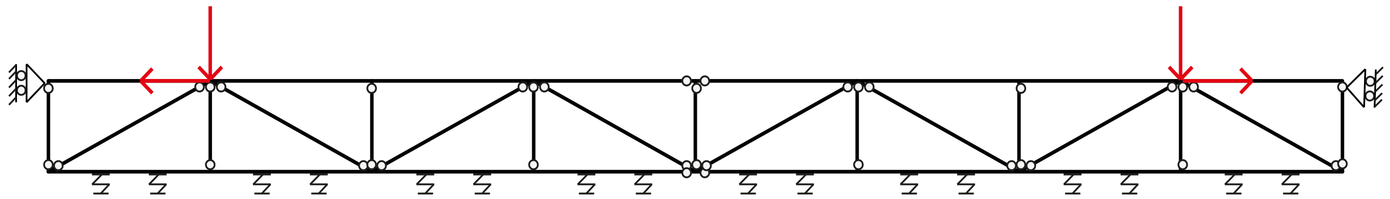
Load combination 10 until 17 are the SLS combinations and will be used to check the maximum tilting and sinking of the platform. Load combination 17 is based on a situation that will most likely never occur in real life (event of a typhoon and where all the occupants will be on one side of the classroom) , but it is nevertheless interesting to assess whether even in this situation the platform will still meet the requirements set for sinking and tilting.



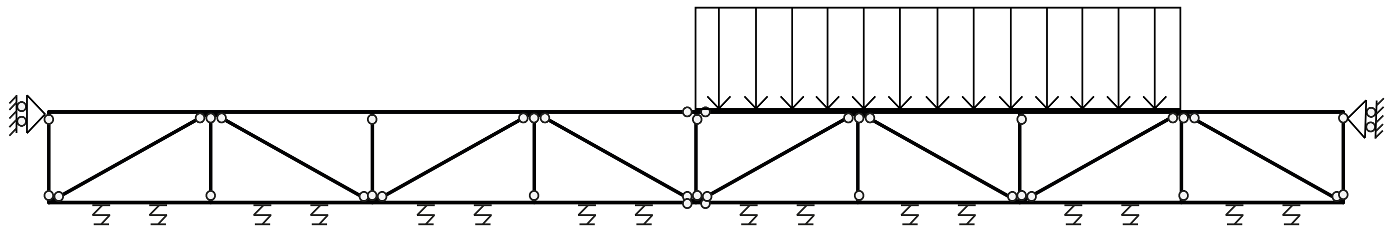
Load case 1 - dead load



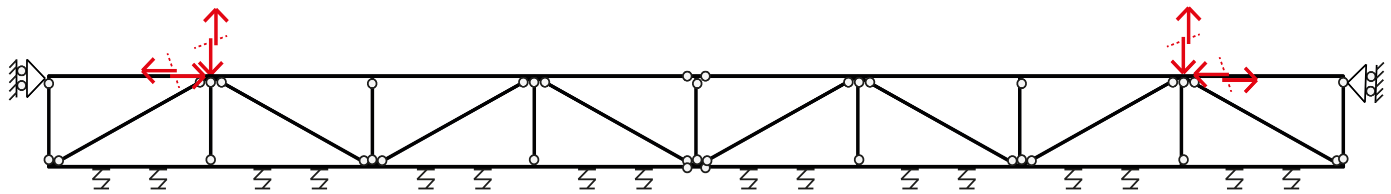
Load case 2 - live load classroom



Load case 3 - live load roof



Load case 4 - eccentric load classroom



Load case 5-8 - wind loads

8.3 Element design

This chapter presents the dimensioning for the elements of the structural models. The dimensions of an element will be determined by strength (tension in the element) and stiffness (deflection of the element). NEN- EN 1995-1-1 Timber structures were used for strength and NEN-EN 1990 for stiffness.

Chapter 7.1 describes that Meranti wood is used for this design. Meranti wood is categorized as C20. In the table, the characteristic values of the material properties of sawn meranti wood are presented. For the calculation these characteristic values were multiplied by Rd, which depends on the partial factor for a material property and the modification factor. The partial factor γm for sawn timber is 1.3. kmod depends on the moisture content and the load duration. Since the floating classroom is located in a humid environment and in a warm tropical climate with regular rain showers, it will be classified in climate class 2, which falls under outdoor but covered. For the load duration class, the choice is based on the most decisive load, the wind, and therefore short is chosen as the load duration class. This gives a kmod of 0.9 (see table 11)

In table 10 the characteristic values of the material properties are shown on the left and the calculation values on the right.

In table 9 the nominal sizes of meranti wood are placed in an overview, these are used to choose from in picking the sizes of the dimensions.

	Width (mm)													
Thickness (mm)	50	63	75	88	100	113	125	150	175	200	225	275	300	325
16	-	-	X	-	X	-	X	-	-	-	-	-	-	-
19	-	-	X	-	X	-	X	X	-	-	-	-	-	-
22	X	X	X	-	X	-	X	X	-	-	-	-	-	-
25	X	X	X	-	X	-	X	X	X	X	X	X	X	-
32	-	-	-	-	X	-	X	X	X	X	X	X	-	-
38	-	-	X	-	X	-	X	X	X	X	X	X	X	-
44	-	-	-	-	X	-	X	X	X	X	X	X	X	-
50	-	X	X	-	X	-	X	X	X	X	X	X	X	-
63	-	X	X	X	X	-	X	X	X	X	X	X	X	-
75	-	-	-	-	X	X	X	X	X	X	X	X	X	-
100	-	-	-	-	-	-	X	X	X	X	X	X	X	X
125	-	-	-	-	-	-	-	-	X	X	X	X	X	X

Table 9 - Nominal sizes meranti wood (Scheijmans)

Yellow Meranti (C20)					
$f_{m,0,k}$	20	N/mm^2	$f_{m,d}$	13,8	N/mm^2
ρ_k	330	kg/m^3			
$f_{t,0,k}$	12	N/mm^2	$f_{t,0,d}$	8,3	N/mm^2
$f_{c,0,k}$	19	N/mm^2	$f_{c,0,d}$	13,2	N/mm^2
$f_{c,90,k}$	2,3	N/mm^2	$f_{c,90,d}$	1,6	N/mm^2
$E_{0,mean,k}$	9500	N/mm^2	$E_{0,mean,d}$	9500	N/mm^2
			$E_{0,u,d}$	6577	N/mm^2
$E_{0,0.5,k}$	6400	N/mm^2	$E_{0,0.5,d}$	6400	N/mm^2
$E_{90;mean,k}$	320	N/mm^2	$E_{90;mean,d}$	320	N/mm^2
$G_{mean,k}$	590	N/mm^2	$G_{mean,d}$	590	N/mm^2

Table 10 - Material properties meranti wood

Materiaal	Norm	Klimaat-klasse	Belastingsduurklasse				
			Blijvend	Lang	Middellang	Kort	Zeer kort
Gezaagd hout	EN 14081-1	1	0,60	0,70	0,80	0,90	1,10
		2	0,60	0,70	0,80	0,90	1,10
		3	0,50	0,55	0,65	0,70	0,90

Table 11 - Modification factor wood (NEN-EN 1995-1-1)

8.3.1 Structural frame

Figure 16 provides an overview of the structural frame with the associated numbering of the elements. The other figures show an overview of the fundamental forces that occur in the frame.

Because all elements are hinged connected, mainly tensile and compressive forces arise in the frame. It can be seen that all internal components are mostly under pressure and tension. The components in the roof are alternately loaded on tension and compression; this depends on the wind direction. In addition to pressure and tensile forces, the components on the outside of the frame also have stresses due to moment and shear forces. This is because external forces act directly on the elements. An evenly distributed load has been applied to beams 1, 3, 2 and 5, while in practice it will be loaded by point loads due to the facade that is attached on to the frame at two points.

Control for strength

Formula 6.23 from the Eurocode is used for the components under compression to check if the component can handle the pressure and deflection. For the components loaded under tension and compression, formula 6.17 was used. Based on the results of this check, it can be seen that there is still margin-left in the strength capacity of the profiles. Beam 14 is most heavily loaded, partly due to a pressure force of 109 kN and a bending moment of 6.5 kN which gives a unity check of 0.84.

Deflection control

The components on the outside of the frame are checked for deflection and displacement. These are seen as normative because the roof and facade connect to them, so you prefer to see as little deformation as possible. For the columns component, 1 is fundamental. The maximum displacement that may occur here is the height divided by 300, so 10 mm. The displacement that occurs here is 10 millimetres, so this complies.

Based on both checks, it can be concluded that the displacement is decisive for the choice of the profiles. Through trial and error and by making the cross-sections smaller and smaller in the calculation program Technosoft, three different profiles were chosen. Figure 15 shows the difference in profiles in a colour scheme. The width of the profiles has been deliberately kept the same so that they fit together well from an aesthetic point of view. The largest profile sizes are for the roof beams, and the columns here are used 2x 100x175 mm.

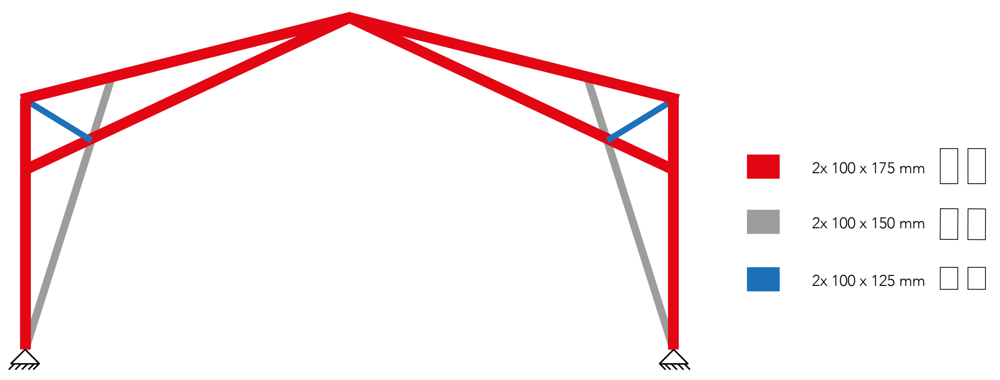


Figure 15 - Chosen dimensions

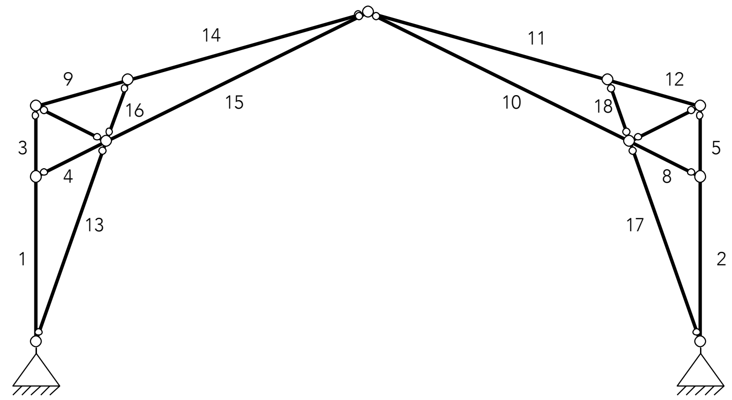
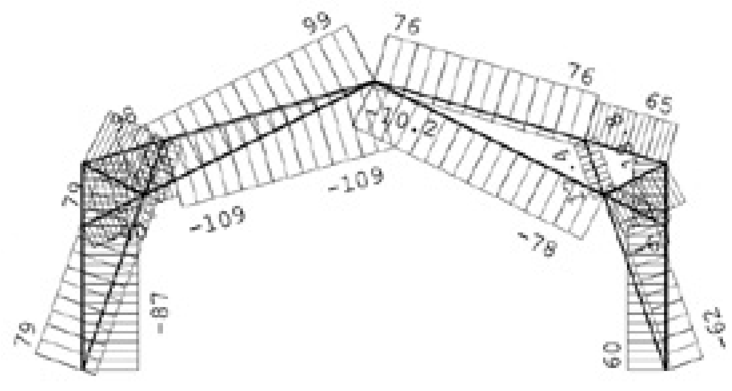
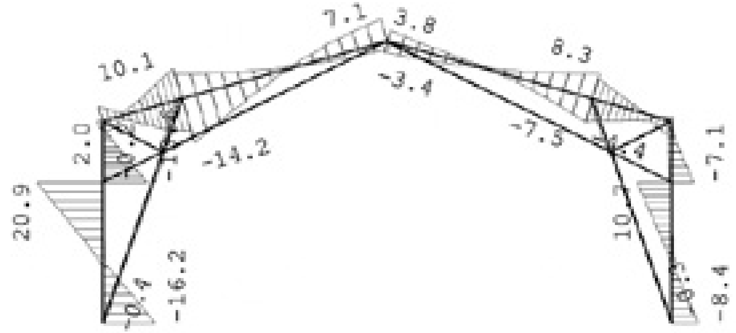


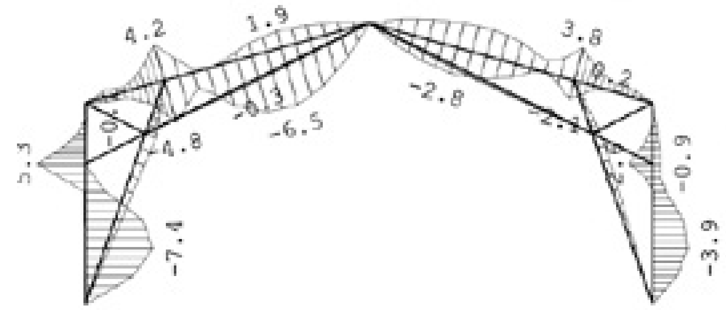
Figure 16 - Structural elements



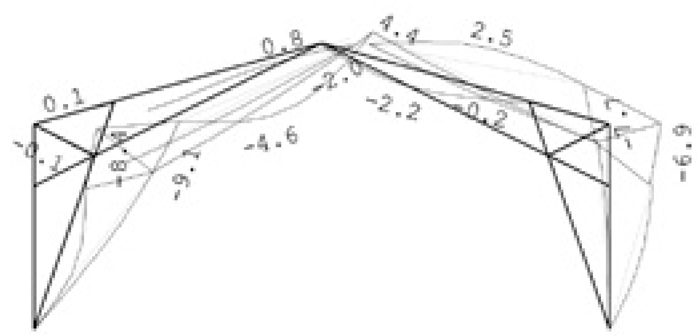
Nmax,min



Vmax,min



Mmax,min



Vertical and horizontal displacement

Element	$N_{,min,tension}$ kN	$N_{,max,pressure}$ kN	$V_{,min}$ kN	$V_{,max}$ kN	$M_{,min}$ kNm	$M_{,max}$ kNm
1	-87	-0,7	-16	20,9	-7,4	5,3
2	-1,8	60,3	-8,4	10,7	-3,9	2,6
3	-70	-0,1	-13,6	2	0	5,3
4	-38,4	-0,2	0	0	0	0
5	-1,3	52	-7	1,8	-0,9	2,6
6	-0,4	19,9	0	0	0	0
7	-0,7	93,7	0	0	0	0
8	-66,7	-0,6	0	0	0	0
9	-90	0,6	-10,3	10	-4,8	4,2
10	-78	-1,55	-0,3	-0,2	-0,3	-0,2
11	-10,3	75,9	-7,5	8,3	-2,8	3,75
12	0,4	65,4	-7,4	6,6	-2	3,8
13	-20,6	79,4	-0,4	0,1	-1,3	0,1
14	-108,7	-3,3	-14,2	8	-6,5	4,2
15	-1,8	98,7	-0,3	0,3	-0,3	-0,2
16	-30	22,1	-0,2	1,5	-1,26	0,1
17	-62	-9	-0,3	-0,1	-0,9	-0,1
18	-18,9	17,5	0,1	1,1	-0,9	-0,1

Overview of the internal forces

Element	BC	UC frm	U.C.
1	3	(6.23)	0,74
2	4	(6.17)	0,48
3	3	(6.23)	0,51
4	5	(6.23)	0,1
5	4	(6.17)	0,33
6	6	(6.17)	0,08
7	3	(6.17)	0,45
8	4	(6.23)	0,22
9	3	(6.23)	0,5
10	4	(6.23)	0,55
11	4	(6.17)	0,48
12	4	(6.17)	0,32
13	3	(6.17)	0,44
14	3	(6.23)	0,84
15	3	(6.17)	0,41
16	3	(6.23)	0,2
17	4	(6.23)	0,33
18	4	(6.17)	0,15

Cross section unity check

8.3.2 Foundation truss

To determine the dimensions of the elements of the truss, the results of the outcome of Axisvm have been used. From the fundamental load combination, the maximum forces that occur in the trusses are obtained. The dimensions are determined based on the element under the highest compressive stress. This is because the element can buckle as a result of a high compressive force.

The fundamental foorces can be found in load combination six which is composed of the permanent load and wind load 2 (see chapter 8.2.3). Looking at the forces that are distributed over the structure, it can be seen that as a result of the wind, upward forces are created on the platform (figure 17). The effect of these upward forces is that the platform tense the bend, which creates tension in the lower beams and pressure in the upper beams.

Due to this upward forces, the maximum pressure that occurs in the upper beam is 32,5 kN. This was used to determine the dimensions of the truss.

By using the formulas 6.23 and 6.24 stated in the NEN-EN1995, the cross-section will be checked for compression and buckling.

Table 12 shows the calculation of the beam. The cross-section chosen for the truss of the foundation is 63x125 mm.

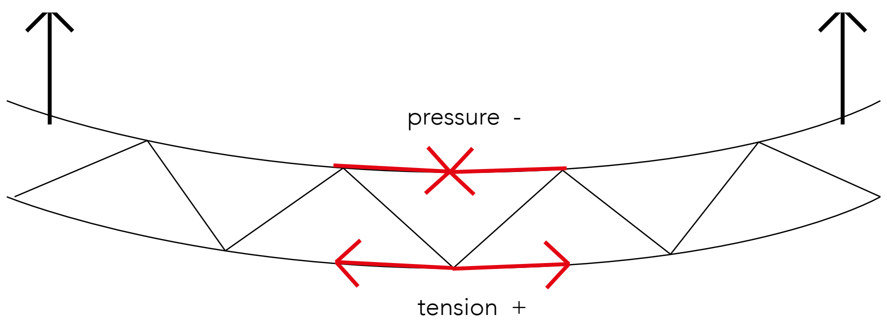


Figure 17 - Force flow in foundation

	N force =	32	kN						
	Moment in Y =	0	kNm						
	Moment in Z =	0	kNm						
	Ly =	1500	mm						
	Lz =	1500	mm						
	w =	63	mm	A =	7875	mm^2			
	h =	125	mm						
	W_y =	164063	mm^3	I_y =	10253906	mm^4			
	W_z =	82688	mm^3	I_z =	2604656	mm^4			
	i_y =	36,1	mm	λ_y =	41,6				
	i_z =	18,2	mm	λ_y =	82,5				
6.21	$\lambda_{rel,y}$ =	0,72		bc =	0,2				
6.22	$\lambda_{rel,z}$ =	1,43							
6.27	k_y =	0,80		Strenght					
6.28	k_z =	1,64		pressure $\sigma_{c,0,d}$ =	4,06	N/mm^2	≤	U.C.	0,31
6.25	$k_{c;y}$ =	0,87		tension $\sigma_{m,y,d}$ =	0,00	N/mm^2	≤	U.C.	0,00
6.26	$k_{c;z}$ =	0,41		tension $\sigma_{m,z,d}$ =	0	N/mm^2	≤	U.C.	0,00
Stability									
6,23	0,36	≤		1	OK				
6,24	0,75	≤		1	OK				

Table 12 - Cross section check truss beam

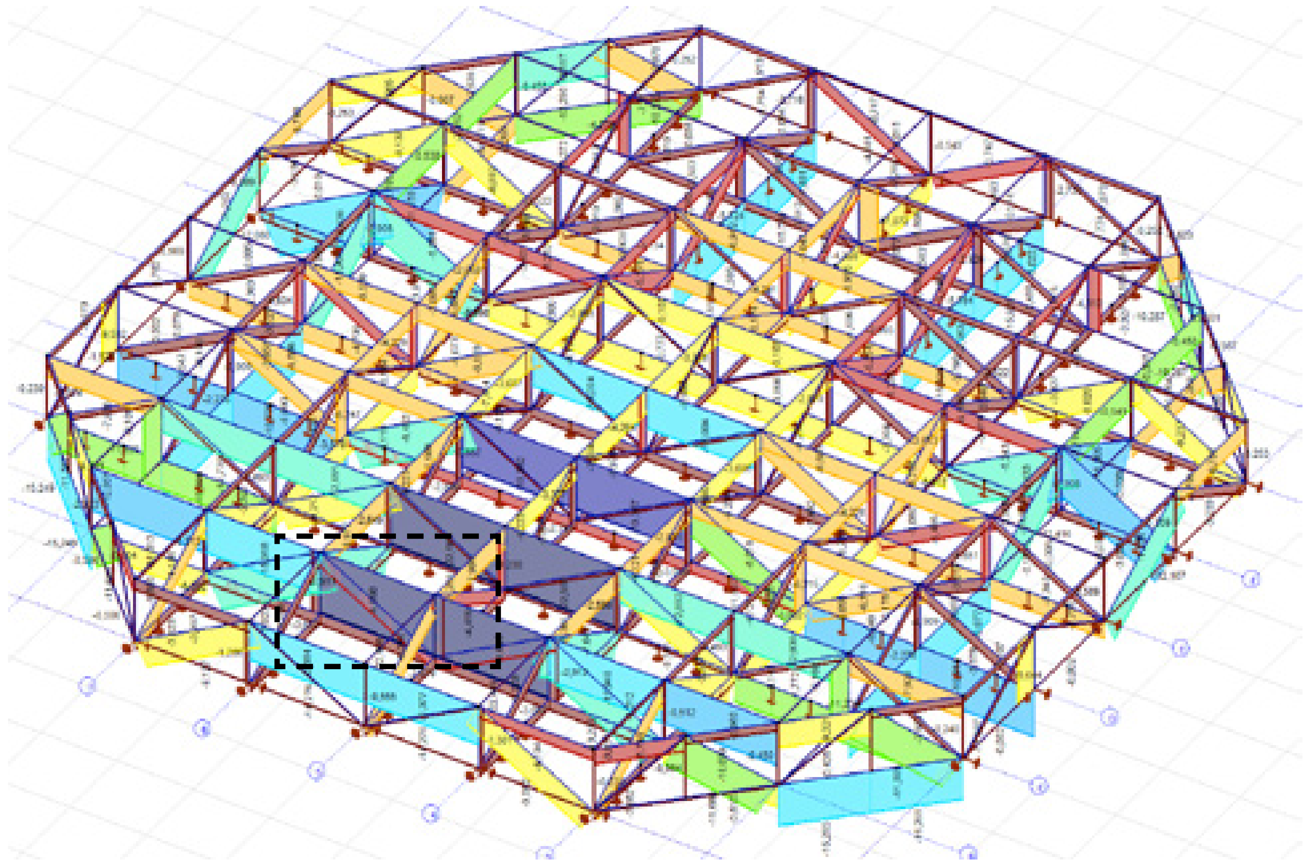


Figure 18 - Maximum compressive forces

8.3.3 Stability wall

The stabilization walls are partly made out of wooden rails finished with cement fibreboard. This is simplified in the model as two diagonal beams placed between beam 1 and 2 (see figure 19). The other stabilization elements are the diagonals in the top of the wall indicated with the number 6.

The wind load on the wall was determined accordingly to wind pressure on the left side of the building. Figure 20 shows which zone of the wind was used. In table 14, the different combination with the load setup is shown. The wind pressure on facade D and E were used and multiplied by the width of the loaded zone.

Figure 21 shows the placement of different load cases. After analyzing the load combinations through Technosoft the fundamental compression load on element six and element, one was found and used to determine the size of the elements. Table 15 shows the calculation of beam 1, which results in a cross-section of 63x100 mm with Yellow meranti as wood type.

The calculation of element six can be found in the appendix.

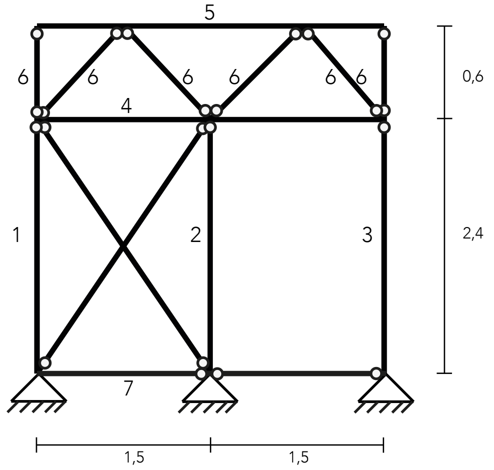


Figure 19 - Element numbering

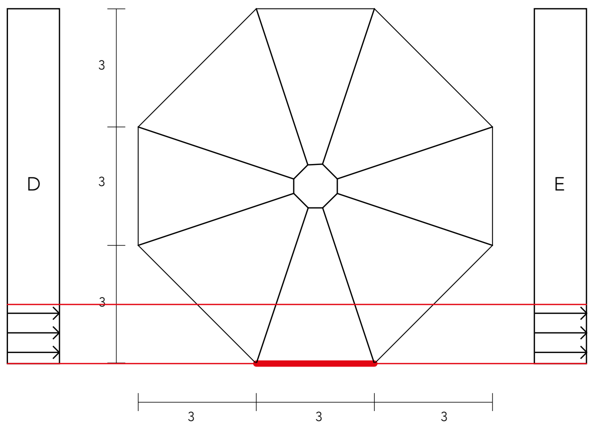


Figure 20 - Wind on the wall

Load combination	LC1 - Dead load	LC2 - Wind left	LC3 - Wind right
C1 - ULS 1:	1,2	1,5	-
C2 - ULS 2:	1,2	-	1,5
C3 - ULS 3:	1	1	-
C4 - ULS 4:	1	-	1

	windfactor	wind pressure in [kN/m²]	width [m]	wind pressure in [kN/m']	F1 [kN]	F2 [kN]
Facade - zone D	0,73	2,4	1,5	3,6	5,42	1,1
Facade - zone E	-0,35	-1,2	1,5	-1,7	-2,60	-0,5 +
					8	2,1

Table 14 - Loads and load cases

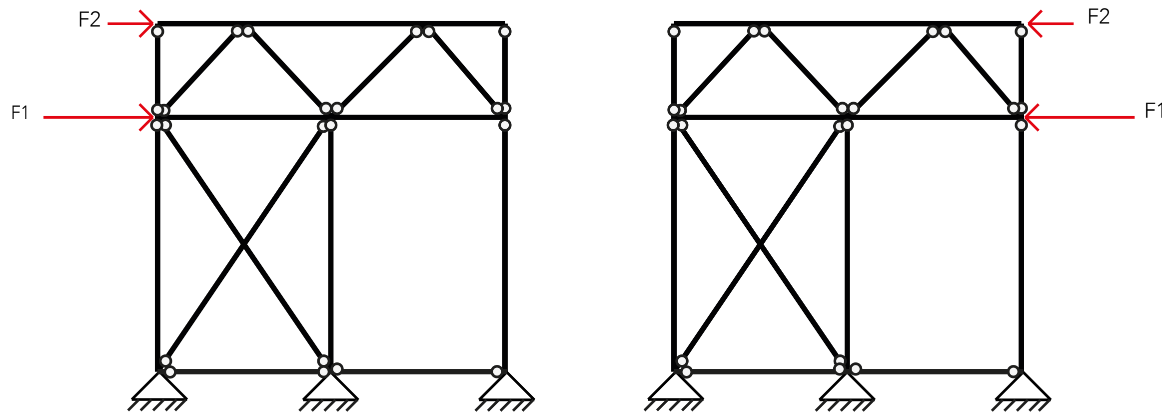


Figure 21 - Loads on stabilization wall: wind from the left and wind from the right

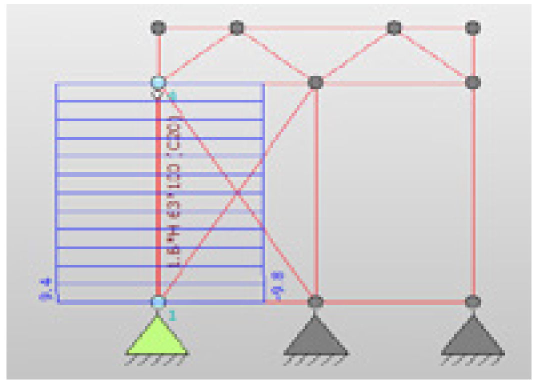


Figure 22 - Fundamental load on element 1

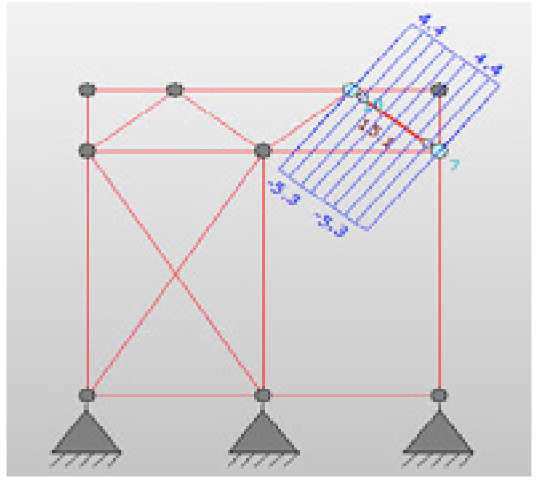


Figure 23 - Fundamental load on element 6

N force =	9,8	kN			
Moment in Y =	0	kNm			
Moment in Z =	0	kNm			
Ly =	2400	mm			
Lz =	2400	mm			
w =	63	mm	A =	6300	mm²
h =	100	mm			
W_y =	105000	mm³	I_y =	5250000	mm⁴
W_z =	66150	mm³	I_z =	2083725	mm⁴
i_y =	28,9	mm	λ_y =	83,1	
i_z =	18,2	mm	λ_y =	132,0	

6.21	$\lambda_{rel,y}$ =	1,44	bc =	0,2				
6.22	$\lambda_{rel,z}$ =	2,29						
6.27	k_y =	1,65	Strenght					
6.28	k_z =	3,32	pressure $\sigma_{c,o,d}$ =	1,56	N/mm²	≤	U.C.	0,12
6.25	$k_{c;y}$ =	0,41	tension $\sigma_{m,y,d}$ =	0,00	N/mm²	≤	U.C.	0,00
6.26	$k_{c;z}$ =	0,17	tension $\sigma_{m,z,d}$ =	0	N/mm²	≤	U.C.	0,00
Stability								
6.23	0,29	≤	1	OK				
6.24	0,68	≤	1	OK				

Table 15 - Cross section check element 1

8.4 Stability

To test the stability of the building, a distinction is made between the floating foundation and the structural frame of the classroom. Both have their own stability requirements and will be briefly described in this chapter.

Structural framing

For the structural framing, the horizontal displacement requirements from the NEN-EN 1990 Principles of the structural design were used.

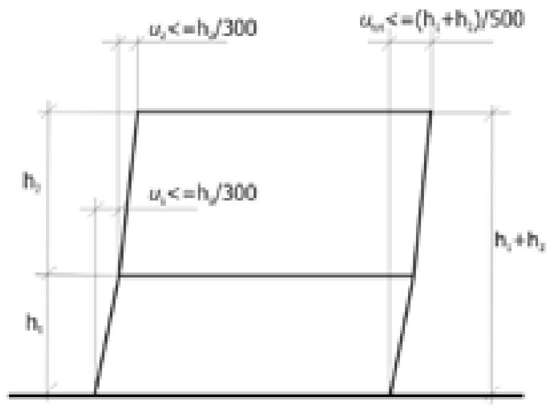


Figure 24 - Requirements for the tilt of a building (NEN-EN 1990)

The total tilt for a single-storey building may not exceed u ≤ h / 300. (figure 24)

Floating foundation

The floating foundation was tested in 2 ways to determine the stability and buoyancy of the platform

The stability (tilting of the platform) and buoyancy (sinking of the floor storm) will be considered for each load combination.

Tilting
To test the tilting of the floating foundation, the principle is described as used in section 5.3. In short, this means that the floating platform may have a maximum angular displacement of 4 degrees. (NTA 811).

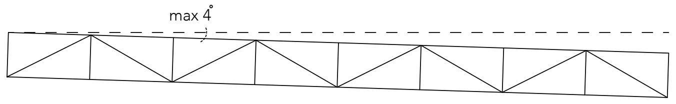


Figure 25 - Maximum angular displacement

Sinking
To check the sinking of the floating foundation, there are no requirements described for the type of structure that is supported with barrels. Therefore, an own maximum depth for sinking the foundation was drawn up. The barrels used have a total height of 1 meter which means that if 1 meter gets exceeded, the foundation will sink. Therefore a maximum requirement is set that the platform may not sink any deeper than 0.8 meters. As a result, the foundation will always maintain its buoyancy, and a safety margin of 0.2 meters is guaranteed

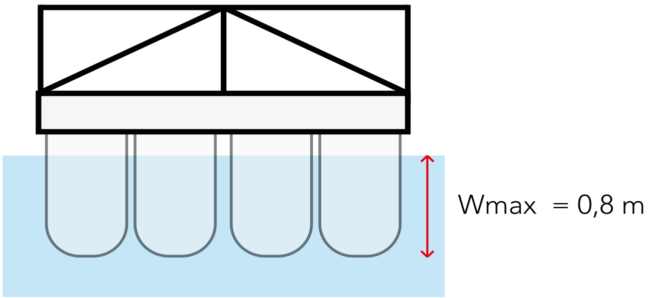


Figure 26 - Maximum depth for sinking

8.4.1 Stability structural framing

The results of the overall displacements of the structural framing are the results of the 3D model set up, as described in chapter 8.1.
The horizontal displacements was checked according to the requirements described in 8.4.

Figure 27 and 28 show the displacement of the structural framing in the x-direction. The biggest deformation in the x-direction is 8,4 mm. Since the height of the facade is 3 meters, the maximum allowed horizontal displacement is 3000/300 = 10 mm. So the occurring displacement in the x-direction of 8,4 mm is allowed.

Figure 29 and 30 show the displacement of the structural framing in the y-direction. The biggest deformation in the x-direction is 3,87 mm. So the occurring displacement in the x-direction of 3,87 mm is allowed.

So overall, the structural framing is stable in x as in the y-direction. However, this remains a schematic representation of reality, and an accurate calculation will be required to determine the actual displacement.

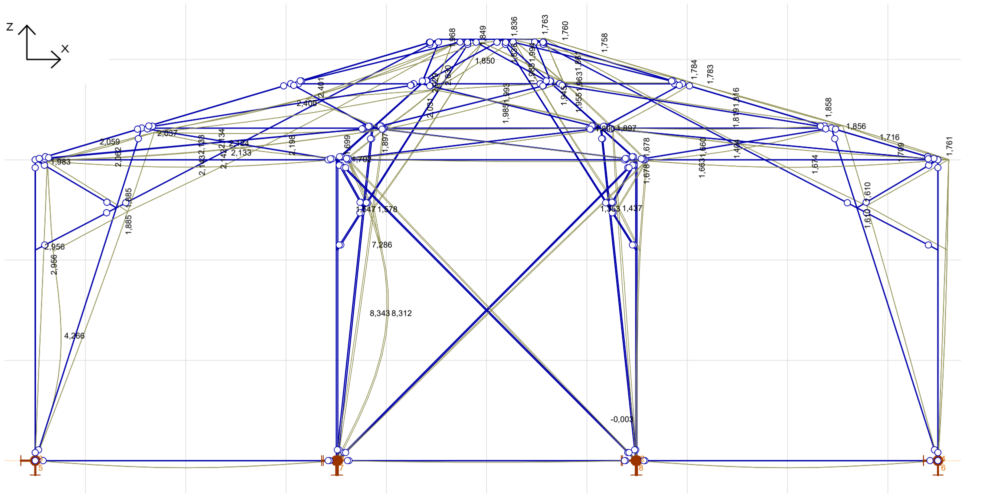


Figure 27 - displacement in the x direction

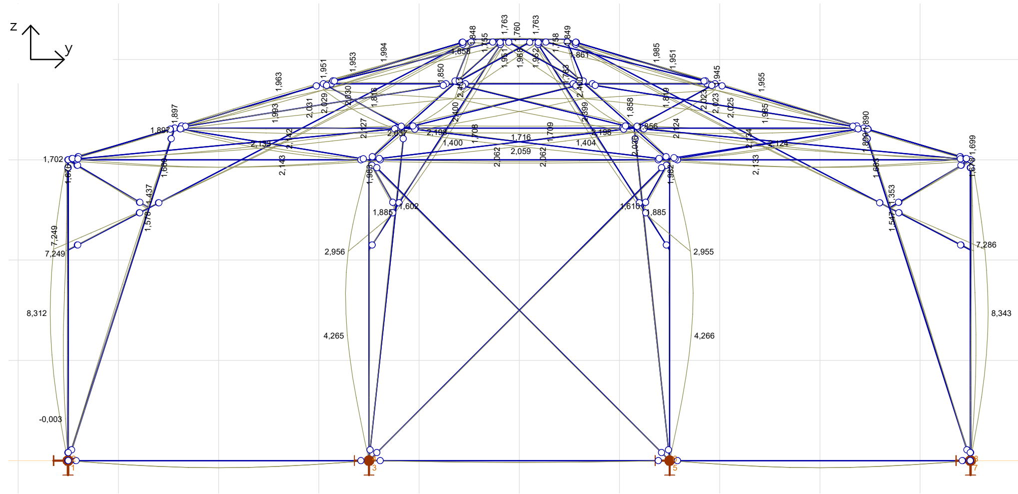


Figure 28 - displacement in the x direction

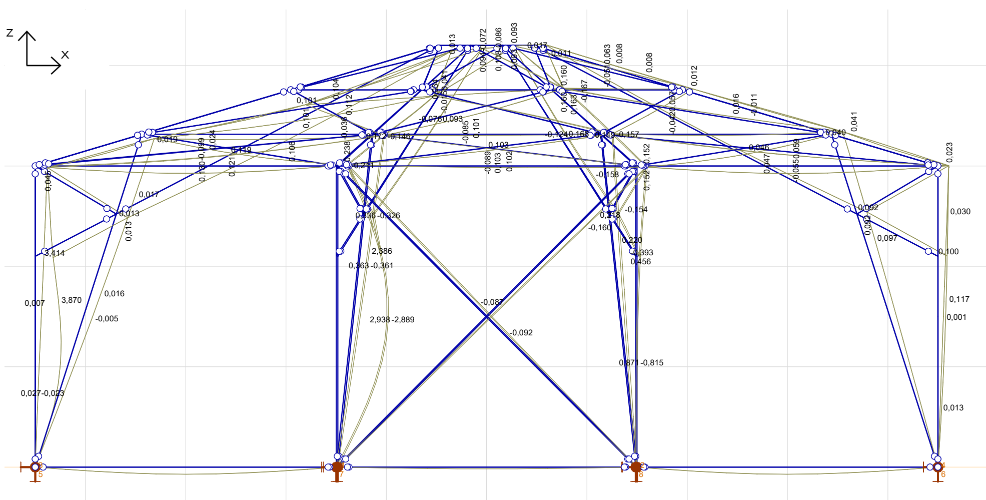


Figure 29 - displacement in the y direction

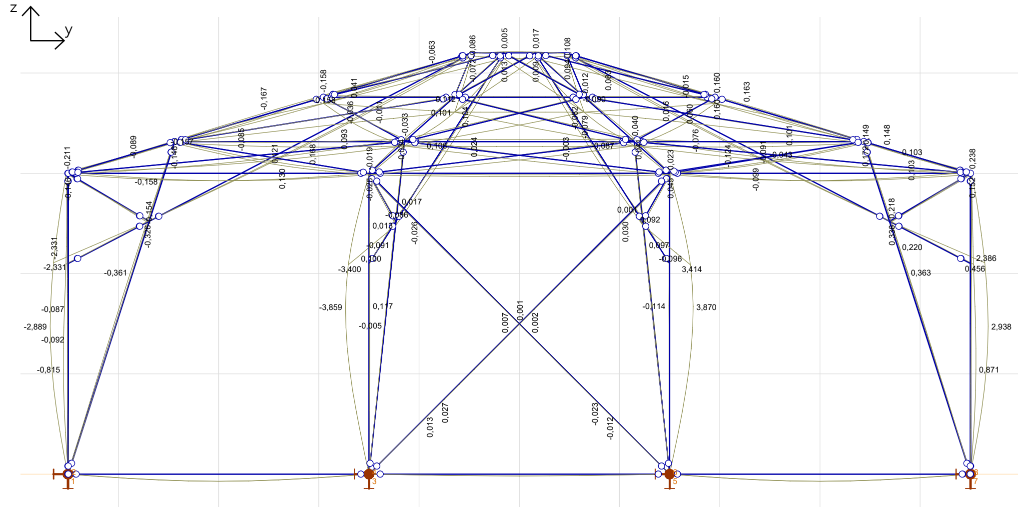


Figure 30 - displacement in the y direction

8.4.2 Stability floating foundation

The results of the overall displacements of the floating foundation are the results of the 3D model set up, as described in chapter 8.1.
The sinking and tilting were checked according to the requirements described in 8.4.

Figure 31 shows the sinking of the platform based on the dead load of the construction. The sinking is 411 mm, so when the classroom is not used, and there is no wind, it will be underwater for +/- 0,4 meter.

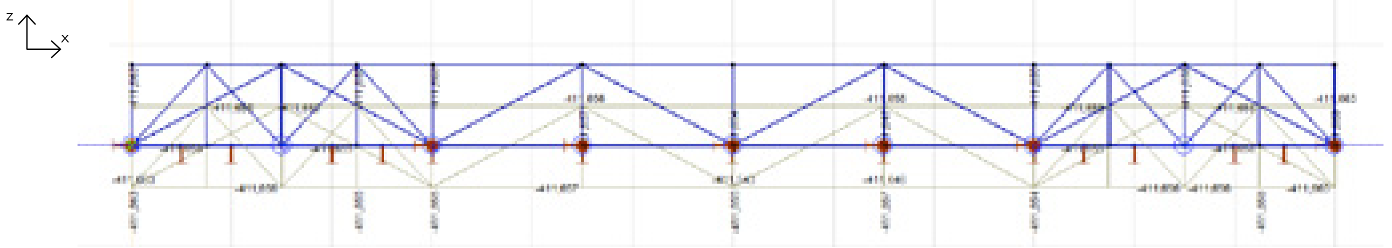
Figure 32 shows the sinking of the classroom when the classroom is fully filled with occupants based on the 1,9 kN/m2 The platform will sink for 700 mm.

Figure 34 shows the effect of an eccentric load on the platform; basically, what will happen if half of the occupants are on one side of the platform. The platform will have a tilt of 2 degrees, and the loaded side of the platform will sink 760 mm which almost exceeds the maximum sinking of 800 mm, but it is still within limits.

Figure 37 shows the most significant displacement of the different wind load cases. With a total sinking of 655 mm on one side and tilt, of 3 degrees is it still wihtin limits.

Figure 39 shows load combination 17 which is based on a situation that will most likely never occur in real life (event of a typhoon and where all the occupants will be on one side of the classroom but could happen if the classroom is used as a emergency shelter). The tilt is at the limit of 4 degrees, and the maximum depth of sinking is 600 mm on one side. So even if this situation occurs, the platform will still be useable and won't sink.

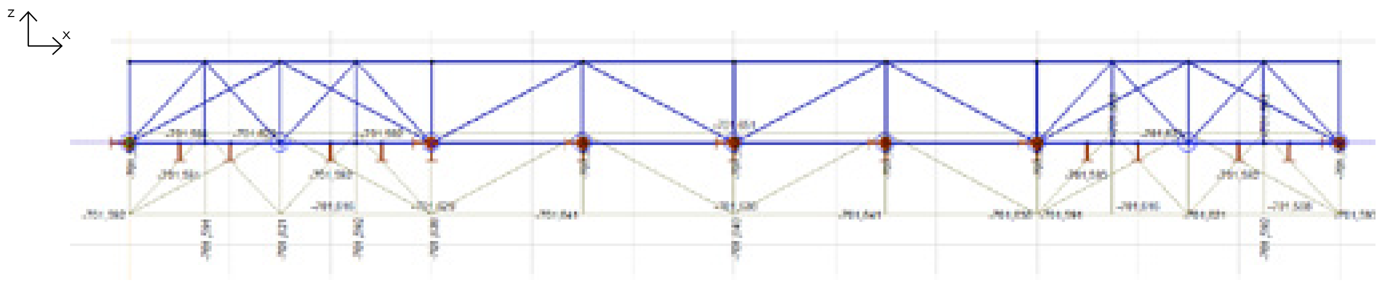
Overall the classroom is safe under all the load combinations in terms of sinking and tilting. Further research is needed to see how the classroom performs with influences of waves and the 2nd order moment.



C9 - dead load

W_{left}	-411	mm	≤	800	mm	OK
W_{right}	-411	mm	≤	800	mm	OK
Tilt	0	degrees	≤	4	degrees	OK

Figure 31 - Load combination 09 - Dead load



C10 - dead + live load classroom

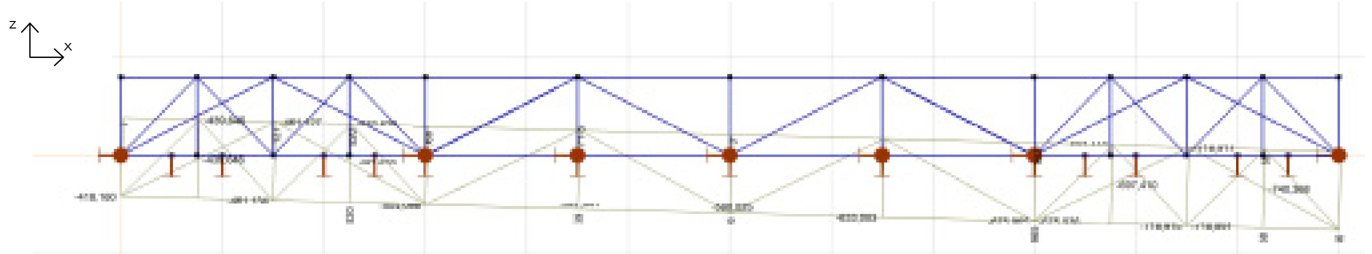
W_{left}	-701	mm	≤	800	mm	OK
W_{right}	-701	mm	≤	800	mm	OK
Tilt	0	degrees	≤	4	degrees	OK

Figure 32 - Load combination 10 - Dead load + live load classroom

C11 - dead + live load roof

W_{left}	-592	mm	≤	800	mm	OK
W_{right}	-592	mm	≤	800	mm	OK
Tilt	0	degrees	≤	4	degrees	OK

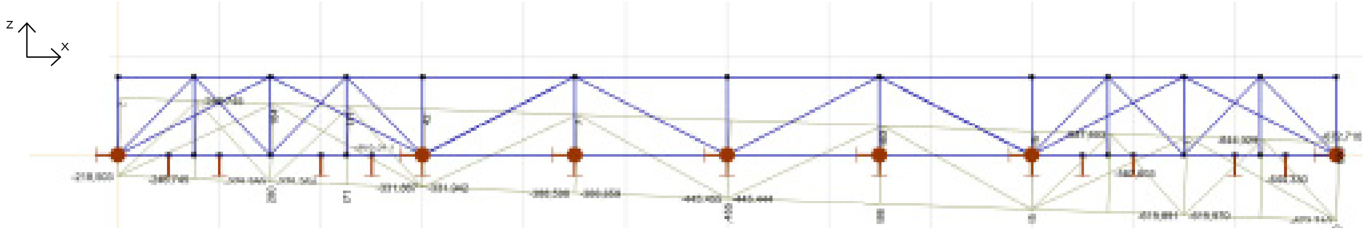
Figure 33 - Load combination 11 - Dead + live load roof



C12 - dead load + eccentric load classroom

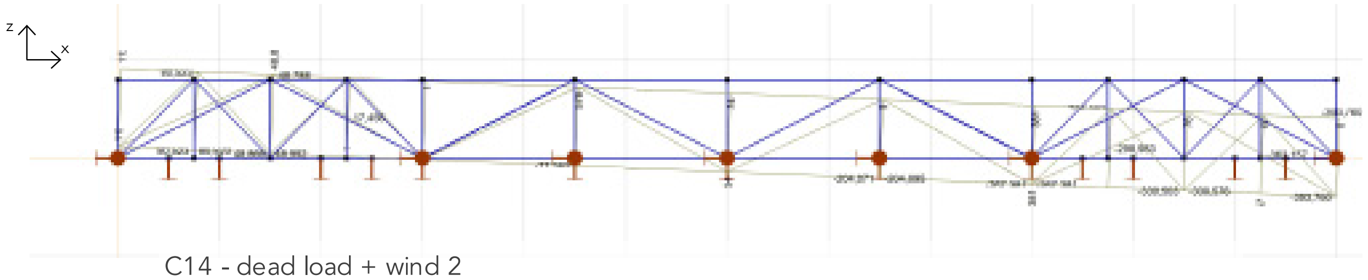
W_{left}	-418	mm	≤	800	mm	OK
W_{right}	-761	mm	≤	800	mm	OK
Tilt	2	degrees	≤	4	degrees	OK

Figure 34 - Load combination 12 - Dead load + eccentric load classroom



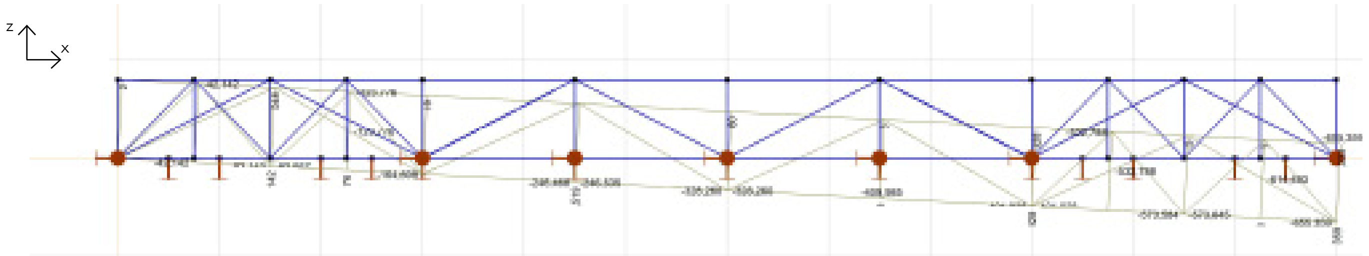
C13 - dead load + wind 1						
W_{left}	-218	mm	≤	800	mm	OK
W_{right}	-672	mm	≤	800	mm	OK
Tilt	2	degrees	≤	4	degrees	OK

Figure 35 - Load combination 13 - Dead load + wind 1



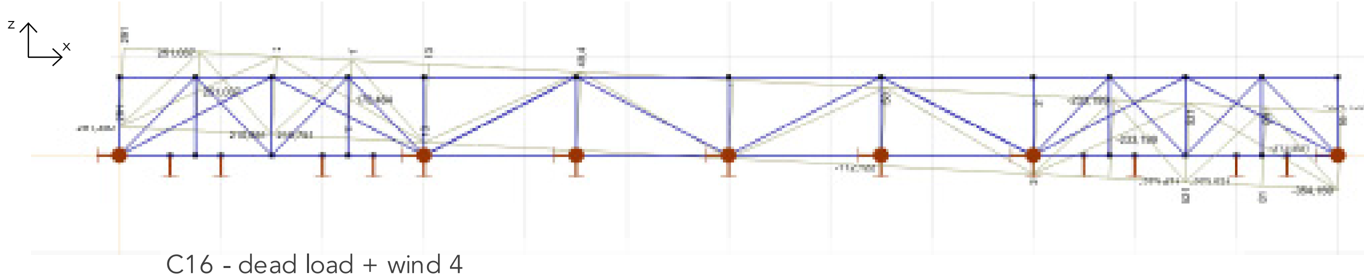
C14 - dead load + wind 2						
W_{left}	112	mm	≤	800	mm	OK
W_{right}	394	mm	≤	800	mm	OK
Tilt	1	degrees	≤	4	degrees	OK

Figure 36 - Load combination 14 - Dead load + wind 2



C15 - dead load + wind 3						
W_{left}	2	mm	≤	800	mm	OK
W_{right}	-655	mm	≤	800	mm	OK
Tilt	3	degrees	≤	4	degrees	OK

Figure 37 - Load combination 15 - Dead load + wind 3



C16 - dead load + wind 4						
W_{left}	291	mm	≤	800	mm	OK
W_{right}	-355	mm	≤	800	mm	OK
Tilt	3	degrees	≤	4	degrees	OK

Figure 38 - Load combination 16 - Dead load + wind 4

C17 - dead load + wind 3 +						
W_{left}	287	mm	≤	800	mm	OK
W_{right}	-599	mm	≤	800	mm	OK
Tilt	4	degrees	≤	4	degrees	OK

Figure 39 - Load combination 17 - Dead load + wind 3 + eccentric load

8.5 Validation of calculations

8.5.1 Validation floating foundation

To control if the results from the Axisvm model are accurate, the results were compared using a manual calculation based on the theory of floating stability.

In the Axisvm model, a part of the floating foundation was separately modelled in Axisvm, and the results were compared with the results of the manual calculation. Based on this comparison, it was clear whether both outcomes are consistent, and the Axisvm model responds as expected.

The hand calculation was performed according to the theory described in chapter 5.5.
The equation looked at the vertical equilibrium and the rotation of the platform.

8.5.1.1 Results 3D model

Both models include the variable loads of a classroom and the own weight of the floor and the floating foundation.

To achieve a slope of the platform, an asymmetric load has to act on the platform, so the eccentric load of the classroom was put on one half of the platform, and the other half unloaded kept unloaded

The loads were entered as line loads distributed on the three longitudinal axes of the platform (figure 41).

Sinking of the platform

Figure 42 shows the sinking of the platform due to the dead load. The dead load causes the platform to sink for -201,3 mm.

	G [kN/m²]	Q [kN/m²]	
1 Classroom floor			
bamboo flooring + bamboo mats	0,2		
wooden framing	0,3		
school load		1,9	+
	0,5	1,9	[kN/m²]

Table 16 - Loads used for validation

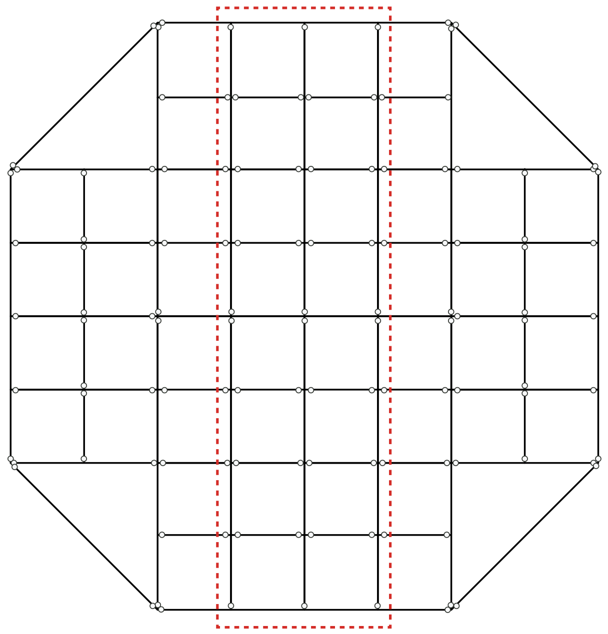


Figure 40 - Part of floating foundation used for validation

Figure 43 shows the sinking of the platform due to dead load + dead load. The dead load combined with live load causes the platform to sink for -737 mm.

Tilting of the platform

Figure 44 shows the sinking of the platform due to the dead load and an eccentric live load on the platform. The left side of the platform sinks for 875,8 mm and the right side for 63,5 mm. With this height difference, the rotation of the platform was calculated.

Rotation = $\tan \varphi = ((U_{right} - U_{left}) / \text{width})$
$\tan \varphi = ((63{,}5 - 875{,}8) / 12000) = 0{,}6768...$
$\varphi = \tan^{-1}(0{,}6768...) = 3{,}87°$

So the platform undergoes a rotation of 3,87 degrees due to the eccentric live load of a classroom.

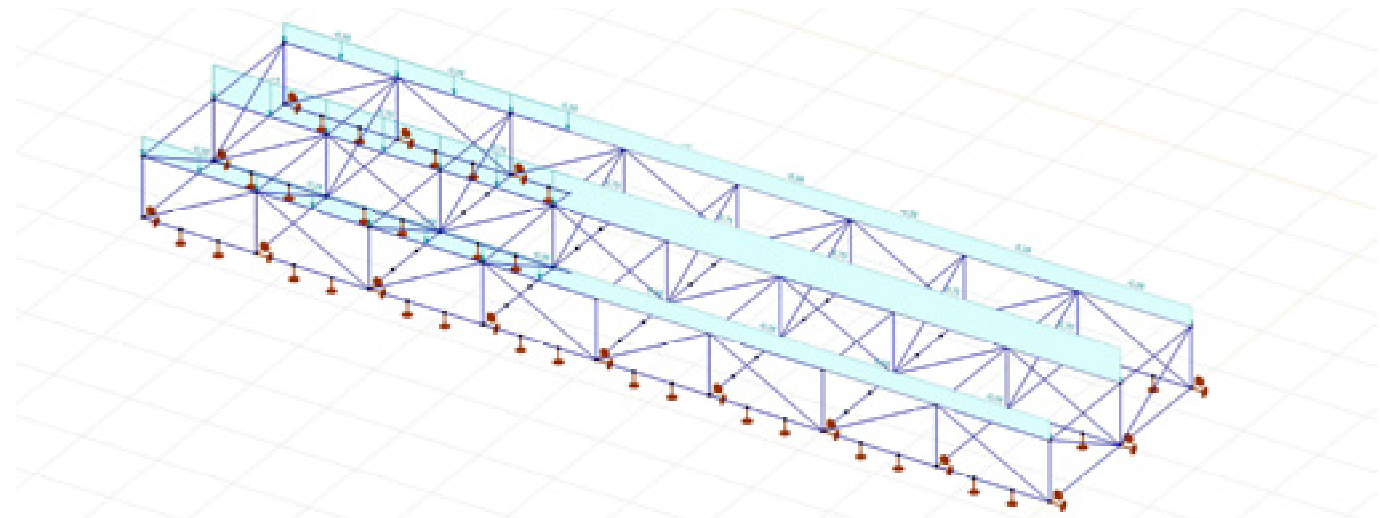


Figure 41 - Part of floating foundation used for validation + dead load

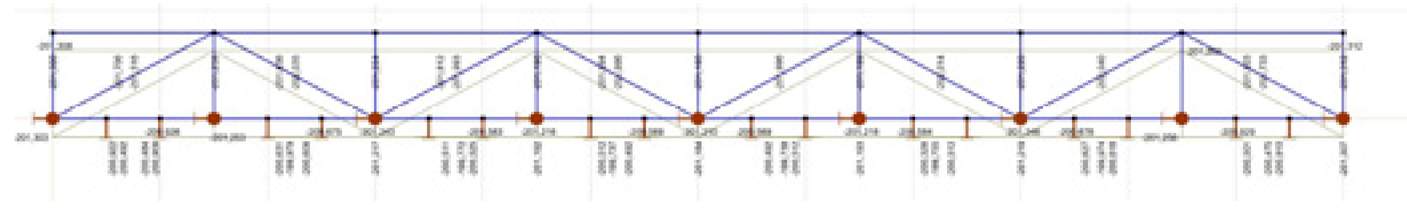


Figure 42 - Sinking of the platform due to dead load only (-201,3 mm)

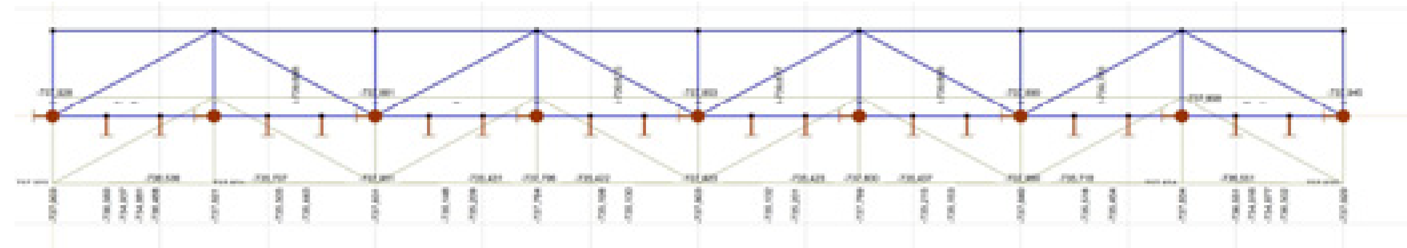


Figure 43 - Sinking of the platform due to dead load + live load (-737 mm)

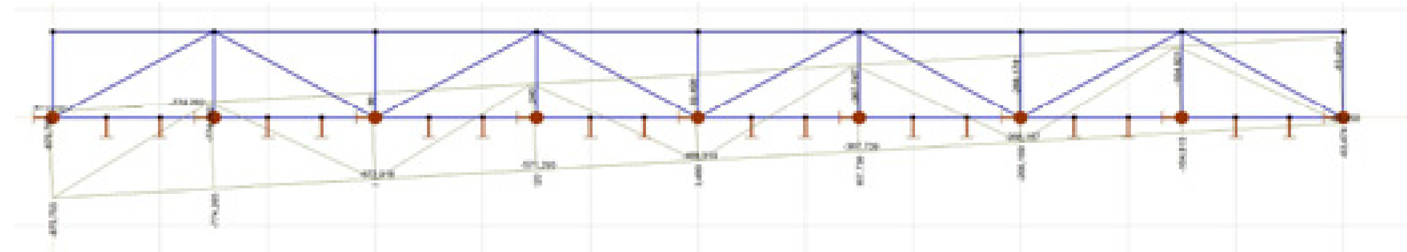


Figure 44 - Sinking of the platform due to dead load + eccentric live load (-875,8 mm left side and -63,5 mm on the right side)

8.5.1.2 Results hand calculation

From the 3D model, a part of the floating foundation will be considered separately, and the results will be compared with the manual calculation. To test whether the results are consistent and whether the computer model responds as expected.

The hand calculation will be performed according to the theory described in chapter 5.5. The equation will look at the vertical equilibrium and the rotation of the platform.

Bouyancy of the platform

The total bouyancy of the platform is the amount of kg's which the platform can carry.

Bouyancy force F_b of one barrel

$F_b = p \times \triangledown$

p = density [kg/m³] = 997 kg/m³ = 10 kN/m³
$\triangledown$ = volume of displacement = 0,2 m³

F_b = 10 kN/m³ x 0,2 m³ = 2 kN

Figure 45 shows the placement of the barrels; the red dots indicate Fb of 1 barrel, and the blue dots indicates 2 barrels. In total there are 32 red dots and 16 blue dots, which indicates a total amount of 64 barrels.

$F_{b,\,total}$ = amount of barrels x F_b
$F_{b,\,total}$ = 64 x 2 kN = 128 kN

Total load on platform

The total own weight of the foundation trusses is 780.2 kg = 7.8 kN.
The total surface of the selected zone is 3 by 12 meters. The total surface is 36 m2.
In table 16 the loads acting on this surface are shown.

The total dead load is the weight of the foundation trusses plus the weight of the floors.
Total dead load = (0,5 kN/m² x 36 m²) + 7,8 kN = 25,8 kN

Total live load = (1,9 kN/m² x 36 m²) = 68,4 kN

Total load = dead load + live load = 25,8 + 68,4 = 94,2 kN

Validation sinking of the platform

The buoyancy is based on barrels of one meter high; this means that the total buoyancy of the platform is exceeded if the platform sinks more than one meter.

This can be used to determine how many cm the platform will sink as a result of a certain load. The total buoyancy is 128 kN which is achieved with a displacement of 1 meter.
This equals 128 kN / 100 cm = 1.28 kN / cm.

In other words, 1.28 kN is needed to lower the platform by 1 cm.

Sinking due to dead load:

Sinking of platform is the total dead load divided by 1.28 kN / cm
25.8 kN / 1.28 kN / cm = 20.16 cm = 201.6 mm.

Looking at figure 37, the platform in the 3D model sinks 201,3 mm this almost matches the hand calculation, so OK.

Sinking due to dead and live load:

94.2 kN / 1.28 kN / cm = 73.6 cm = 736 mm.

Looking at figure 43, the platform in the 3D model sinks 737 mm; this almost matches the hand calculation, so OK.

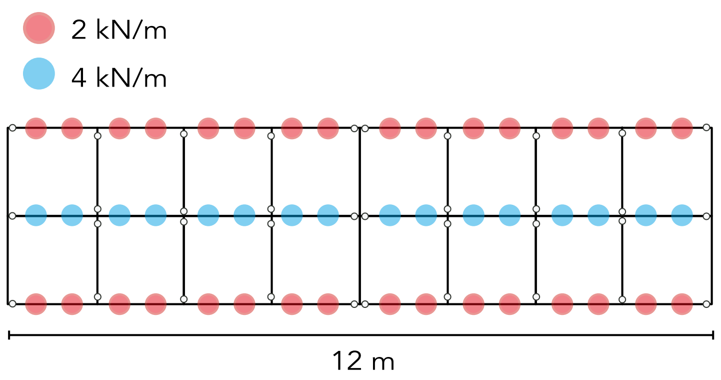


Figure 45 - Indication of the barrels with the bouyancy force

Validation tilting of the platform

To validate the tilting of the platform the heeling moment on the platform and the metacentric height of the floating structure is determined

For the validation of the dead load and an eccentric live load is used, which causes a heeling moment in the platform.

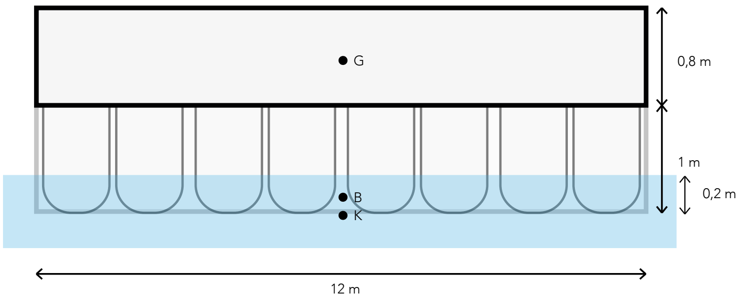


Figure 46 - Shematization floating platform

The platform sinks 0.2 meters due to dead load. The truss foundation is simplified as a rectangular body as well as for the barrels.

Point of gravity of the truss foundation (G) is in the middle of the box, which is 0.4 meter from the bottom of the box.

Point of buoyancy is at the middle of the sunken part. So (B) is at 0.1 meters from K.

Heeling moment

In order to validate the tilting of the platform we need to determine the heeling moment which is working on the platform and the metacentric height of the floating structure

For the validation of the dead load and an eccentric live load is used, which causes a heeling moment in the platform.

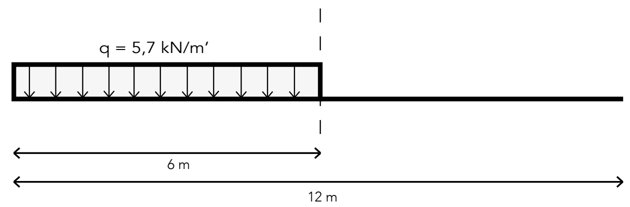


Figure 47 - Shematization eccentric load

M_H = q x (1/2 x l) x (1/4 x l)
= 5,7 x 6 x 3 = 102,6 kNm
The heeling moment is 102,6 kNm.

Meta centric height

GM = KB + BM - KG

BM = b² / 12 d

BM = 12² / 12 x 0,2 = 60 m

KB = 1/2 x d

KB = 1/2 x 0,2 = 0,1

KG = 1,4 m

GM = 0,1 + 60 - 1,4 = 58,8 m

Rotation of the platform

Sinφ = M_H / (F_b x GM)
Sin = 102,6 / (25,8 x 58,8) = 0,067....

Sin^{-1}(0,067....) = 3,87°

The rotation of the platform in the Axisvmodel is also 3,87° so the model is behaving the same accordingly the hand calculation.

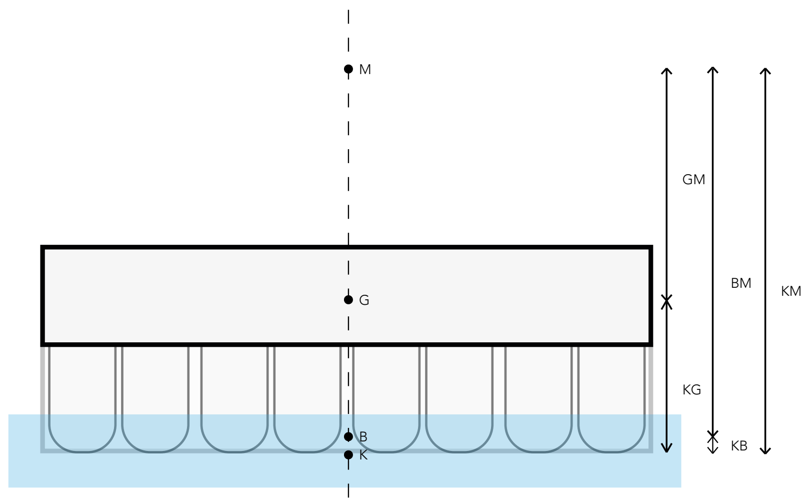


Figure 48 - Schematization meta centre

8.5.2 Validation structural framing

To control if the results of the model in Technosoft frameworks are accurate, the results were compared using a manual calculation based on the force equilibrium in a three-hinged frame.

The vertical and horizontal support reactions as a result of the permanent load on the roof of the three-hinged frame were examined.

The manual calculation is performed according to the basic mechanical rules of the equilibrium of forces in a structure.

8.5.2.1 Results 3D model

In figure 45 the schematization of the structural framing is shown. Figure 50 shows the load on the structural framing. It's based on the load assumptions shown in table 17.

Reaction forces in the supports

Due to the dead load of the roof, the structure has reaction forces in the supports of the structure.

The vertical reaction forces are 4.88 kN on both sides since the frame is symmetrical.

The horizontal reaction forces are 1.86 kN in support A as in support B.

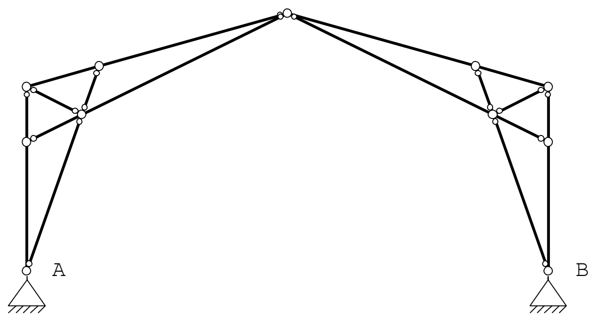


Figure 49 - Schematization of the structural frame

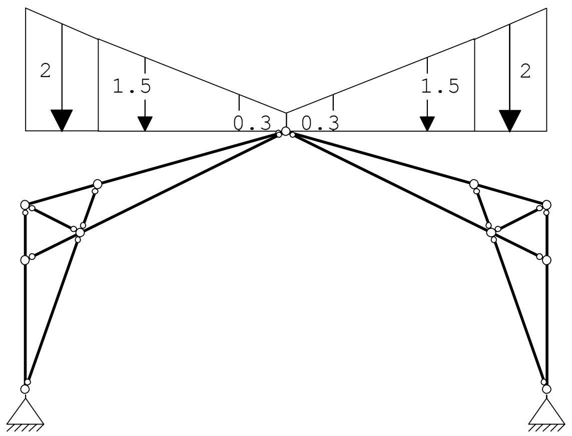


Figure 50 - Dead load on roo

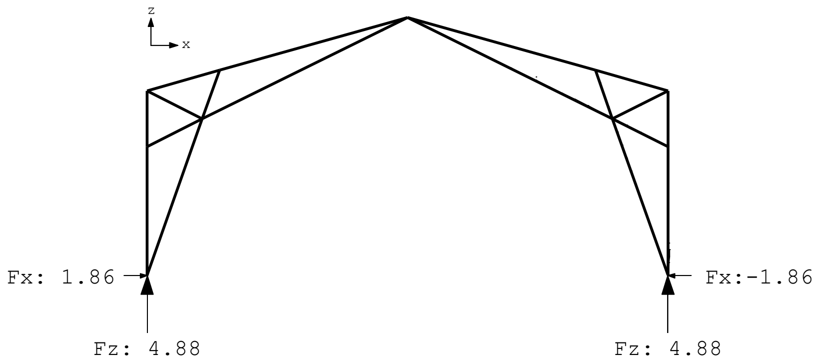


Figure 51 - Reaction forces in the supports

2 Roofing			
wooden framing	0,3		
steel roof sheets	0,1		
plywood sheets	0,1		
insulation	0,05		
roof load		1	+
	0,55	1	[kN/m²]

Table 17 - Loads used for validation

8.5.2.2 Results hand calculation

For the manual calculation, the structural frame has been simplified to the following diagram (figure 52).

Vertical reaction forces in the supports

Because the frame is symmetrical and the loads on both sides are identical, the vertical reaction forces will be equal. For the total vertical load, it is easy to stack the two loads together, so it becomes a rectangular shape of 2.3 kN / m with a length of 4.25 meters.

Total load is the surface of the rectangular shape: 2,3 kN/m' x 4,25 m = 9,77 kN

$AF_v = BF_v$ = 9,77 kN / 2 = 4,88 kN ↑

Horizontal reaction forces in the supports

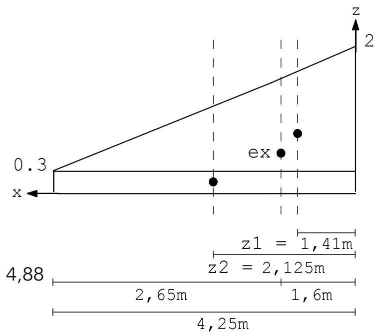
To determine the horizontal reaction force in the supports, there is looked at the right side of the frame (figure 54). For the q-load, the resultant force is determined Fqr. Fqr equals half of the total load or 4.88 kN.

Fqr acts on the centre of gravity of a double profile consisting of an elongated rectangle and a triangle.

Center of gravity

$ex = (A_1 x Z_1 + A_2 x Z_2)/A_{total}$
A_1 = 4,25 x 0,3 = 1,27 m^2
A_2 = (0,5 x 4,25 x 1,7) = 3,61 m^2
Z_1 = (0,5 x 4,25) = 2,125 m
Z_2 = (1/3 x 4,25) = 1,41 m
A_{total} = 4,88 m^2

ex = (1,27 x 2,125 + 3,61 x 1,41) / 4,88
= 1,6 m



BFh was determined by the moment around point S. Point S is a hinged connection and no moment can occur here, this gives the first starting point
Ms = 0
Ms = F,qr x 2,65 + B,Fh x 4,2 - B,Fv x 4,25 = 0
4,88 x 2,65 +B,Fh x 4,2 - 4,88 x 4,25 = 0
12,93 x 4,2B,Fh - 20,74 = 0
4,2B,Fh = 7,81
B,Fh = 1,86 kN ←

Looking at the results from the Technosoft model and the results from the hand calculation, we can say that the computer acts as expected.

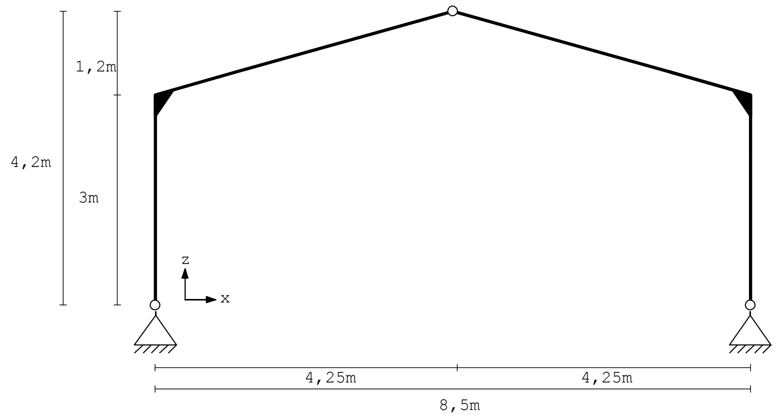


Figure 52 - Dead load on roof

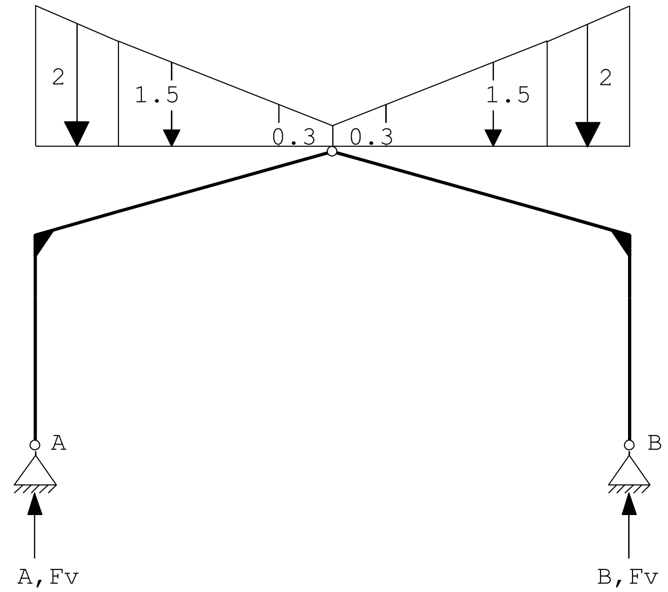


Figure 53 - Dead load on roof

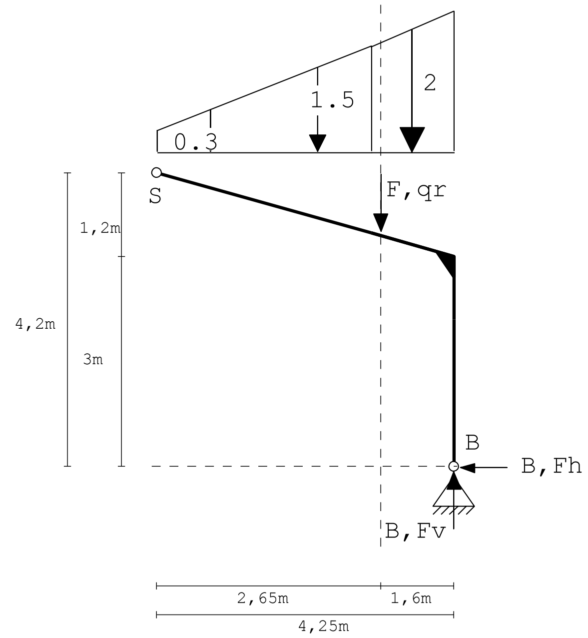


Figure 54 - Dead load on roof

8.6 Connections

For the design, three connections are analyzed. For each connection, it is shown how the connection works, and for some, several calculations have been made for validation.

The three connections are the connection between the structural framing and the truss foundation, the connections in the frame itself and the connections of the frame with the pressure ring.

8.6.1 Connection foundation - frame

Figure 56 is a section of the detail. The connection is made out of a steel cross which is connected to the trusses of the foundation using a bolted connection.

On this steel cross, a steel plate is welded to which the frame will be attached using a bolted connection. A short calculation is made to determine the dimensions of the steel plate, the bolts and the wood.

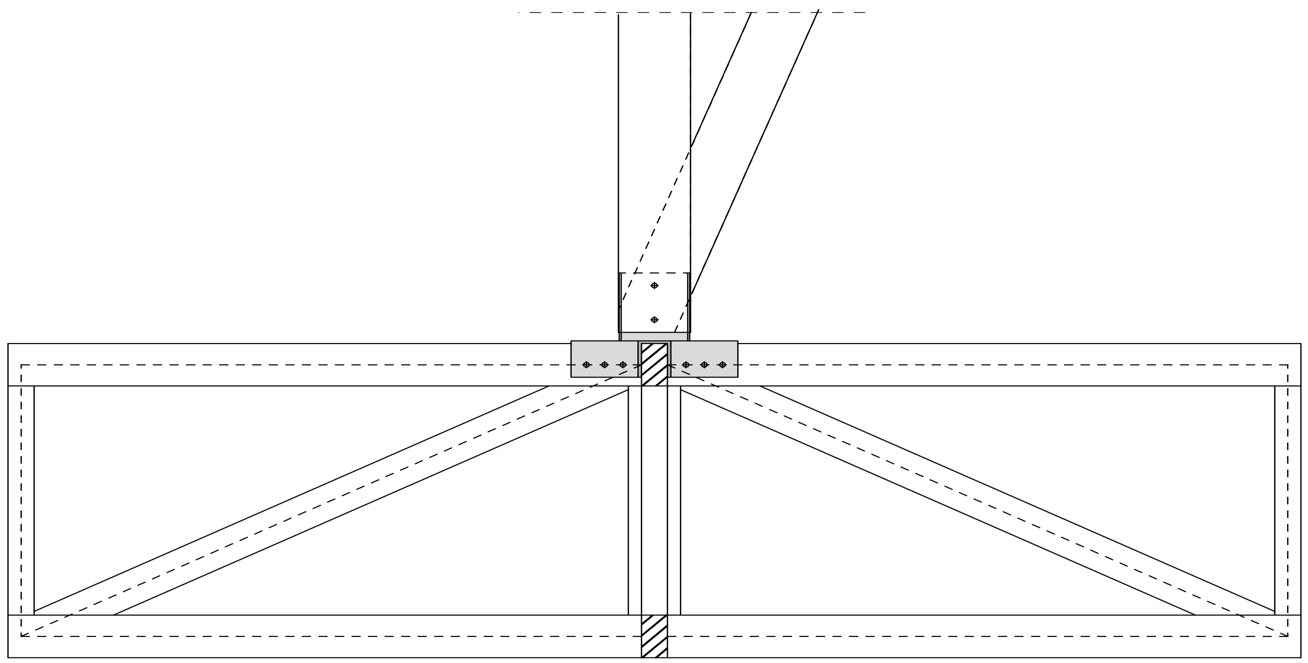


Figure 56 - Connection of frame to the foundation

The largest support reactions are achieved from the Technosoft model, which must therefore be passed on by this connection.

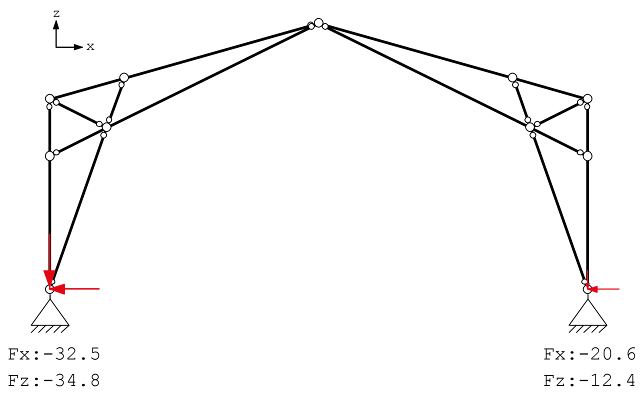


Figure 55 - Support reaction due to load combination 5

The largest reaction forces in the supports are found in load combination 5: dead load + wind 4. Figure 55 shows the reactions forces in the supports, the support on the left has a vertical force of -32,5 kN which pulls up and has a horizontal force of 34,8 kN.

The connection was dimensioned with the reaction forces from combination five as fundamental forces that the connection must transfer.

Control of the steel plate

The steel plate has to transfer the load to the foundation. As a result, the steel plate is loaded on shear as a result of the horizontal force coming from the truss. There will also be a moment in the plate as a result of the horizontal force.

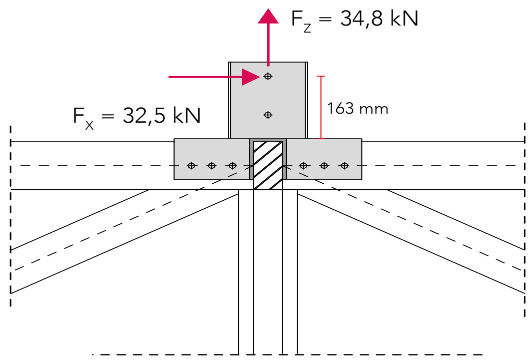


Figure 57 - Forces acting on the steel plate

Dimensions of the steel plate are 15 mm by 175 mm. This gives an A of 2625 mm^2

Control on tension (NEN-EN 1993-1-1 art. 6.2.5)

$$\frac{M_{Ed}}{M_{Rd}} \leq 1{,}0 \quad (6.12)$$
$$W_y = \frac{b \cdot h^2}{6} = \frac{15 \cdot 175^2}{6} = 76{,}6 \cdot 10^3 \text{ mm}^3$$
$$M_{Rd} = \frac{Wy \cdot f_y}{\gamma_{M0}} = \frac{76{,}6 \cdot 10^3 \text{mm}^3 \cdot 235 \text{ N/mm}^2}{1} = 18 \text{ kNm} \quad (6.13)$$
$$M_{ed} = F_x \cdot a = 32{,}5 \text{ kN} \cdot 0{,}163 \text{ m} = 5{,}3 \text{ kNm}$$
$$\frac{M_{ed}}{M_{Rd}} = \frac{5{,}3 \text{ kNm kNm}}{18 \text{ kNm}} = 0{,}3 \leq 1{,}0 \text{ OK}$$

Control on shear (NEN-EN 1993-1-1 art. 6.2.6)

$$\frac{V_{Ed}}{V_{Rd}} \leq 1{,}0 \quad (6.17)$$
$$V_{Rd} = \frac{A_v \cdot \frac{f_y}{\sqrt{3}}}{\gamma_{M0}} \quad (6.18)$$
$$V_{Rd} = \frac{1312{,}5 \text{ mm} \cdot \frac{235 \text{ N/mm}^2}{\sqrt{3}}}{1} = 178 \text{ kN}$$
$$\frac{V_{Ed}}{V_{Rd}} = \frac{32{,}5 \text{ kN}}{178 \text{ kN}} = 0{,}18 \leq 1{,}0 \quad \text{OK}$$

Control on tension and shear (NEN-EN 1993-1-1 art. 6.2.1),

$$\sqrt{\sigma^2 + 3\tau^2} \leq f_y$$
$$\sigma = \sigma_N + \sigma_M = \frac{N_{Ed}}{A} + \frac{M_{Ed}}{W} = \frac{34{,}8 \cdot 10^3 \text{ N}}{2625 \text{ mm}^2} + \frac{5{,}3 \cdot 10^6 \text{Nmm}}{76{,}6 \cdot 10^3 \text{ mm}^3} = 82{,}4 \text{ N/mm}^2$$
$$\tau = \frac{V_{Ed}}{A_v} = \frac{32{,}5 \cdot 10^3 \text{N}}{1312{,}5 \text{ mm}} = 24{,}7 \text{ N/mm}^2$$
$$\sqrt{\sigma^2 + 3\tau^2} = \sqrt{82{,}4^2 + 3 \cdot 24{,}7^2} = 92{,}8 \text{ N/mm}^2 \leq 235 \text{ N/mm}^2 \quad \text{OK}$$

Control of the bolts - frame

The frame is connected to the steel plate by using 2 M16 bolts. The bolts are calculated based on the shear resistance of the bolt.

For the connection 2 bolt of M16 are used from the bolt class (4,6)

Control on shear resistance per shear plane (NEN-EN 1993-1-8)

$$F_{v,Rd} = \frac{\alpha_v \cdot f_{ub} \cdot A_s}{\gamma_{M2}} \quad (2.14)$$

In which:
$\alpha_v = 0{,}6$ for bolt class 4.6, 5.6 en 8.8
$f_{ub} = 400 \text{ N/mm}^2$
$A_s = 157 \text{ mm}^2$
$\gamma_{M2} = 1{,}25$

$$F_{v,Rd} = \frac{0{,}6 \cdot 400 \text{ N/mm}^2 \cdot 157 \text{ mm}^2}{1{,}25} = 30{,}1 \text{ kN} = 2 \text{ bolts} = 60{,}2 \text{ kN}$$

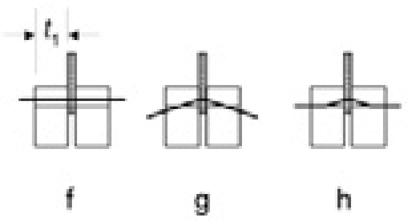
Total shear force:

$$F_{v,Ed} = \sqrt{F_x^2 + F_h^2} = \sqrt{32{,}5^2 + 34{,}8^2} = 47{,}6 \text{ kN}$$

$$F_{v,Ed} \leq F_{v,Rd} = 47{,}6 \text{ kN} \leq 60{,}2 \text{ kN} = \text{OK}$$

Control of the wooden profiles - frame

The wooden profiles are tested for shear. For a steel plate as a middle element with a double-edged connection, there are 3 possible failure mechanisms.



$$F_{v,Rk} = \min \begin{cases} f_{h,1,k} t_1 d & (f) \\ f_{h,1,k} t_1 d \left[\sqrt{2 + \frac{4 M_{y,Rk}}{f_{h,1,k} d t_1^2}} - 1 \right] + \frac{F_{ax,Rk}}{4} & (g) \\ 2{,}3 \sqrt{M_{y,Rk} f_{h,1,k} d} + \frac{F_{ax,Rk}}{4} & (h) \end{cases}$$

Figure 58 - Failure mechanisms (NEN-EN 1995-1-1)

$F_{v,Rk} = f_{h,k} \cdot t_1 \cdot d = 22{,}7 \cdot 140 \cdot 16 = 50{,}8$ kN (f)

$F_{v,Rk} = f_{h,k} \cdot t_1 \cdot d \cdot (\sqrt{2 + \frac{4 \cdot M_{y,Rk}}{f_{h,k} \cdot d \cdot t_1^2}} - 1) + \frac{F_{ax,Rk}}{4}$ (g)

$= 22{,}7 \cdot 140 \cdot 16 \cdot (\sqrt{2 + \frac{4 \cdot 162141}{22{,}7 \cdot 140 \cdot 16^2}} - 1) + \frac{2{,}05}{4} = 52{,}7$ kN

$F_{v,Rk} = 2{,}3 \sqrt{M_{y,Rk} \cdot f_{h,k} \cdot d} + \frac{F_{ax,Rk}}{4}$ (h)

$= 2{,}3 \sqrt{162141 \cdot 22{,}7 \cdot 16} + \frac{2{,}05}{4} = 18{,}15$ kN

$F_{v,Rk,min} = 18{,}15$ kN

$F_{v,Rd,min} = \frac{18{,}15}{1{,}3} = 14$ kN

2 bolts with in total 4 shear planes comes to a

$F_{v,Rd,total} = 14 \text{ kN} \cdot 4 = 56$ kN

$F_{v,Ed} = 47{,}6 \text{ kN} \leq 56 \text{ kN OK}$

Crushing strength wood $f_{h,k}$

$f_{h,k} = 0{,}082 \cdot (1 - 0{,}01 \cdot d) \cdot \rho_k =$

$0{,}082 \cdot (1 - 0{,}01 \cdot 16) \cdot 330 = 22{,}7 \text{ N/mm}^2$

$\rho_k \rightarrow$ wood class C20 $\rightarrow 330 \text{ kg/m}^3$

$d \rightarrow$ diameter bolt $\rightarrow 16$ mm

Flow moment bolt $M_{y,Rk}$ (8.5.1)

$M_{y,Rk} = 0{,}3 \cdot f_{u,k} \cdot d^{2,6} = 0{,}3 \cdot 400 \cdot 16^{2,6} = 162141$ Nmm

$f_{u,k} =$ bolt class 4,6 $= 400 \text{ N/mm}^2$

Pull out strength of the bolt F_{ax}, Rk (8.5.2)

$F_{ax}, Rk = 3 \cdot f_{c,90,k} \cdot A_{ring} = 3 \cdot 2{,}3 \cdot 2{,}98 \cdot 10^2 = 2{,}05$ kN

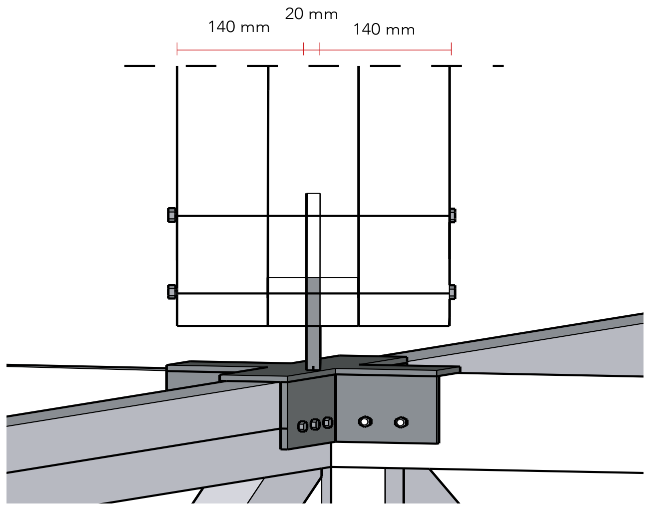


Figure 59 - Side view of the connection

Control of the bolts - foundation

The frame is not perpendicular to the frame of the truss, but at an angle of 19 degrees to the cross of the truss. As a result, the horizontal reaction force from the frame is disolved into an x and y component. (figure 60)

F_H is dissolved in to F_{HX} and F_{HY}.

$F_{Hx} = F_H \times \sin \varphi = 32{,}5 \times \sin(19) = 10{,}6$ kN
$F_{HY} = F_H \times \sin \varphi = 32{,}5 \times \cos(19) = 30{,}7$ kN

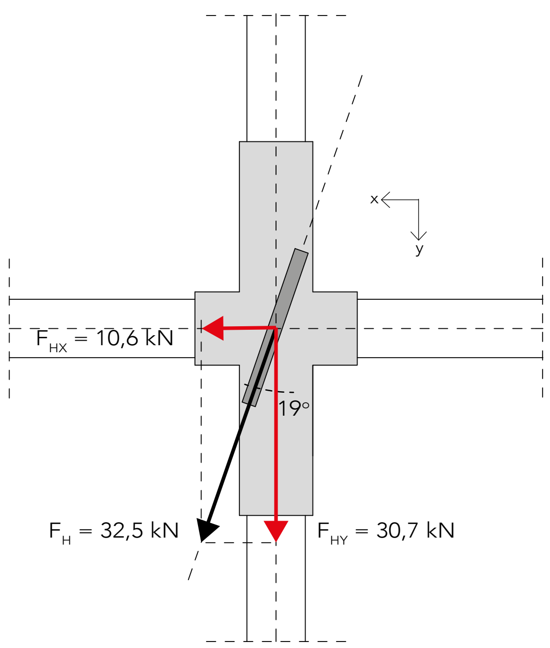


Figure 60 - Support reactions due to load combination 5

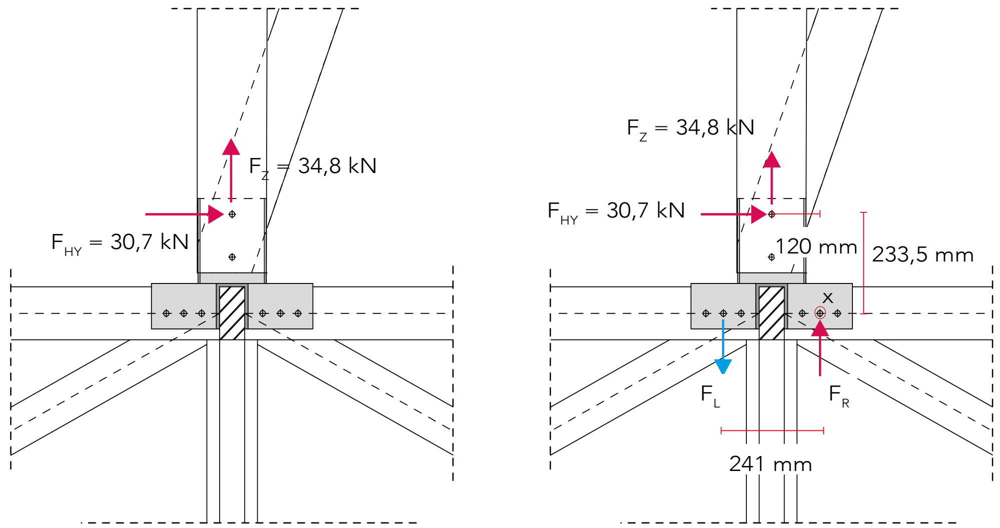


Figure 61 - Extra forces in the bolts due to F_{HY}

As a consequence of the force F_{HY} additional tension and compression forces will arise in the bolts that hold the connection to the trusses.

The force F_L can be found by taking the moments of equilibrium from point X.

$M_x = F_z \times l + F_{HY} \times l - F_L \times l = 0$
$M_x = 34{,}8 \times 0{,}12 + 30{,}7 \times 0{,}234 - F_L \times 0{,}241 = 0$
$0{,}241 F_L = 11{,}36$ kN
$F_L = 11{,}36 / 0{,}241 = 53$ kN

In total there are 3 forces acting on the bolts, F_z which is distributed to all 10 bolts, F_{HY} which is distributed to the 6 bolts in that direction and F_L die wordt verdeeld over de 3 which is distributed to the 3 bolts on the left.

The vertical force in a bolt is:
$F_v = F_L / 3 + F_z / 10 = 53 / 3 + 34{,}8 / 10 = 21{,}1$ kN

The horizontal force in a bolt is:
$F_H = F_{HY} / 6 = 30{,}7 / 6 = 5{,}1$ kN

The resulting shear force in a bolt is:

$$F_{v,Ed} = \sqrt{F_v^2 + F_h^2} = \sqrt{21{,}1^2 + 5{,}1^2} = 21{,}7 \text{ kN}$$

For the connection 10 bolts of M14 are used from the bolt class (4,6)

Control on shear resistance per shear plane (NEN-EN 1993-1-8)

$F_{v,Rd} = \frac{\alpha_v \cdot f_{ub} \cdot A_s}{\gamma_{M2}}$ (2.14)

In which:
$\alpha_v = 0{,}6$ for bolt class 4.6, 5.6 en 8.8
$f_{ub} = 400 \text{ N/mm}^2$
$A_s = 101 \text{ mm}^2$
$\gamma_{M2} = 1{,}25$

$F_{v,Rd} = \frac{0{,}6 \cdot 400 \text{ N/mm}^2 \cdot 101 \text{ mm}^2}{1{,}25} = 19{,}4 \text{ kN} = 2 \text{ shear planes} = 38{,}8 \text{ kN}$

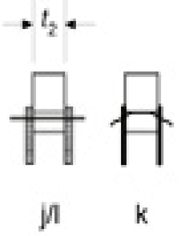
Total shear force:

$F_{v,Ed} = 21{,}7$ kN

$F_{v,Ed} \leq F_{v,Rd} = 21{,}7 \text{ kN} \leq 38{,}8 \text{ kN} = \text{OK}$

Control of the wooden profiles - foundation

The wooden profiles are tested for shear. For a steel plate as a middle element with a double-edged connection, there are 2 possible failure mechanisms.



$$F_{v,Rk} = \min \begin{cases} 0{,}5 f_{h,2,k} t_2 d \\ 2{,}3\sqrt{M_{y,Rk} f_{h,2,k} d} + \frac{F_{ax,Rk}}{4} \end{cases}$$

Figure 62 - Failure mechanisms (NEN-EN 1995-1-1)

$F_{v,Rk} = 0{,}5 \cdot f_{h,2,k} \cdot t_2 \cdot d = 0{,}5 \cdot 23{,}3 \cdot 75 \cdot 14 = 12{,}3$ kN
$F_{v,Rk} = 2{,}3\sqrt{M_{y,Rk} \cdot f_{h,2,k} \cdot d} + \frac{F_{ax,Rk}}{4}$
$= 2{,}3\sqrt{114581{,}4 \cdot 23{,}3 \cdot 14} + \frac{1{,}12}{4} = 14{,}3$ kN

$F_{v,Rk,min} = 12{,}3$ kN

1 bolt M14 with in total 2 shear planes comes to a
$F_{v,Rd,total} = 12{,}3 \text{ kN} \cdot 2 = 24{,}6$ kN
$F_{v,Ed} = 21{,}7 \text{ kN} \leq 24{,}6$ kN OK

Crushing strength wood $f_{h,k}$

$f_{h,k} = 0{,}082 \cdot (1 - 0{,}01 \cdot d) \cdot \rho_k =$
$0{,}082 \cdot (1 - 0{,}01 \cdot 14) \cdot 330 = 23{,}3 \text{ N/mm}^2$
$\rho_k \rightarrow$ wood class C20 $\rightarrow 330 \text{ kg/m}^3$
$d \rightarrow$ diameter bolt $\rightarrow 14$ mm

Flow moment bolt $M_{y,Rk}$ (8.5.1)

$M_{y,Rk} = 0{,}3 \cdot f_{u,k} \cdot d^{2,6} = 0{,}3 \cdot 400 \cdot 14^{2,6} = 114581{,}4$ Nmm
$f_{u,k}$ = bolt class 4,6 = 400 N/mm^2

Pull out strength of the bolt F_{ax}, Rk (8.5.2)

$F_{ax}, Rk = 3 \cdot f_{c,90,k} \cdot A_{ring} = 3 \cdot 2{,}3 \cdot 1{,}8 \cdot 10^2 = 1{,}12$ kN

8.6.2 Connection pressure ring

Due to the octagonal shape, all the frames of the classroom will come together at one point. As a result, a unique connection will have to be made to connect the frames together.

One type of building that has a similar construction is the yurt. In the yurt, all elements come together in a point and are mutually connected by means of a pressure ring. The weight and load of the roof are partially distributed over the ring, keeping the whole structure upright.

The pressure in the design of the classroom is made out of 8 wooden parts that are connected together using steel plates. The steel plates will connect both ends of the wooden parts and connected with a bolted connection (see figure 63)

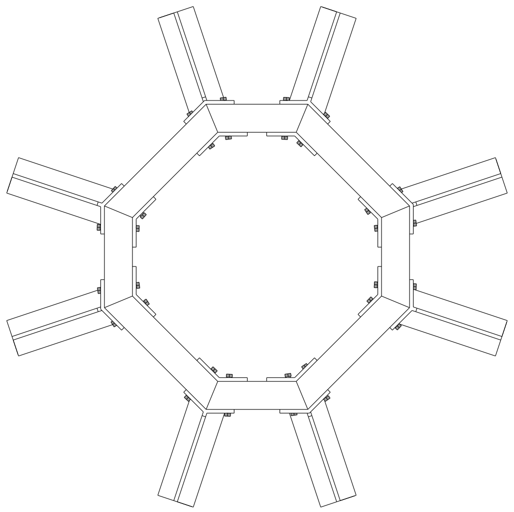


Figure 63 - Eight wooden parts connected by steel plates which forms the pressure ring

Two steel plates are welded to the outer steel plates. The horizontal plate serves as a support point for the trusses. And the vertical plate is used to connect to the end of the truss by a bolted connection. (figure 65)

The plates are attached to the corners of the wooden elements. In this way, the compressive forces coming from the frames will be dissolved in the pressure ring, and an equilibrium will arise because the contrary forces are equal to each other. (figure 66)

As a result of an asymmetrical wind load, small tensile forces can also occur in the ring. Looking at the profiles of the wooden parts and the steel connections used to connect them, the connection is considered to be able to absorb these tensile forces.

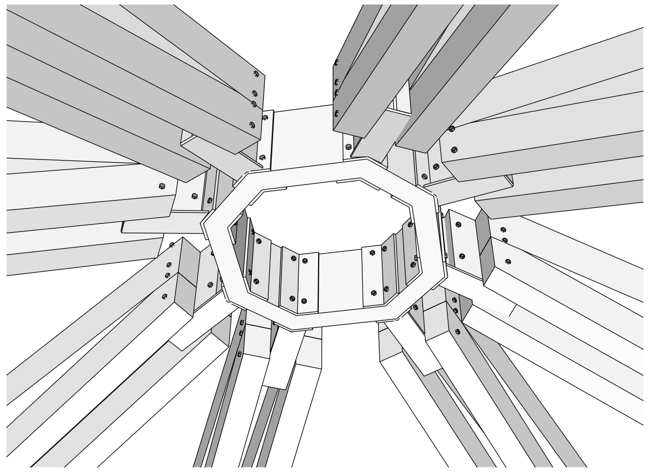


Figure 64 - View from underneath

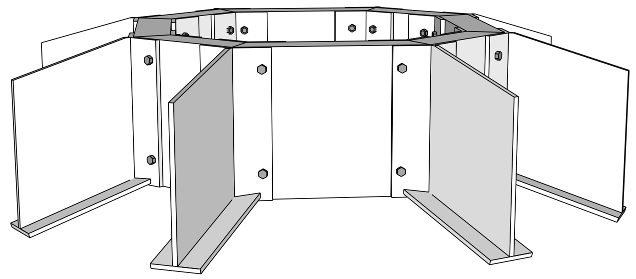


Figure 65 - Steel connection plates

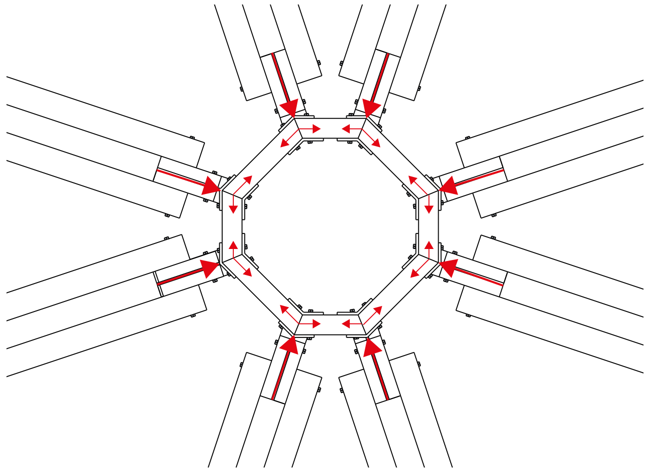


Figure 66 - Equilibrium of forces

Part D: Design

9. Climatic design

9.1 Introduction

In chapter 4, the different design strategies are drawn up to make an indoor building comfortable in a passive way. This chapter will briefly discuss the aspects and strategies used in the design.

Chapter 9.2 explains how the results of the questionnaires can be translated into design. hapter 9.3 describes the passive strategies implemented in the design and the materialization of some of the building elements. Chapter 9.4 shows which measures can be taken based on the clustering of the classrooms

Figure 1 - Schoolyard macabebe elementary school

9.2 Input questionnaires

The input from the questionnaires and interviews is divided into four topics: temperature, light, acoustics and space.

Temperature:

Majority of the students and teachers felt slightly cold in the classrooms with air conditioning, and they preferred the passive methods for thermal comfort: Large openings can be provided for ventilation, overhangs and sloped roof to protect from the sun, stack effect for hot air to escape, the building shaped is expected to benefit in terms of reducing solar heat gain.

Light:

Most of the students and teachers prefer natural light: large windows and openings to provide natural light inside the classroom.

Acoustic:

Teachers and students had concerns regarding noises from other classrooms and outdoor activities.

Space:

The students were satisfied with the space they had in the classrooms that are based on the requirement of the DepEd. The DepEd states that a classroom must be able to offer at least 1.4 m^2 of space per student. So with the floating classroom which is built for 40 students, at least 56 m^2 is required, and 63 m^2 is provided.

9.3 Passive strategies

This chapter will describe which design strategies have been applied in the classroom design based on the literature review and the preferences of the students and teachers based on the questionnaires and interviews.

Light

To ensure there is enough natural light in the classroom, the design must provide enough openings to let daylight enter the classroom. Windows with louvres have been installed on four sides of the building. This allows the students to regulate how much light enters by opening or closing the louvres. In addition to the windows, openings have also been made at the top of the wall to provide extra natural light. These openings can be controlled from the inside so the light can be regulated or the openings can be closed in the event of rain.

Ventilation

To ensure that the classroom is provided with fresh air, we looked at how cross and stack ventilation can be used in the design.

By creating large openings on each side of the classroom, there is cross ventilation throughout the whole space. Moreover, by creating an opening in the roof, this helps to let the hot air dissipate by means of stack effect.

For the flooring of the classroom, there is chosen to use a bamboo flooring the idea behind this is that air can also rise through the floor, which provides more fresh air.

Prevent overheating and direct sunlight

To ensure that the classroom does not overheat, it is essential to protect the elements from direct sunlight and to provide the parts that are exposed to direct sunlight with insulation and/or reflective colours.

The roof exists out plywood plates and is finished with a layer of insulation and reflective steel roof plates.

The removable overhang protects the walls from solar radiation and can be closed during strong wind. The material of the overhang has to be further researched.

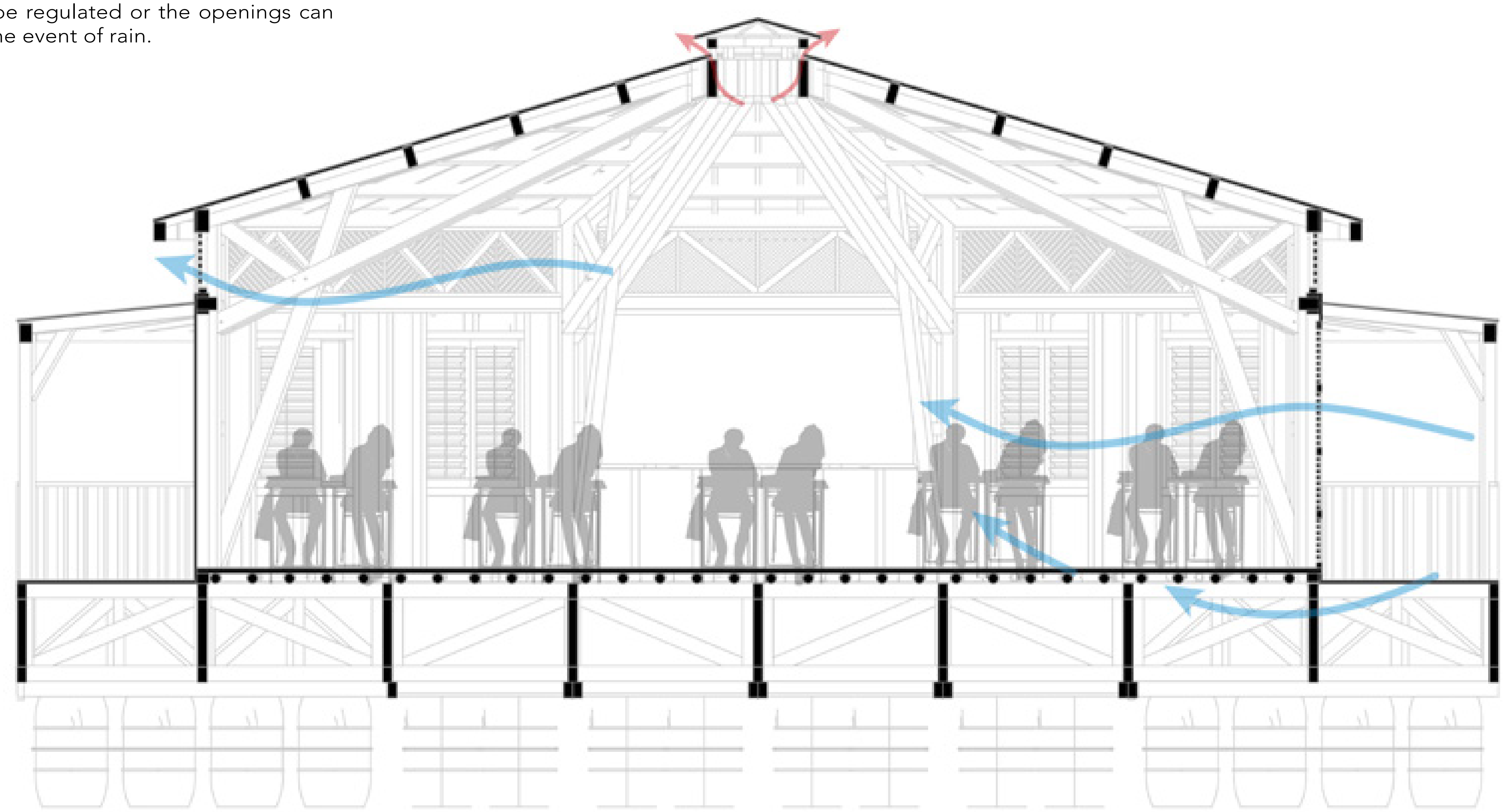


Figure 2 - Passive design strategies implented in the classroom

9.4 Clustering strategies

In the case of clustering of the classrooms, the arrangement can also have an effect on the indoor comfort of the classroom. The most important aspects to take into account are noise nuisance and the disruption in the supply of fresh air due to another classroom.

During the interviews, the teachers indicated that the hallways are often located on the side with windows, which lead to noise disturbance and distraction by the students.

Figure 3 shows a clustering of 4 classrooms. All four rooms have several sides in which the supply of fresh air is not blocked by other obstacles.

On the sides where the walls of the classrooms are directly adjacent to each other, it may be necessary to separate them visually.

A solution could be by installing coconut husk walls, which also has sound-absorbing properties. It is also possible to look at the use of plants to block or reduce the sightlines between both classrooms. Further research is required.

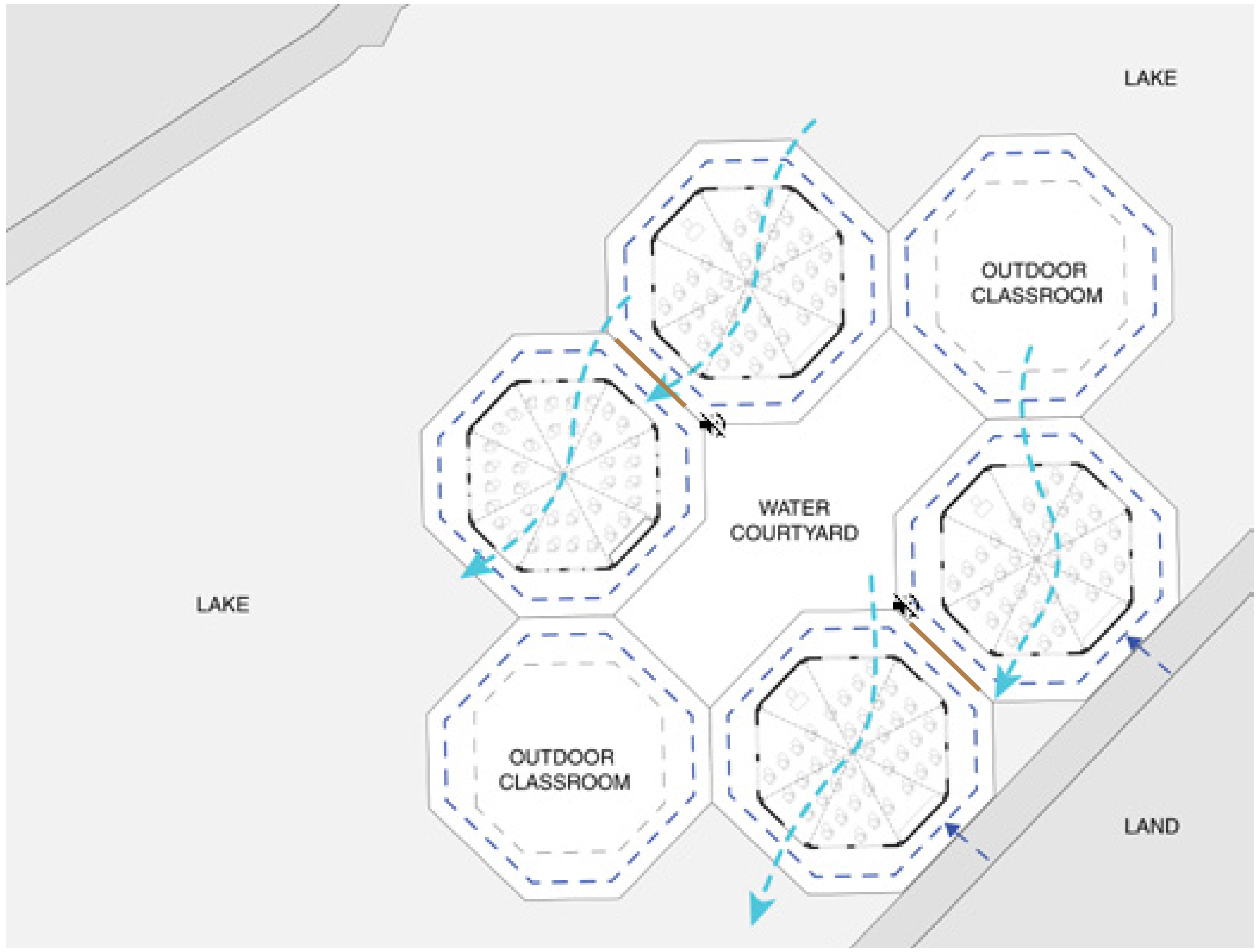


Figure 3 - Classroom clustering with wind flow and acoustical walls

Part D: Design

10. Architectural design

10.1 Introduction

In this chapter, a brief introduction will be given to a number of architectural concepts that can be used to determine the layout of the facades, cluster classrooms and accessibility at the Collegio de San Lorenzo.

Chapter 10.2 describes the choices on how the floorplan can be arranged, especially in terms of deciding the different functions of the facade. Chapter 10.3 describes how the floating classrooms can be made accessible at the Colegio de San Lorenzo. In chapter 10.3, options are given on how classrooms can be clustered. And finally, in chapter 10.4 and 10.5 drawings and impressions of the floating classroom are given.

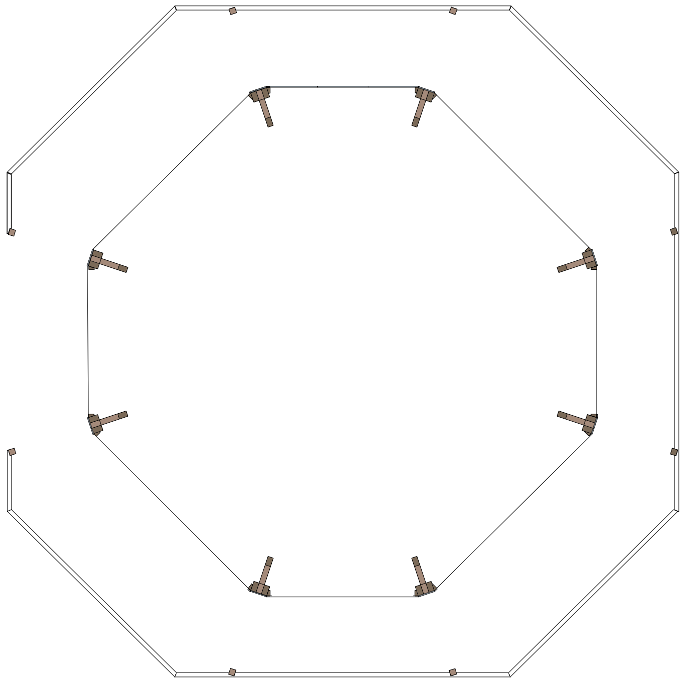
Figure 1: Students waiting outside the classroom

10.2 Floorplan

Now that the shape of the building and the main supporting structure has been established, the various functions of the facades can be fulfilled. The functions of the facades are based on 3 different aspects, namely construction, classroom layout and indoor comfort. The functions of the facades are shown per aspect in the steps below.

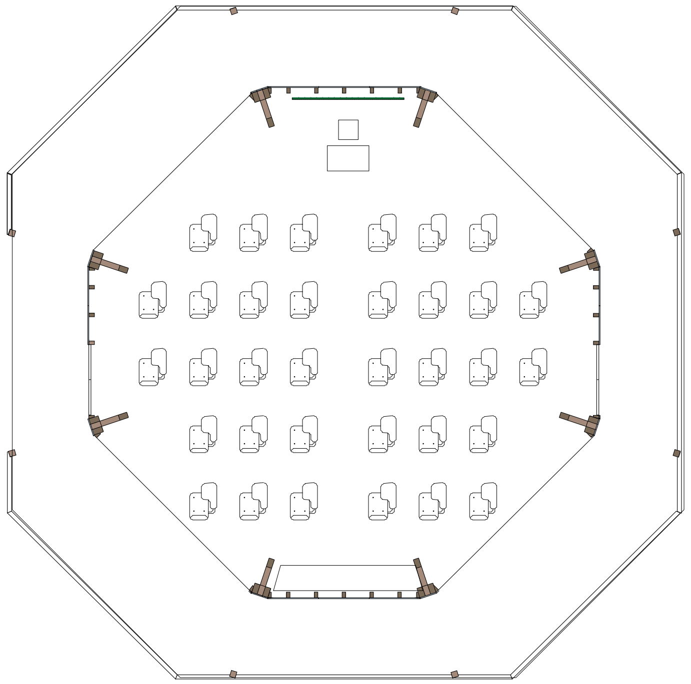
Main supporting structure

Outline of the classroom shape showing the main supporting structure.



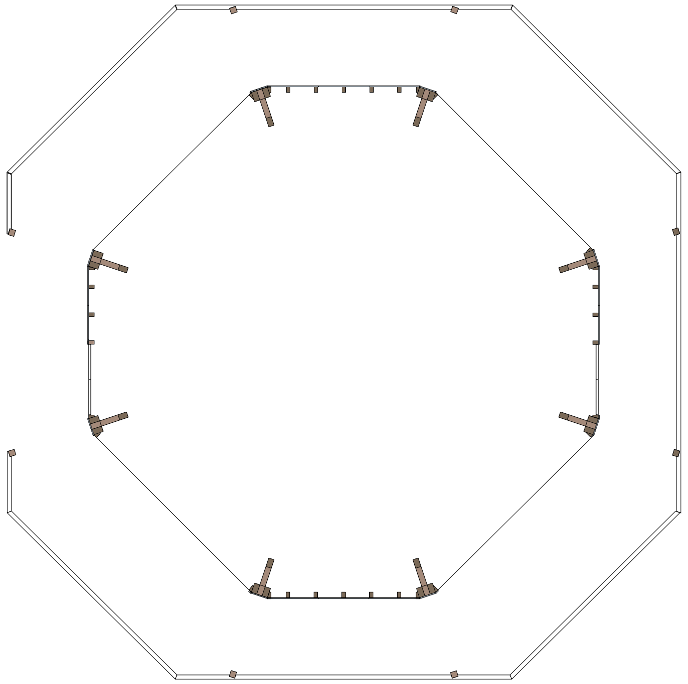
Function 2: Classroom layout

The two closed walls are used as a place for the blackboard and storage . Also, an option is showed on how the seats can be placed.



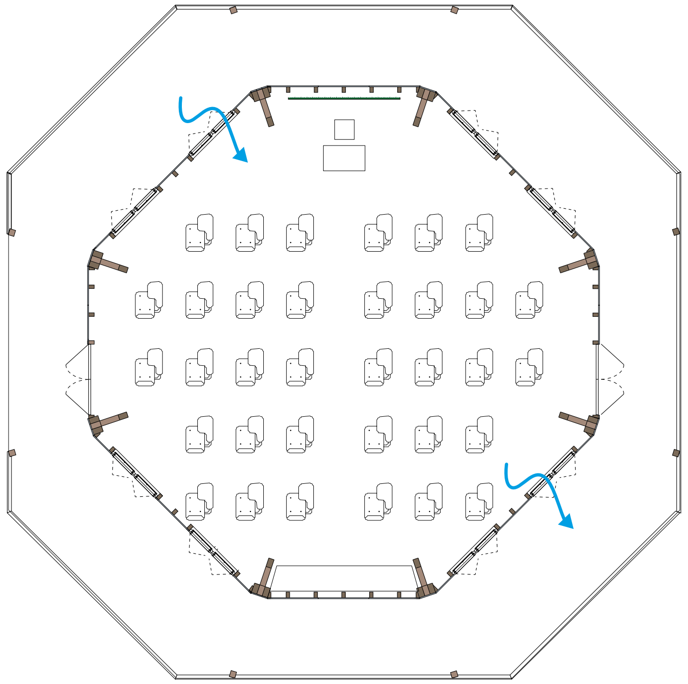
Function 1: Stability walls

Placement of the stability walls.



Function 3: Indoor comfort

Placing the doors and windows that provide light in the room and supply fresh air.



10.3 Accessibility

The pond is surrounded by a dike which makes it not easily accessible from the school building. A path will have to be made to make the floating classrooms accessible from the school building. The path towards the floating classrooms will start at the extension of the main entrance, from the canteen and an exit halfway at the end of the pathway.

Connecting the main entrance to the central path of the floating classrooms will make the floating classrooms more a part of the school as they are visible from the most prominent point. By making a staircase or a slight ramp, the dike becomes accessible. The staircase or ramp takes you to the central path on top of the dike from which the classrooms will be accessible.

Figure 2 - Main entrance

Figure 3 - Hallway behind the school

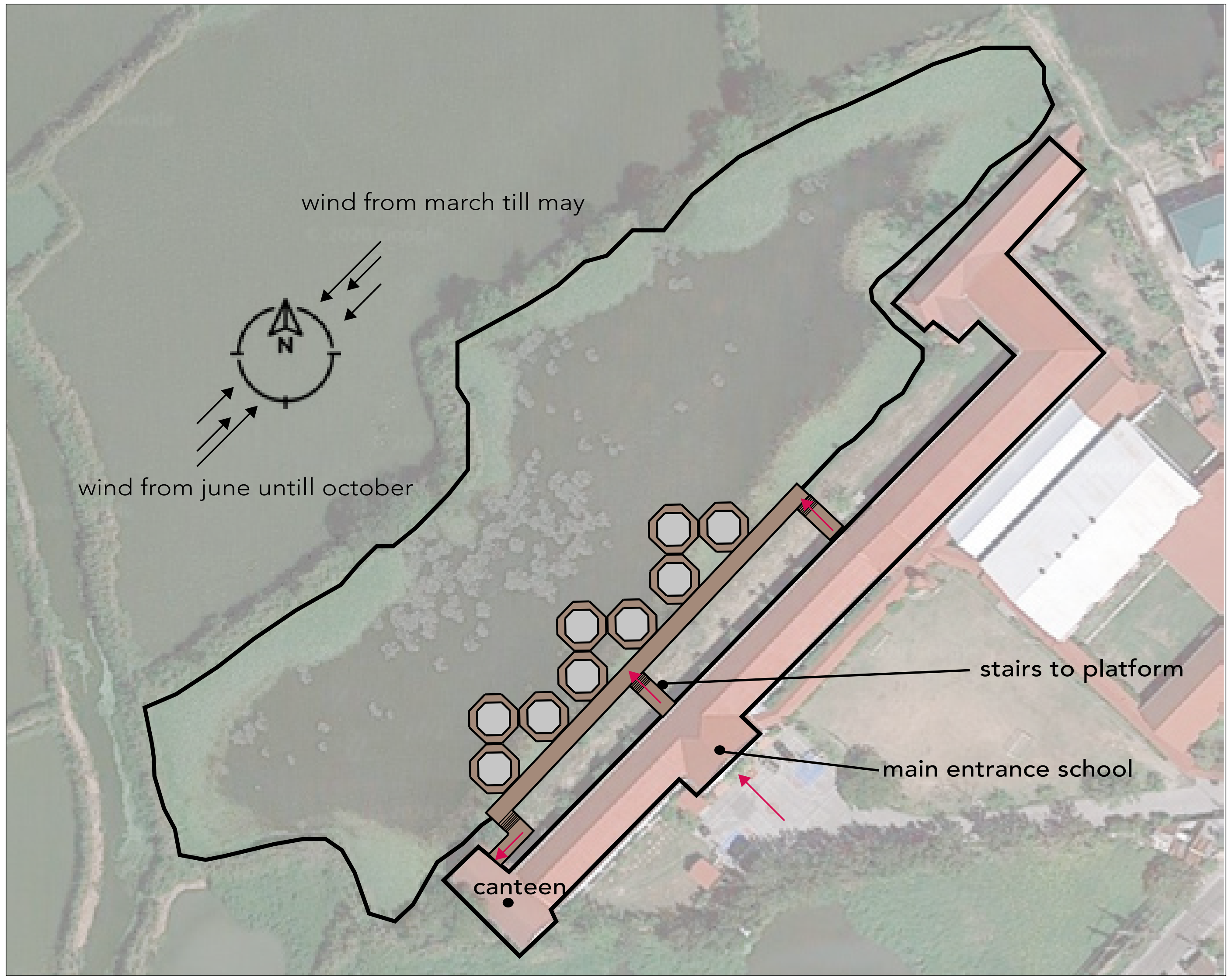


Figure 4 - Location with the organization of the floating classrooms

Figure 5 - View from the pond

10.4 Clustering

When a school desires more than one classroom, the octagonal shape offers eight sides to which the next classroom can be connected. This ensures that there are many possibilities when it comes to expanding the classrooms and the desired paths that can be formed with them.

Figures 6 and 7 show different types of clustering that can be created by connecting the classrooms. In addition to classrooms, other places can be created, such as an outdoor classroom, in which classes can be given outside or as a space fir other outdoor activities.

Schoolyards can be created by filling the space between classrooms, that provides a space for students to rest, play and social activities.

Water yards that for example can be used by the school to breed its own fish.

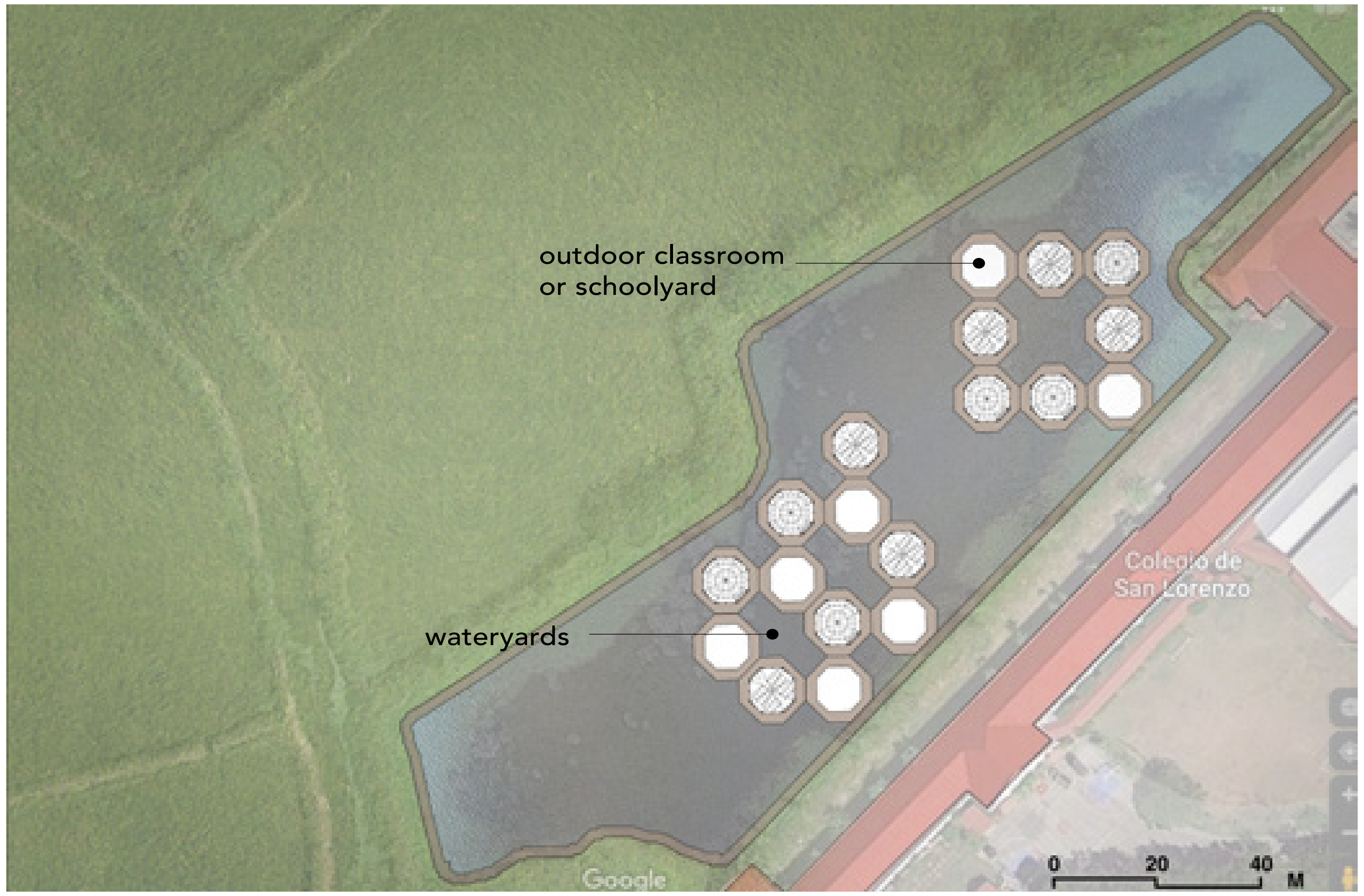


Figure 6 - Options of clustering

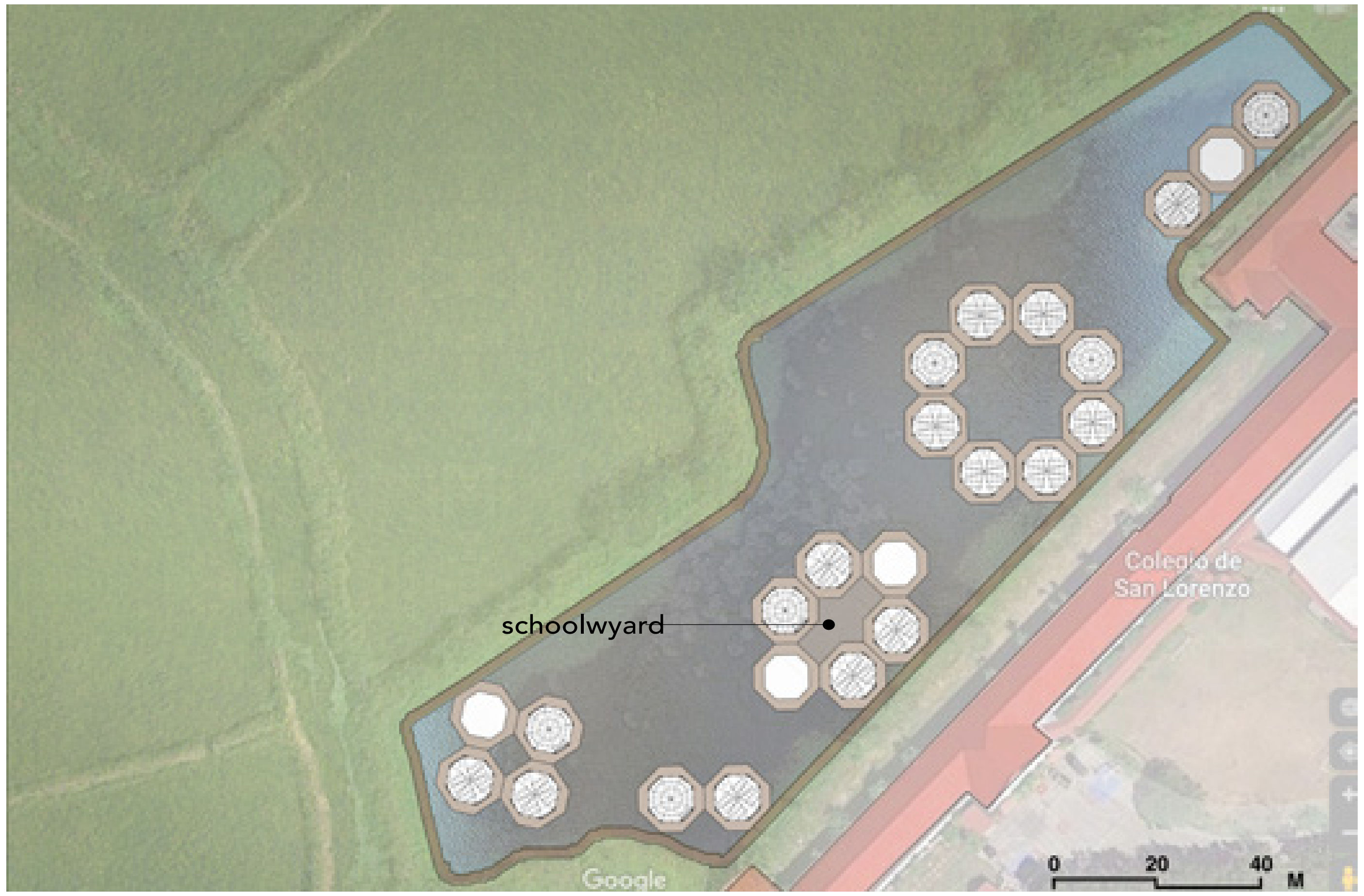
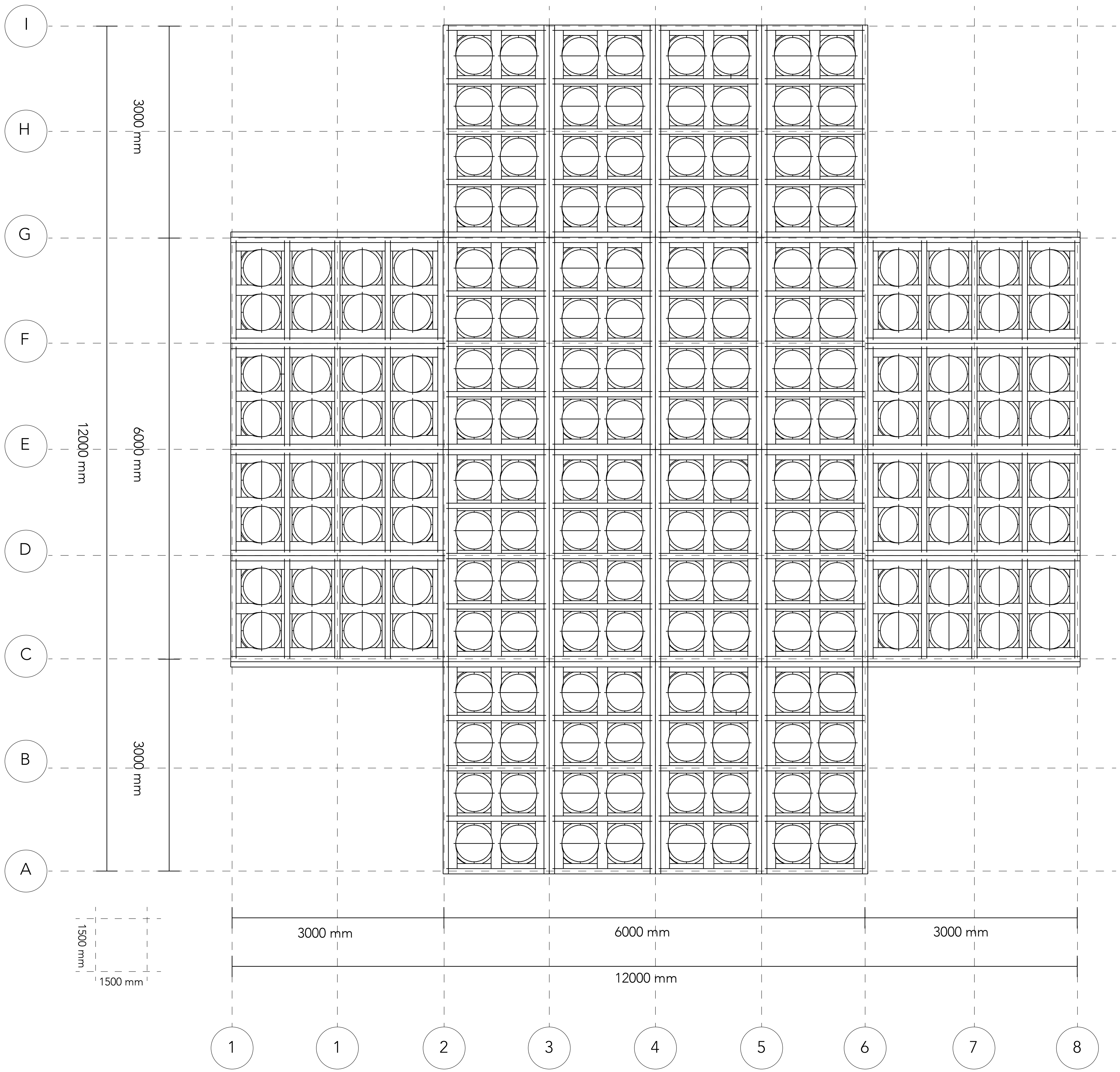


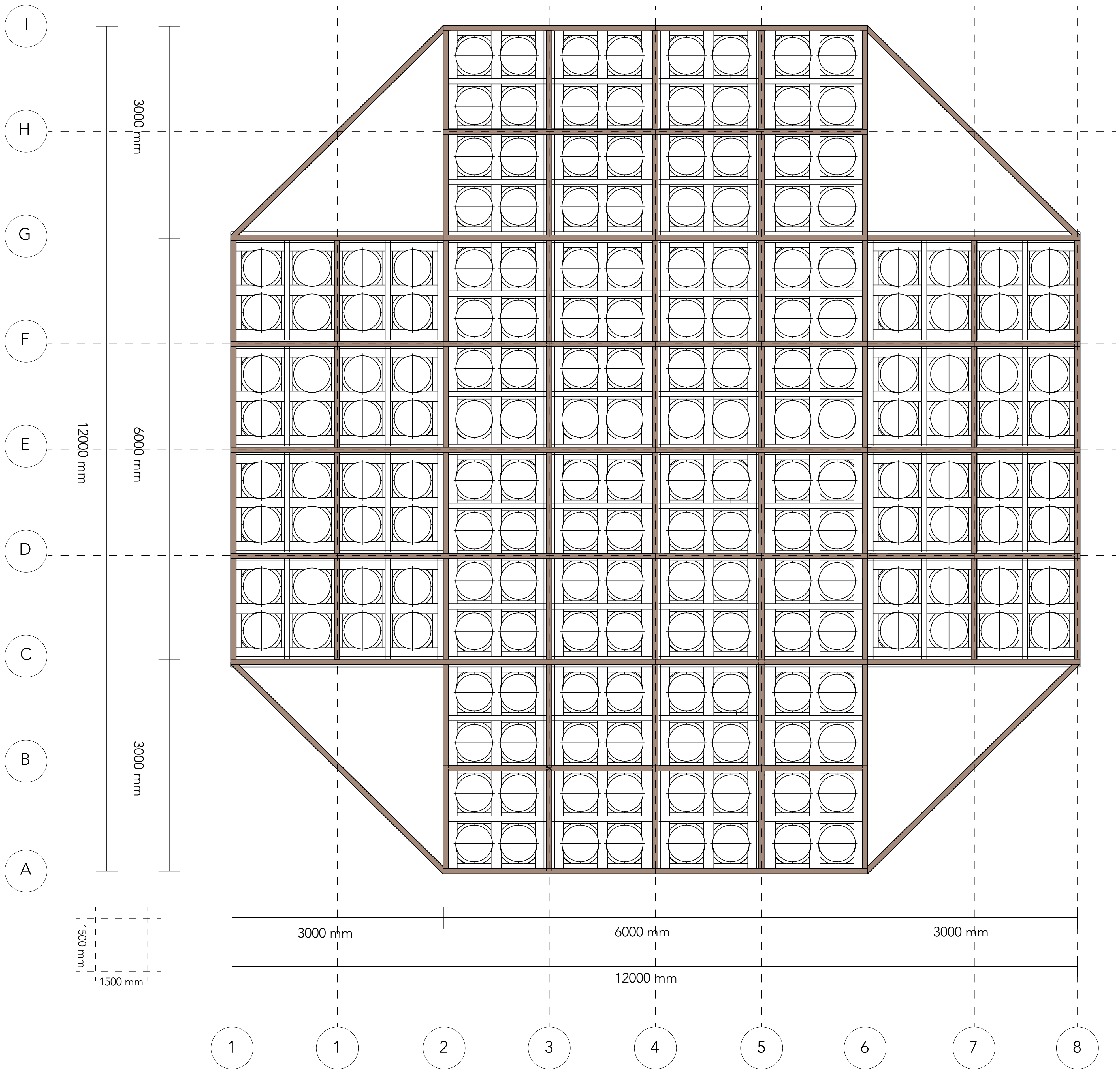
Figure 7 - Options of clustering

10.5 Drawings

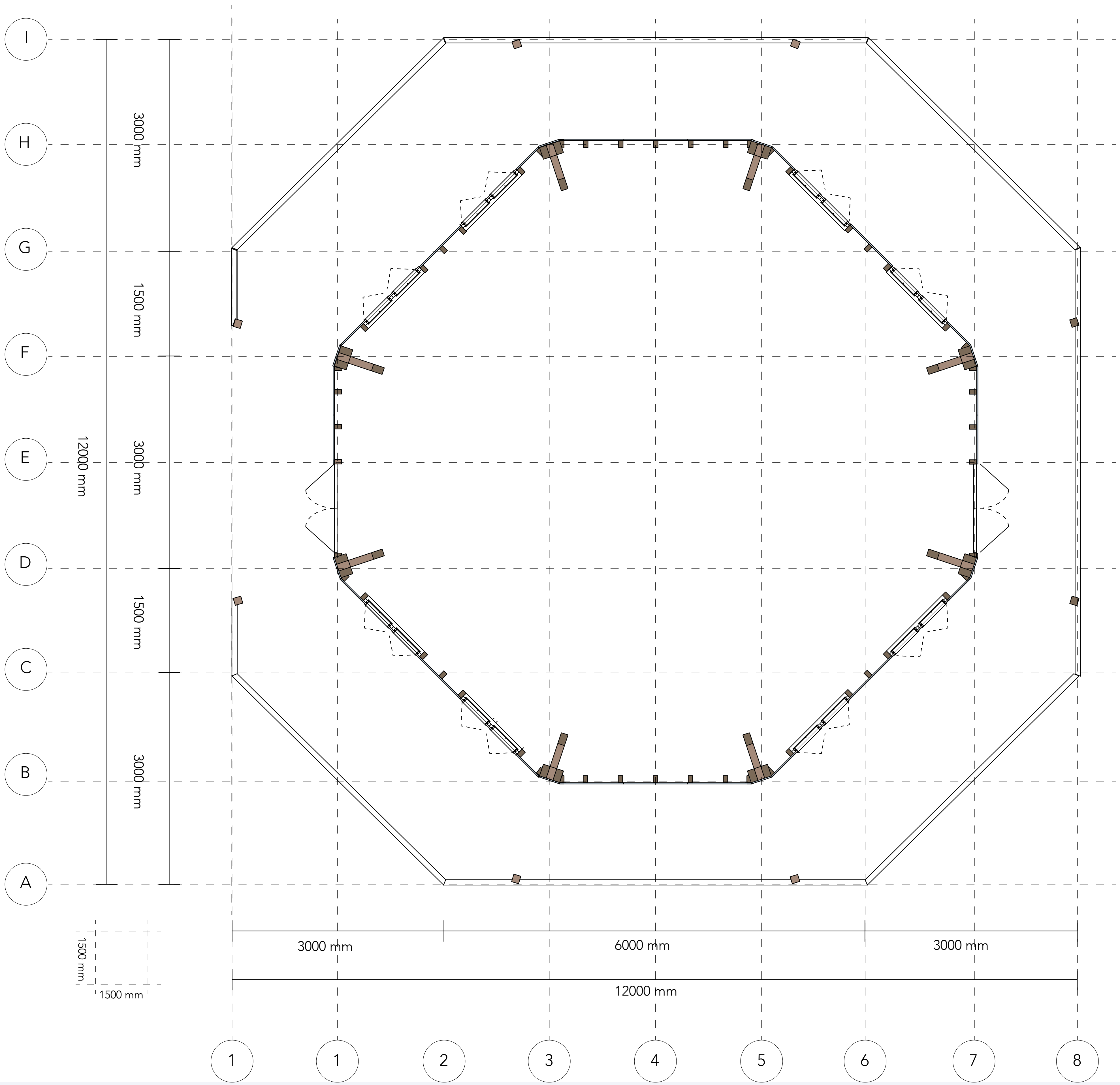
10.5.1 Floating modules



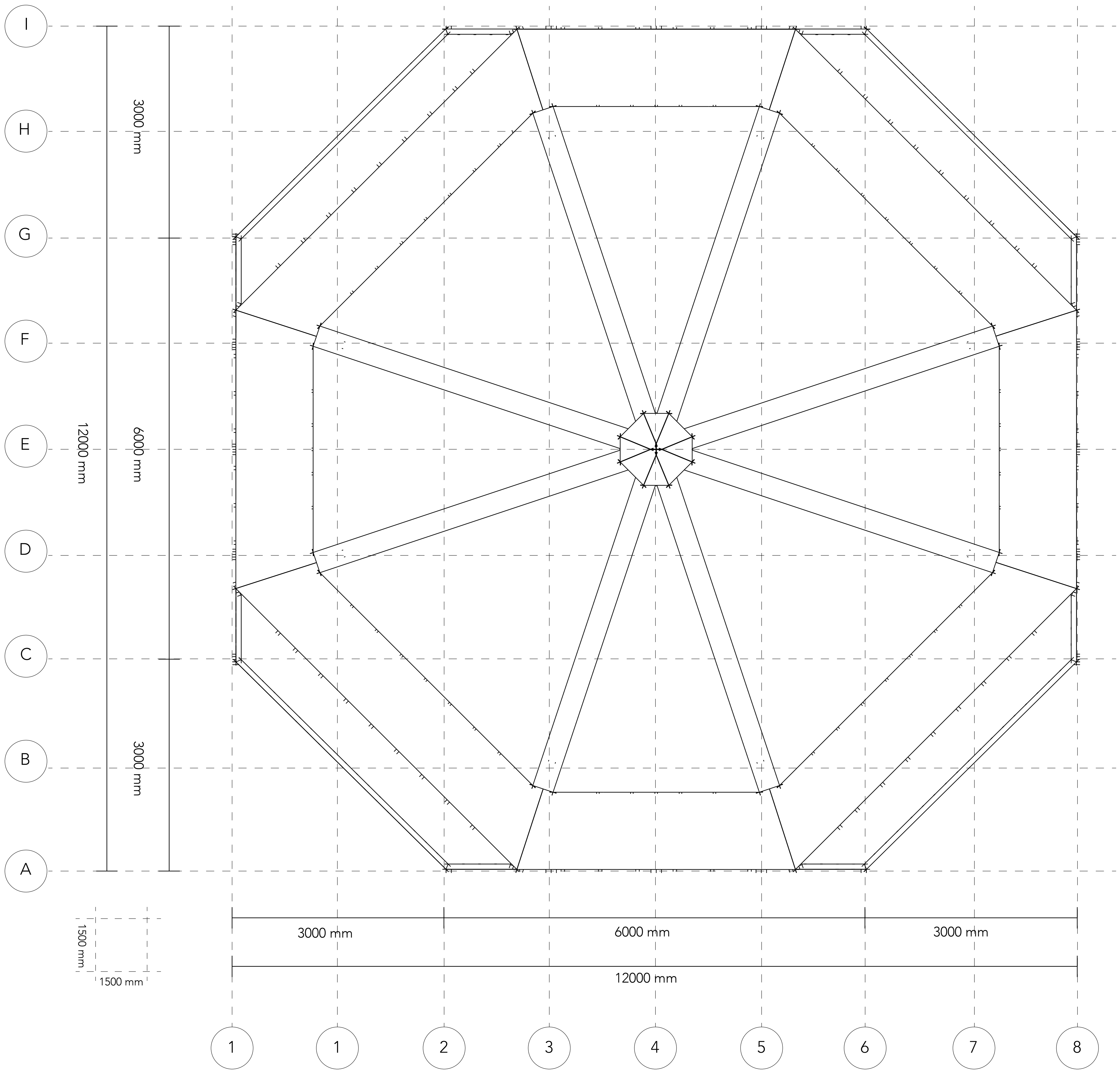
10.5.2 Foundation Trusses



10.5.3 Classroom floor



10.5.4 Roof


I
H
G
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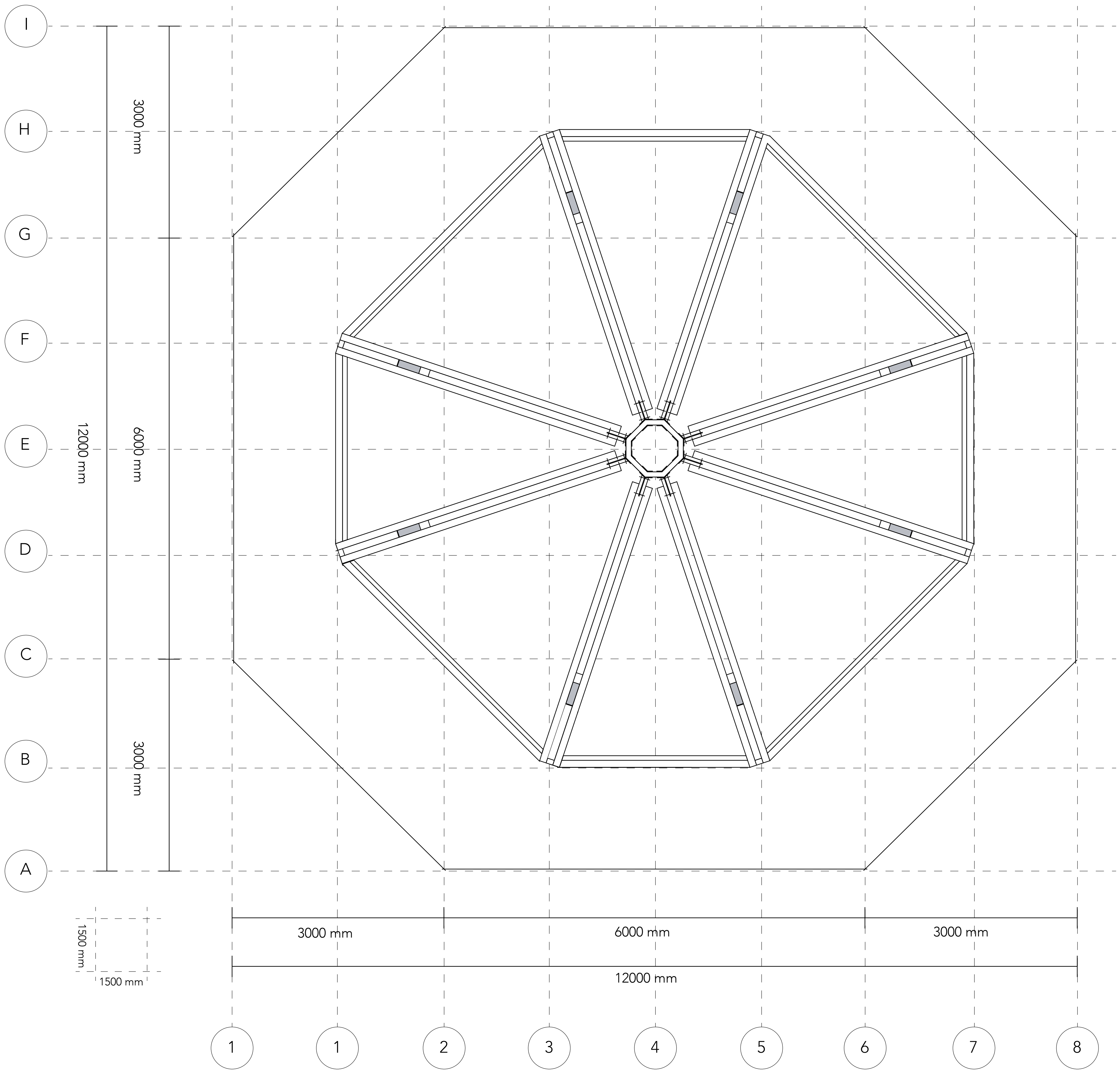
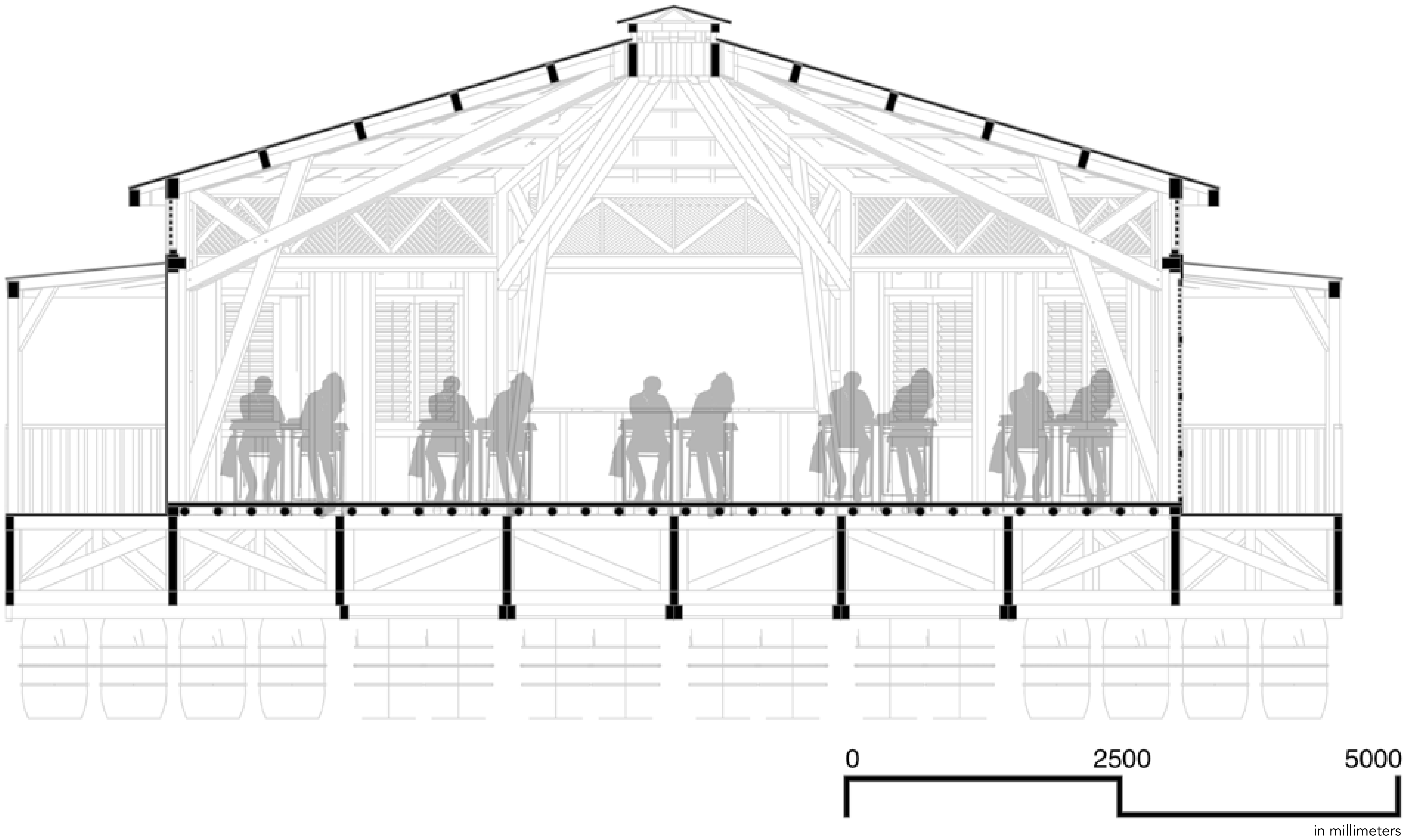
8

10.5.5 Structural framing



10.5.6 Section of the classroom



10.6 Impressions

10.6.1 Single classroom

10.6.2 Clustering of classrooms

10.6.3 View from on of the walkways

10.6.4 Interior view

11. Conclusion

11.1 Introduction

In this chapter, the conclusions and recommendations are discussed. Chapter 11.2 answers the research questions for each of the different topics and verifies if the objective is reached. Chapter 11.3 provides recommendations for further research.

11.2 Conclusion

11.2.1 Schools

What is the impact of natural hazards on an education level?

The impacts of floodings on an educational level in the schools of Macabebe can be mainly categorized in the suspension and disruption of classes, absence of students due to inaccessibility of the school.
Frequent interruption, by natural hazards, of education affects the students in being unable to concentrate and to maintain study habits, which leads to poor performance at school. Children who attend the affected schools also report that they have less time to play outside and to meet their friends because they spend more time on schoolwork at home.

How are they currently designing schools?

The current school modules are designed according to the national building code and the national structural code of the Philippines and designed to withstand 250 kph wind velocity and major earthquakes. The floor plan of school buildings is mostly rectangular. Looking at materialization, the school buildings are constructed out of a basic concrete structure of columns and beams. The walls are built with hollow concrete blocks finished off with a stucco layer. The cable roof is built out of a streel truss connected to the concrete columns.

In order to make the school flood-proof, the ground floor is raised with one meter above the ground. However, due to the ground subsidence, this solution will no longer be sufficient in the decades come.

How can we make a school more child friendly?

Child-friendly schools focus on the student, the participants of the community and the families. An understanding of the cultural and environmental background of the children should have prominence in design considerations for a child-friendly school.

When the architecture of the school design is a reflection of the culture and community, the school becomes an interactive place at which students can learn and explore new opportunities that match their abilities and potential.

In the new design of the school, transparency is considered by designing the facade with enough "open" windows, so activities inside the school are visible from the outside, which makes it a more controlled environment and acts as an open space which enables children to be in close contact with the outdoor. The shape of the new design offers much flexibility, fit for various learning activities and integrated with outdoor spaces and surrounding.

How do schools now deal with typhoons and floods?

Due to floods, schools are forced to raise the floors of the classroom and walkways. Raising the floor of the classroom makes the height of the classroom lower each time, resulting in an unpleasant situation regarding classroom environment (daylight and temperature). Toilets have to be raised due to broken drains to the septic tanks. Unavailability of classrooms leads to overcrowded situations.

Another response of the school is planting vegetation and gardens to absorb water of the flood faster. Schools are also creating awareness due to wall art and signs, which explains to students how to react during a natural disaster.

What are the local needs regarding a classroom?

The results of the questionnaires and interviews of the teachers gave more insight into what students and teachers need in a classroom or what they prefer in terms of indoor comfort.
Teachers mention they would like to see more classrooms designed based on the cultural identity of the region made of local materials, to make the students aware of their cultural background. The teachers prefer spacious classrooms which provide flexibility for indoor activities and presentations.. The teachers and students prefer natural lighting and natural ventilation.
Teachers mention they would like to have a proper drainage system so the floodwater does not remain in and around the classrooms and classes can continue.

11.2.2 Location

What are the local climate characteristics ?

The climate in the Philippines is tropical and maritime and can be divided into two major seasons, the rainy season, from June to November and the dry season, from December to May.

The major climate processes that impact the weather conditions in the Philippines are the Southwest and Northeast monsoon with rainfall and heavy winds, El Nino that is associated with droughts and the low pressure over the Pacific or south china sea which can lead to tropical cyclones.

The average yearly temperature of the Philippines is 26.2°C with a range between the 21 and 32 degrees. The northeast monsoon brings northeast winds from November to February. From March till May there are mostly warm dry winds from the south-east direction. The south-west monsoon from June until October brings south-west winds.

The humidity in the Philippines is high during all seasons; the relative humidity ranges from 68% in April to 86% in September.

What extreme circumstances can occur?

The extreme circumstances that can occur in the Pampanga delta where Macabebe is situated are mainly floods, ground subsidence and high wind speeds. The delta has one of the most important river basins in the Philippines, the Pampanga river basin, and it experiences at least one flood event a year. The excessive groundwater extraction causes the land to sink by an average of 5 cm/year. The land subsidence combined with tidal and fluvial flood causes flood in low lying areas of the Pampanga delta.

Macabebe is located in the region where a 3-second gust wind speed of 260 km/h is maintained. Therefore the classroom must withstand wind speeds of 174.2 km/h or 48.4 m/.

11.2.3 Materials

Which materials are locally available?

During the field research, multiple local suppliers of building materials were visited. Various wood species are offered from elsewhere in the world, this is due to the log ban policy. This makes it hard to predict what kind of wood can be used for the design, because it highly depends on the type of wood that is in stock or which wood just has been imported. For the design of the floating classroom, Yellow Meranti was chosen partly because it was the most locally available wood and also because it is easy to work with and the local carpenters are familiar with the material.

11.2.4 Typhoon resilient

How can a classroom be typhoon resilient and what parameters need to be taken into account?

The classroom should provide a safe learning environment in the event of high wind speeds and flooding during an event of a typhoon.

In the design of the classroom, a floating foundation has been designed that gets its buoyancy from using recycled barrels that are locally available. The design of the foundation was modelled and checked for buoyancy and stability using AxisVM. The requirements set to validate if the floating offers a save environment is that it may not sink more than 0.8 meters and cannot exceed a maximum tilt of 4 degrees. The design has been tested on dead loads and live load of the occupants and wind. According to the results described in chapter 8, the platform meets all set requirements.

The structural framing of the classroom should be resistant to the high wind speeds that occur with typhoons. The wind speed used in the design of the structure is a wind speed of 174.2 km / h.

To check whether the structural framing of the classroom can withstand the wind speeds, it was tested on strength and stability. To test the design on strength, Technosoft Frameworks was used. The design was modelled with the indicative wind loads based on the Eurocode. From the results, the cross-sections of the structural frame have been determined.

The stability was assessed using AxisVM. The structural frame together with the stability elements has been tested for horizontal and vertical displacements. Based on the results described in chapter 8, it can be concluded that the design of the structural framing can offer a safe learning environment.

11.2.5 Indoor comfort

How can a classroom be indoor comfortable and which parameters need to be taken into account?

As descirberd in paragraph 4.3 movement of air is the only available way to relief from heat stress and therefore vital for to indoor comfort.

To ensure the movement of air in the classroom multiple measure are taken into the design. The passive design strategies incorporated are large openings on the sides of the classroom that makes sure there is cross ventilation throughout the whole space. The roof opening helps the hot air to dissipate by means of stack effect. Also for the flooring of the classroom there is chosen to use a bamboo flooring in which air can rise through the floor. The removable overhang protects the wall from solar radiation and can be closed while strong wind. The openings above the window provides natural light and ventilation even when the windows are closed. All these design strategies must ensure a good indoor comfort for the occupants

What measures do they apply locally in classrooms to ensure a good indoor comfort?

Currently, in most classrooms the indoor comfort is controlled by the use of air conditioners or fans. Also, most schools did not have external blinds, so the teachers put up sun protection curtains and often keep them closed during lessons. This often makes the classrooms dark during class, which is at the expense of comfort in terms of light.

11.3 Recommendations

In this chapter, recommendations are given for further research. The recommendations for research are given to the different elements of the building, the structural analysis and the climatic design.

11.3.1 Building elements

Shape

The choice for an octagonal shape of the classroom is mainly based on the aerodynamic properties, flexibility in clustering of the classrooms and orientation due to not having a dominant facade side. In terms of a classroom, an octagonal shape is not standard, to test whether this form is cost effective, environment resistant and user-friendly, a pilot project of one classroom could be considered.

Foundation module

The design of the floating modules is based on lifting the wooden frame that fixes the barrels in position on the top of the barrels, so the wood remains dry under loaded circumstances of the platform. Besides clamping the barrels at the wooden frame, the barrels are also kept together in the middle by tensioning a steel cable. Further research might be needed to test to what extent the barrels stay together, deformation of the barrels in relation to the position and tension strength of the steel cable and where possible improvements can be made in the design. This can be done by building a pilot foundation module to research how the foundation module behaves under loaded circumstances on the water. In this way, it can be checked whether the barrels are not pushed out of position and work as expected.

Eaves

The eaves on the outside of the classroom serve to prevent direct sunlight into the classrooms. However, these are vulnerable elements of the building during the occurrence of a typhoon. In this study, no attention was paid on how the eaves can be made typhoon resilient. Possible solutions that can be further studied to protect the eaves from high winds is by folding in the eaves (as in the finch floating home) so that the eaves protect the building. Making the roof of the eaves with air gaps (like louvres) so pressure cannot be built up underneath the eave or to build the eave separately from the building so that in the event of a typhoon only the eave collapses and this has no effect on the building itself.

Top wall openings

In the design, openings have been made in the top part of the wall to get enough daylight into the building and to provide natural ventilation.
In the occurrence of a typhoon, it is preferable to close off these openings to prevent wind can come inside the building. Further research can be done in how to close off the opening in a simple way, the material they are made of and high wind speed resilience. Solutions can be by folding the eaves upwards or by closing them off from the inside.

Connections

The connections are designed with simplicity and affordability in mind. Therefore, the detailing of the connections may need further research for further optimization.

11.3.2 Strucural analysis

Combined 3D model

In this research, the foundation and the upper structure of the classroom are calculated individually. For further research, it would be relevant to research what the effect is of modelling the foundation and the upper structure in one model in terms of stiffness and strength of the whole design. Which can have a positive effect on the dimensions of the structural parts and thus less material is needed

Waves

The floating behaviour in this research is based on wind, and eccentric load by the occupant's further research must be made to see how the design performs under influences of waves.
It is recommended to include wave characteristics in the modelling on top of the current studied influences; wind and eccentric load.

11.3.2 Climatical design

Optimazation of openings

In this research, several passive strategies have been applied to improve the natural ventilation of the building in a passive way. Openings in the design are created to create cross ventilation and a stack effect in the building. The openings in this design could be further researched to see to what extent they contribute to the indoor comfort of the building and how the design can be optimized in terms of natural ventilation.

Materialization

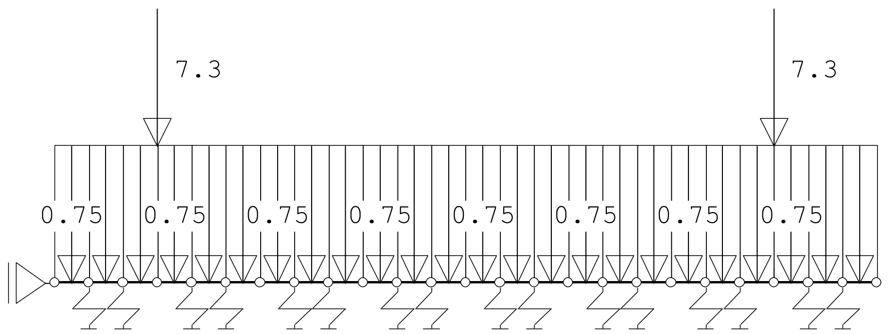
The design of the building indicates that certain material choices can contribute to improving the thermal and acoustical comfort of the building. More research can be done into, for example, reflective or air-permeable materials of the roof to prevent overheating and materials with sound-damping properties to improve acoustic comfort.

Appendix

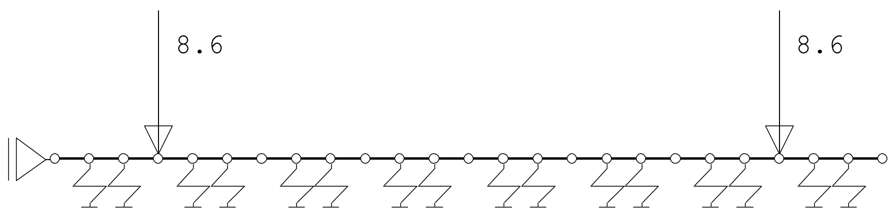
Load cases and combinations flooating foundation 2D model

Load combination	LC1 - Dead load	LC2 - Live load roof	LC3 - Live load classroom	LC4 - Wind 1	LC5 - Wind 2	LC6 - Wind 3	LC7 - Wind 4
C1 - ULS 1:	1,35	-	-	-	-	-	-
C2 - ULS 2:	1,2	1,5	-	-	-	-	-
C3 - ULS 3:	1,2	-	1,5	-	-	-	-
C4 - ULS 4:	1,2	-	-	1,5	-	-	-
C5 - ULS 5:	1,2	-	-	-	1,5	-	-
C6 - ULS 6:	1,2	-	-	-	-	1,5	-
C7 - ULS 7:	1,2	-	-	-	-	-	1,5

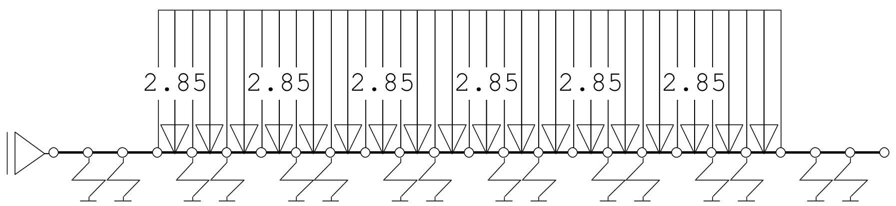
Load case 1 - dead load



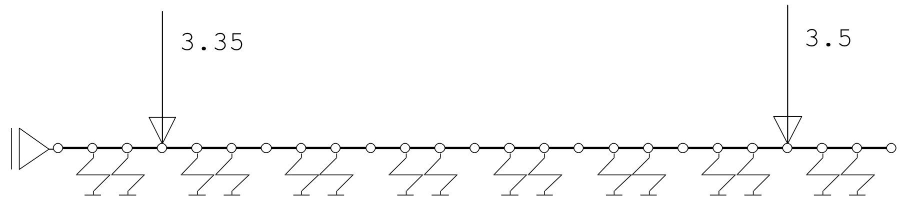
Load case 2 - live load roof



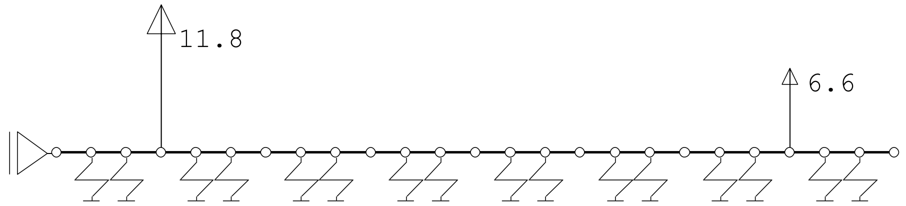
Load case 3 - live load classroom



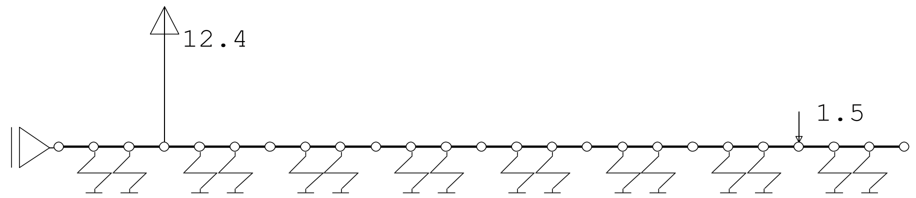
Load case 4 - wind 1



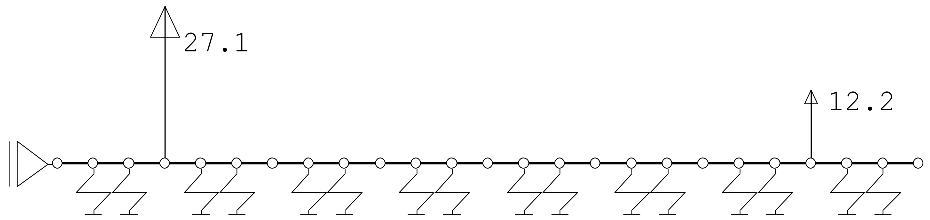
Load case 5 - wind 2



Load case 6 - wind 3



Load case 7 - wind 4

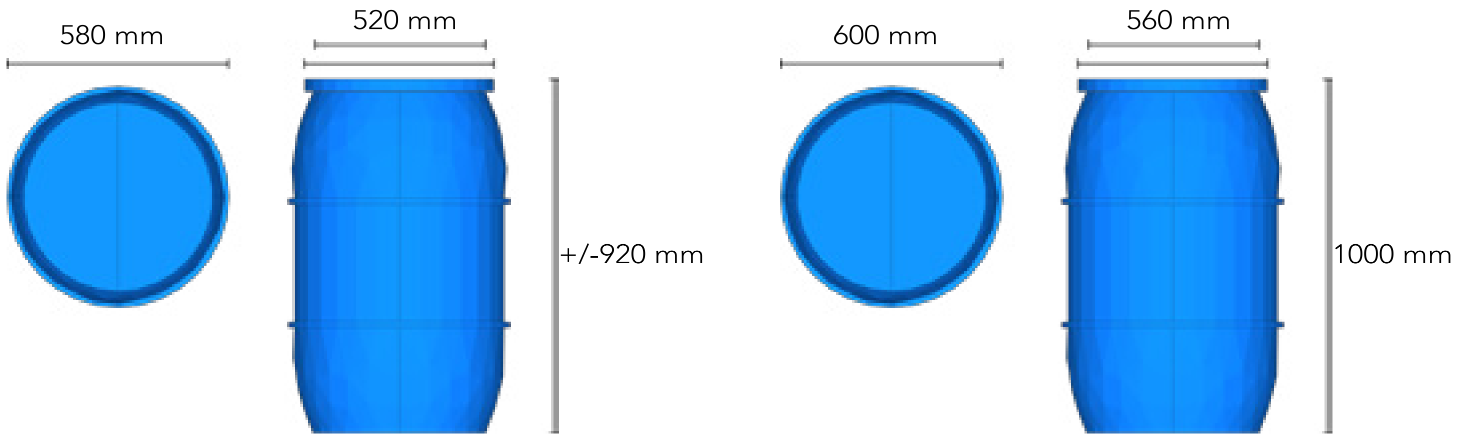


Spring support barrel

Spring support barrels

To push one barrel of a meter high one meter down, 200 litres must be moved.

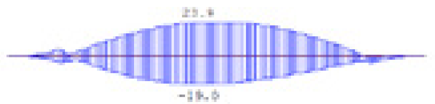
1 barrel	200 L	=	0,2 m3
density of water	997 kg/m3		
spring rate	199 kg/m	=	2 kN/m



Actual size of the barrels

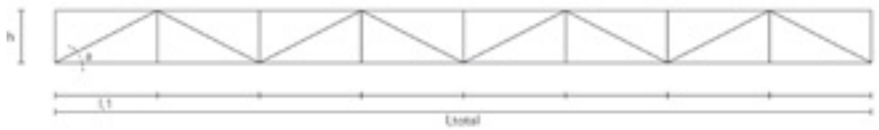
For the detailing and drawings the barrel size on the right is used but the volume used for the calculations is 200 liters.

Hand calculation dimensioning size of truss beams for input 3D model



Mmax output form 2D model in Technosoft

Rule of thumb height of truss: h: 1/15*l



l,total	12 m		
l,1	1,5 m		
h	0,8 m		
a	28 degree		
l diagonal beam	1,7 m		
Max moment	24 kNm		
Upper beam $F_{,u,b}$	29,0 kN	pressure (-)	$F_{,u,b} = F_{,l,b}$ evenwicht in krachten
Lower beam $F_{,l,b}$	29,0 kN	tension (+)	
	= Mmax / height truss		

Upper beam:

l,knik	1,5 m	*(assumed b to be 50 mm as starting point for i)*	*b*	*50*
i	14,4			
λ	104			
λ_{rel}	1,8 → kc	0,274		

$\sigma_{c,0,d} \leq k_c * f_{c,0,d}$ *control on knik tension*

$\sigma_{c,0,d}$ = F/A

$A = \sigma_{c,0,d} / (k_c * f_{c,0,d})$ 9052 mm^2 *required* 50 x 100 6300 mm^2 *chosen*

A smaller profile has been chosen in order to prevent downsizing after the results of the 3D model

Used information the National Structural Code of the Philippines volume I, 7th edtition, 2015.

Table 103-1 Occupancy Category

OCCUPANCY CATEGORY	OCCUPANCY OR FUNCTION OF STRUCTURE
I Essential Facilities	Occupancies having surgery and emergency treatment areas, Fire and police stations, Garages and shelters for emergency vehicles and emergency aircraft, Structures and shelters in emergency preparedness centers, Aviation control towers, Structures and equipment in communication centers and other facilities required for emergency response, Facilities for standby power-generating equipment for Category I structures, Tanks or other structures containing housing or supporting water or other fire-suppression material or equipment required for the protection of Category I, II or III, IV and V structures Public school buildings, Hospitals, Designated evacuation centers and Power and communication transmission lines.
II Hazardous Facilities	Occupancies and structures housing or supporting toxic or explosive chemicals or substances, Non-building structures storing, supporting or containing quantities of toxic or explosive substances.
III Special Occupancy Structures	Buildings with an assembly room with an occupant capacity of 1,000 or more, Educational buildings such as museums, libraries, auditorium with a capacity of 300 or more occupants, Buildings used for college or adult education with a capacity of 500 or more occupants, Institutional buildings with 50 or more incapacitated patients, but not included in Category I, Mental hospitals, sanitariums, jails, prisons and other buildings where personal liberties of inmates are similarly restrained, Churches, Mosques, and other Religion Facilities, All structures with an occupancy of 5,000 or more persons, Structures and equipment in power-generating stations, and other public utility facilities not included in Category I or Category II, and required for continued operation.
IV Standard Occupancy Structures	All structures housing occupancies or havingfunctionsnotlistedinCategory I, II orIIIandCategoryV.
V Miscellaneous Structures	Privategarages,carports,shedsandfences over 1.5mhigh.

Table 205-1 Minimum Uniform and Concentrated Live Loads

Use or Occupancy		Uniform Load[1]	Concentrated Load
Category	Description	kPa	kN
1. Access floor systems	Office use	2.4	9.0[2]
	Computer use	4.8	9.0[2]
2. Armories	–	7.2	0
3. Theaters, assembly areas[3] and auditoriums	Fixed seats	2.9	0
	Movable seats	4.8	0
	Lobbies and platforms	4.8	0
	Stage areas	7.2	0
4. Bowling alleys, poolrooms and similar recreational areas	–	3.6	0
5. Catwalk for maintenance access	–	1.9	1.3
6. Cornices and marquees	–	3.6[4]	0
7. Dining rooms and restaurants	–	4.8	0
8. Exit facilities[5]	–	4.8	0[6]
9. Parking Garages and Ramps	General storage and/or repair	4.8	–[7]
	Public parking and ramps	4.8	–[7]
	Private (residential) or pleasure-type motor vehicle storage	2.4	–[7]
10. Hospitals	Wards and rooms	1.9	4.5[2]
	Laboratories and operating rooms	2.9	4.5[2]
	Corridors above ground floor	3.8	4.5
11. Libraries	Reading rooms	2.9	4.5[2]
	Stack rooms	7.2	4.5[2]
	Corridors above ground floor	3.8	4.5
12. Manufacturing	Light	6.0	9.0[2]
	Heavy	12.0	13.4[2]
	Building corridors above ground floor	3.8	9.0
13. Office	Call centers and business processing offices	2.9	9.0
	Lobbies and ground floor corridors	4.8	9.0
	Other offices	2.4	9.0[2]
14. Printing plants	Press rooms	7.2	11.0[2]
	Composing and linotype rooms	4.8	9.0[2]
15. Residential[8]	Basic floor area	1.9	0[6]
	Exterior balconies	2.9[4]	0
	Decks	1.9[4]	0
	Storage	1.9	0
16. Restrooms[9]	–	–	–
17. Reviewing stands, grandstands, bleachers, and folding and telescoping seating	–	4.8	0
18. Roof decks	Same as area served or occupancy	–	–
19. Schools	Classrooms	1.9	4.5[2]
	Corridors above ground floor	3.8	4.5
	Ground floor corridors	4.8	4.5
20. Sidewalks and driveways	Public access	12.0	–[7]
21. Storage	Light	6.0	–
	Heavy	12.0	–
22. Stores	Retail	4.8	4.5[2]
	Wholesale	6.0	13.4[2]
23. Pedestrian bridges and walkways	–	4.8	–

Notes for Table 205-1

[1] *See Section 205.5 for live load reductions.*

[2] *See Section 205.3.3, first paragraph, for area of load application.*

[3] *Assembly areas include such occupancies as dance halls, drill rooms, gymnasiums, playgrounds, plazas, terraces and similar occupancies that are generally accessible to the public.*

[4] *For special-purpose roofs, see Section 205.4.4.*

[5] *Exit facilities shall include such uses as corridors serving an occupant load of 10 or more persons, exterior exit balconies, stairways, fire escapes and similar uses.*

[6] *Individual stair treads shall be designed to support a 1.3 kN concentrated load placed in a position that would cause maximum stress. Stair stringers may be designed for the uniform load set forth in the table.*

[7] *See Section 205.3.3, second paragraph, for concentrated loads. See Table 205-2 for vehicle barriers.*

[8] *Residential occupancies include private dwellings, apartments and hotel guest rooms.*

[9] *Restroom loads shall not be less than the load for the occupancy with which they are associated, but need not exceed 2.4 kPa.*

Set up wind loads for 2D model

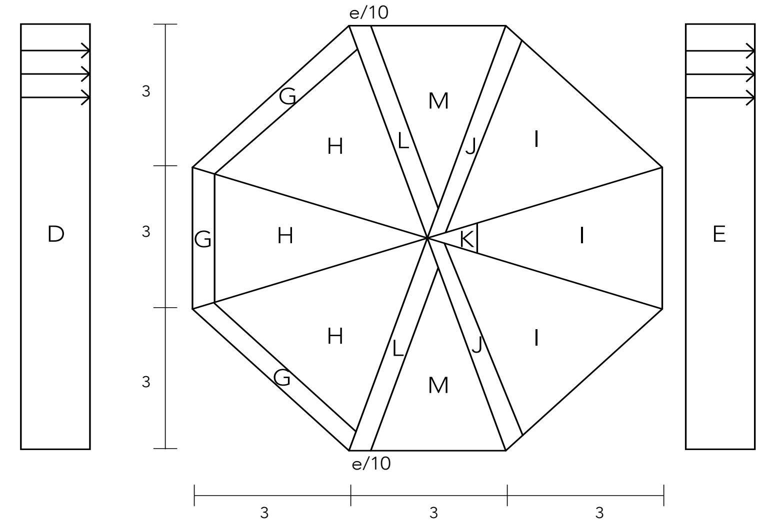
Dead / Live load	G [kN/m²]	Q [kN/m²]	width front [m]	width end [m]	q,Gfront [kN/m']	q,Gend [kN/m']	q,Qfront [kN/m']	q,Qend [kN/m']
Frame 1 = 2 = 3 = 4	0,55	1	3,625	0,5	2,0	0,3	3,6	0,5

Load case wind 1 Wind on:	windfactor	underpressure	wind pressure in [kN/m²]	width [m]	wind pressure in [kN/m']	angle in degree	perpendicular wind pressure [kN/m']	
Facade - zone D	0,73	0,3	3,4	3	10,2	27	11,4	*pressure*
Facade - zone E	-0,35	0,3	-0,2	3	-0,5	27	-0,6	*suction*
Roof - zone G	0,2	0,3	1,7	3,6	5,9	-	5,9	*pressure*
Roof - zone H	0,2	0,3	1,7	3,6	5,9	-	5,9	*pressure*
				0,5	0,8		0,8	*pressure*
Roof - zone K	-1,2	0,3	-3,0	0,5	-1,5	-	-1,5	*suction*
Roof - zone I	-0,5	0,3	-0,7	3,6	-2,4		-2,4	*suction*
				0,5	-0,3		-0,3	*suction*
Eave - D + G							5,5	*pressure*
Eave - E + I							-2,9	*suction*

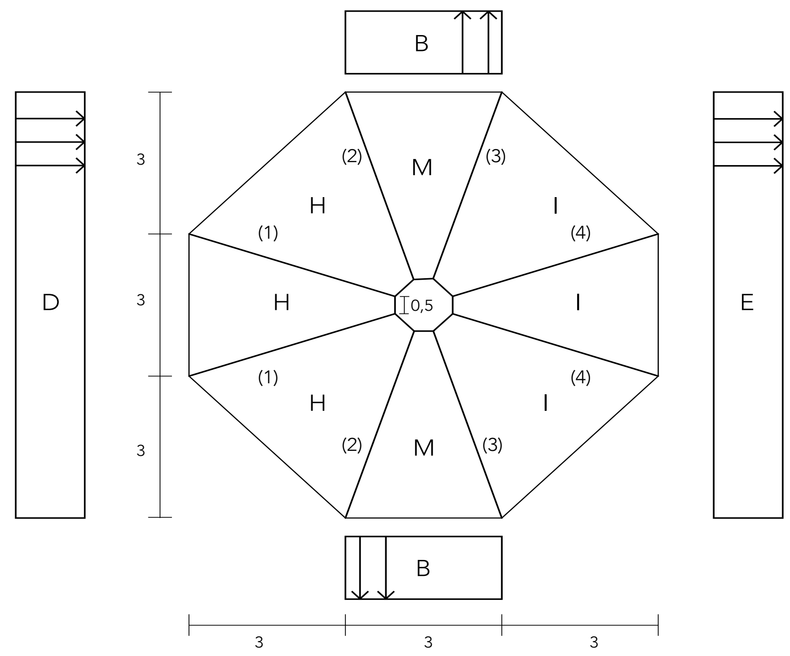
Load case wind 2 Wind on:	windfactor	overpressure	wind pressure in [kN/m²]	width [m]	wind pressure in [kN/m']	angle in degree	perpendicular wind pressure [kN/m']	
Facade - zone D	0,73	-0,2	1,7	3	5,2	27	5,9	*pressure*
Facade - zone E	-0,35	-0,2	-1,8	3	-5,4	27	-6,1	*suction*
Roof - zone G	0,2	-0,2	0,0	3,6	0,0	-	0,0	*suction*
Roof - zone H	0,2	-0,2	0,0	3,6	0,0	-	0,0	*suction*
				0,5	0,0		0,0	*suction*
Roof - zone K	-1,2	-0,2	-4,6	0,5	-2,3	-	-2,3	*suction*
Roof - zone I	-0,5	-0,2	-2,3	3,6	-8,3		-8,3	*suction*
				0,5	-1,2		-1,2	*suction*
Eave - D + G							-5,9	*suction*
Eave - E + I							-14,4	*suction*

Load case wind 3 Wind on:	windfactor	underpressure	wind pressure in [kN/m²]	width [m]	wind pressure in [kN/m']	angle in degree	perpendicular wind pressure [kN/m']	
Facade - zone D	0,73	0,3	3,4	3	10,2	27	11,4	*pressure*
Facade - zone E	-0,35	0,3	-0,2	3	-0,5	27	-0,6	*suction*
Roof - zone G	-0,8	0,3	-1,7	3,6	-5,9	-	-5,9	*suction*
Roof - zone H	-0,3	0,3	0,0	3,6	0,0	-	0,0	*suction*
				0,5	0,0		0,0	*suction*
Roof - zone K	-1,2	0,3	-3,0	0,5	-1,5	-	-1,5	*suction*
Roof - zone I	-0,5	0,3	-0,7	3,6	-2,4		-2,4	*suction*
				0,5	-0,3		-0,3	*suction*
Eave - D + G							-17,4	*suction*
Eave - E + I							-2,9	*suction*

Load case wind 4 Wind on:	windfactor	overpressure	wind pressure in [kN/m²]	width [m]	wind pressure in [kN/m']	angle in degree	perpendicular wind pressure [kN/m']	
Facade - zone D	0,73	-0,2	1,7	3	5,2	27	5,9	*pressure*
Facade - zone E	-0,35	-0,2	-1,8	3	-5,4	27	-6,1	*suction*
Roof - zone G	-0,8	-0,2	-3,3	3,6	-11,9	-	-11,9	*suction*
Roof - zone H	-0,3	-0,2	-1,7	3,6	-5,9	-	-5,9	*suction*
				0,5	-0,8		-0,8	*suction*
Roof - zone K	-1,2	-0,2	-4,6	0,5	-2,3	-	-2,3	*suction*
Roof - zone I	-0,5	-0,2	-2,3	3,6	-8,3		-8,3	*suction*
				0,5	-1,2		-1,2	*suction*
Eave - D + G							-17,8	*suction*
Eave - E + I							-14,4	*suction*



Wind zones octagonal shape used for 2D model



Wind zones octagonal shape used for 3D model

Set up wind loads for 3D model

Dead / Live load	G [kN/m²]	Q [kN/m²]	width front [m]	width end [m]	q,Gfront [kN/m']	q,Gend [kN/m']	q,Qfront [kN/m']	q,Qend [kN/m']
Frame 1 = 2 = 3 = 4	0,55	1	3,625	0,5	2,0	0,3	3,6	0,5

Frame 1 - Wind 1 Wind on:	windfactor	underpressure	wind pressure in [kN/m²]	width [m]	wind pressure in [kN/m']	wind pressure [kN/m']	
Facade - zone D	0,73	0,3	3,4	3	10,2	10,2	pressure
Roof - zone H	0,2	0,3	1,7	3,6	5,9	5,9	pressure
	0,2	0,3	1,7	0,5	0,8	0,8	pressure

Frame 1 - Wind 2 Wind on:	windfactor	overpressure	wind pressure in [kN/m²]	width [m]	wind pressure in [kN/m']	wind pressure [kN/m']	
Facade - zone D	0,73	-0,2	1,7	3	5,2	5,2	pressure
Roof - zone H	0,2	-0,2	0,0	3,6	0,0	0,0	-
	0,2	-0,2	0,0	0,5	0,0	0,0	-

Frame 1 - Wind 3 Wind on:	windfactor	underpressure	wind pressure in [kN/m²]	width [m]	wind pressure in [kN/m']	wind pressure [kN/m']	
Facade - zone D	0,73	0,3	3,4	3	10,2	10,2	pressure
Roof - zone H , front	-0,3	0,3	0,0	3,6	0,0	0,0	-
Roof - zone H , end	-0,3	0,3	0,0	0,5	0,0	0,0	-

Frame 1 - Wind 4 Wind on:	windfactor	underpressure	wind pressure in [kN/m²]	width [m]	wind pressure in [kN/m']	wind pressure [kN/m']	
Facade - zone D	0,73	-0,2	1,7	3	5,2	5,2	pressure
Roof - zone H , front	-0,3	-0,2	-1,7	3,6	-5,9	-5,9	suction
Roof - zone H , end	-0,3	-0,2	-1,7	0,5	-0,8	-0,8	suction

Frame 2 - Wind 1 Wind on:	windfactor	underpressure	wind pressure in [kN/m²]	width [m]	wind pressure in [kN/m']	wind pressure [kN/m']		
Facade - zone D	0,73	0,3	3,4	1,5	5,1	5,1	pressure	
Facade - zone B	-0,8	0,3	-1,7	1,5	-2,5	-2,5	suction	+
Roof - zone H , front	0,2	0,3	1,7	2,125	3,5	3,5	pressure	
Roof - zone M , front	-0,6	0,3	-1,0	1,5	-1,5	-1,5	suction	+
Roof, front total						2,0	pressure	
Roof - zone H , end	0,2	0,3	1,7	0,25	0,41	0,4	pressure	
Roof - zone M , end	-0,6	0,3	-1,0	0,25	-0,25	-0,2	suction	+
Roof, end total						0,2	pressure	

Frame 2 - Wind 2 Wind on:	windfactor	overpressure	wind pressure in [kN/m²]	width [m]	wind pressure in [kN/m']	wind pressure [kN/m']		
Facade - zone D	0,73	-0,2	1,7	1,5	2,6	2,6	pressure	
Facade - zone B	-0,8	-0,2	-3,3	1,5	-5,0	-5,0	suction	+
Roof - zone H , front	0,2	-0,2	0,0	2,125	0,0	0,0	-	
Roof - zone M , front	-0,6	-0,2	-2,6	1,5	-4,0	-4,0	suction	+
Roof, front total						-4,0	suction	
Roof - zone H , end	0,2	-0,2	0,0	0,25	0,00	0,0	-	
Roof - zone M , end	-0,6	-0,2	-2,6	0,25	-0,66	-0,7	suction	+
Roof, end total						-0,7	suction	

Frame 2 - Wind 3 Wind on:	windfactor	underpressure	wind pressure in [kN/m²]	width [m]	wind pressure in [kN/m']	wind pressure [kN/m']		
Facade - zone D	0,73	0,3	3,4	1,5	5,1	5,1	pressure	
Facade - zone B	-0,8	0,3	-1,7	1,5	-2,5	-2,5	suction	
Roof - zone H , front	-0,3	0,3	0,0	2,125	0,0	0,0	-	
Roof - zone M , front	-0,6	0,3	-1,0	1,5	-1,5	-1,5	suction	
Roof, front total						-1,5	suction	
Roof - zone H , end	-0,3	0,3	0,0	0,25	0,00	0,0	-	
Roof - zone M , end	-0,6	0,3	-1,0	0,25	-0,25	-0,2	suction	+
Roof, end total						-0,2	suction	

Frame 2 - Wind 4 Wind on:	windfactor	overpressure	wind pressure in [kN/m²]	width [m]	wind pressure in [kN/m']	wind pressure [kN/m']		
Facade - zone D	0,73	-0,2	1,7	1,5	2,6	2,6	pressure	
Facade - zone B	-0,8	-0,2	-3,3	1,5	-5,0	-5,0	suction	
Roof - zone H , front	-0,3	-0,2	-1,7	2,125	-3,5	-3,5	suction	
Roof - zone M , front	-0,6	-0,2	-2,6	1,5	-4,0	-4,0	suction	+
Roof, front total						-7,5	suction	
Roof - zone H , end	-0,3	-0,2	-1,7	0,25	-0,41	-0,4	suction	
Roof - zone M , end	-0,6	-0,2	-2,6	0,25	-0,66	-0,7	suction	+
Roof, end total						-1,1	suction	

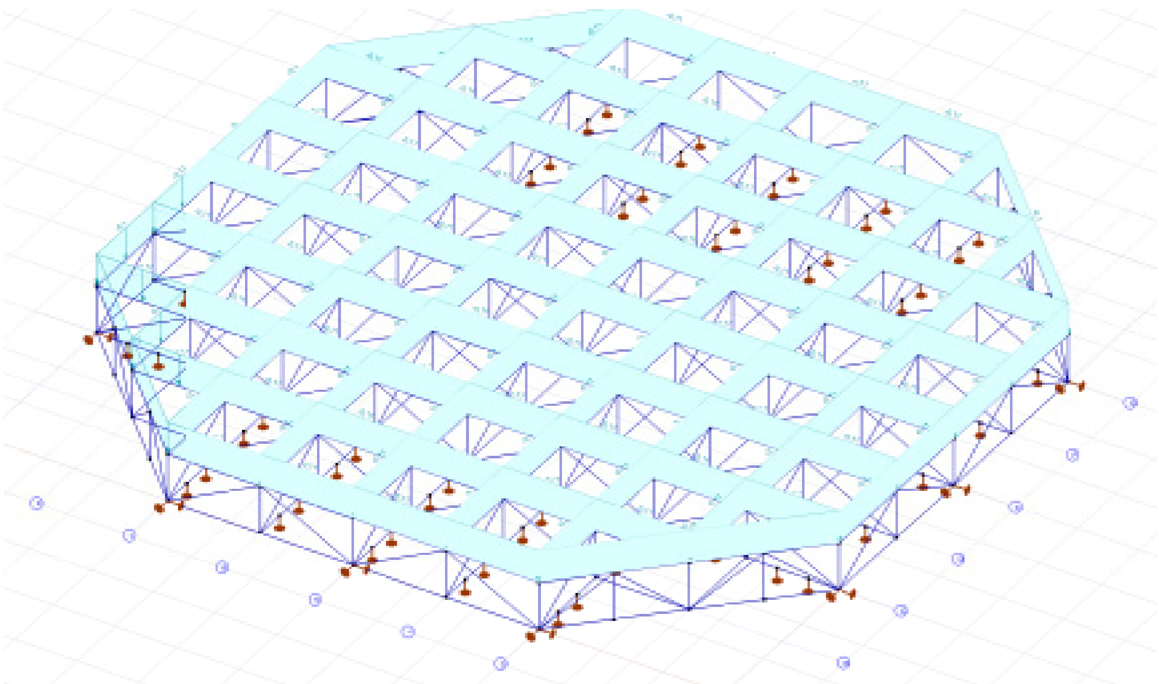
Frame 3 - Wind 1/3 Wind on:	windfactor	underpressure	wind pressure in [kN/m²]	width [m]	wind pressure in [kN/m']	wind pressure [kN/m']		
Facade - zone E	-0,35	0,3	-0,2	1,5	-0,2	-0,2	suction	
Facade - zone B	-0,8	0,3	-1,7	1,5	-2,5	-2,5	suction	+
Roof - zone I , front	-0,5	0,3	-0,7	2,125	-1,4	-1,4	suction	
Roof - zone M , front	-0,6	0,3	-1,0	1,5	-1,5	-1,5	suction	+
Roof, front total						-2,9	suction	
Roof - zone I , end	-0,5	0,3	-0,7	0,25	-0,17	-0,2	suction	
Roof - zone M , end	-0,6	0,3	-1,0	0,25	-0,25	-0,2	suction	+
Roof, end total						-0,4	suction	

Frame 3 - Wind 2/4 Wind on:	windfactor	overpressure	wind pressure in [kN/m²]	width [m]	wind pressure in [kN/m']	wind pressure [kN/m']		
Facade - zone E	-0,35	-0,2	-1,8	1,5	-2,7	-2,7	suction	
Facade - zone B	-0,8	-0,2	-3,3	1,5	-5,0	-5,0	suction	+
Roof - zone I , front	-0,5	-0,2	-2,3	2,125	-4,9	-4,9	suction	
Roof - zone M , front	-0,6	-0,2	-2,6	1,5	-4,0	-4,0	suction	+
Roof, front total						-8,9	suction	
Roof - zone I , end	-0,5	-0,2	-2,3	0,25	-0,58	-0,6	suction	
Roof - zone M , end	-0,6	-0,2	-2,6	0,25	-0,66	-0,7	suction	+
Roof, end total						-1,2	suction	

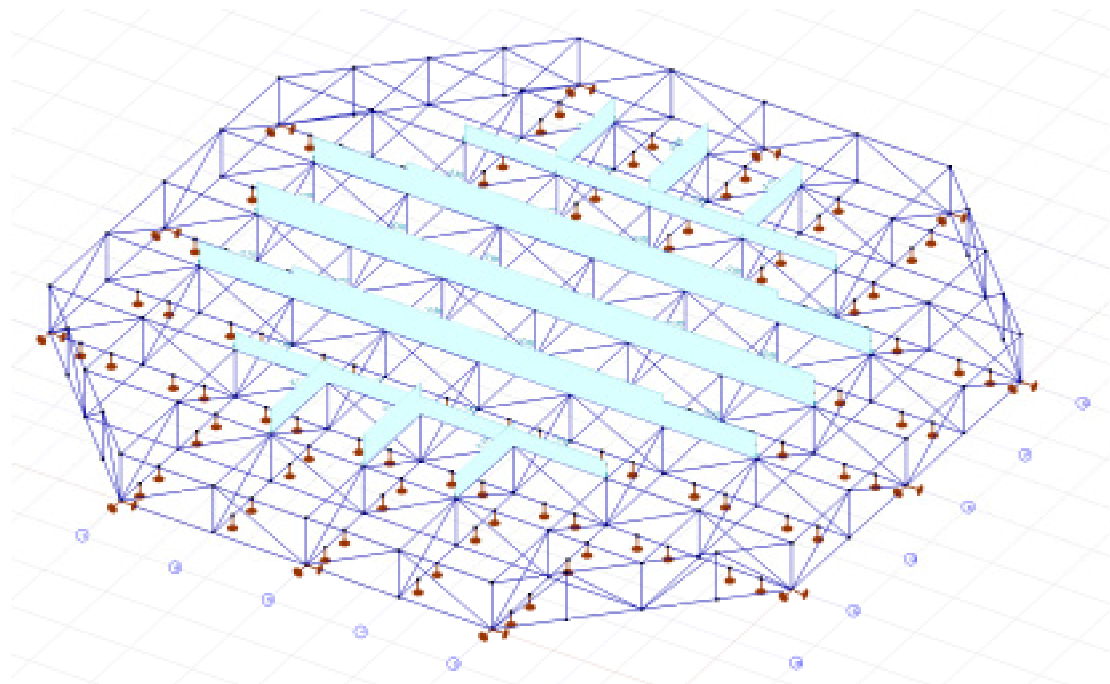
Frame 4 - Wind 1/3 Wind on:	windfactor	underpressure	wind pressure in [kN/m²]	width [m]	wind pressure in [kN/m']	wind pressure [kN/m']	
Facade - zone D	-0,35	0,3	-0,2	3	-0,5	-0,5	suction
Roof - zone I , front	-0,5	0,3	-0,7	3,6	-2,4	-2,4	suction
Roof - zone I , end	-0,5	0,3	-0,7	0,5	-0,3	-0,3	suction

Frame 4 - Wind 2/4 Wind on:	windfactor	overpressure	wind pressure in [kN/m²]	width [m]	wind pressure in [kN/m']	wind pressure [kN/m']	
Facade - zone D	-0,35	-0,2	-1,8	3	-5,4	-5,4	suction
Roof - zone I , front	-0,5	-0,2	-2,3	3,6	-8,3	-8,3	suction
Roof - zone I , end	-0,5	-0,2	-2,3	0,5	-1,2	-1,2	suction

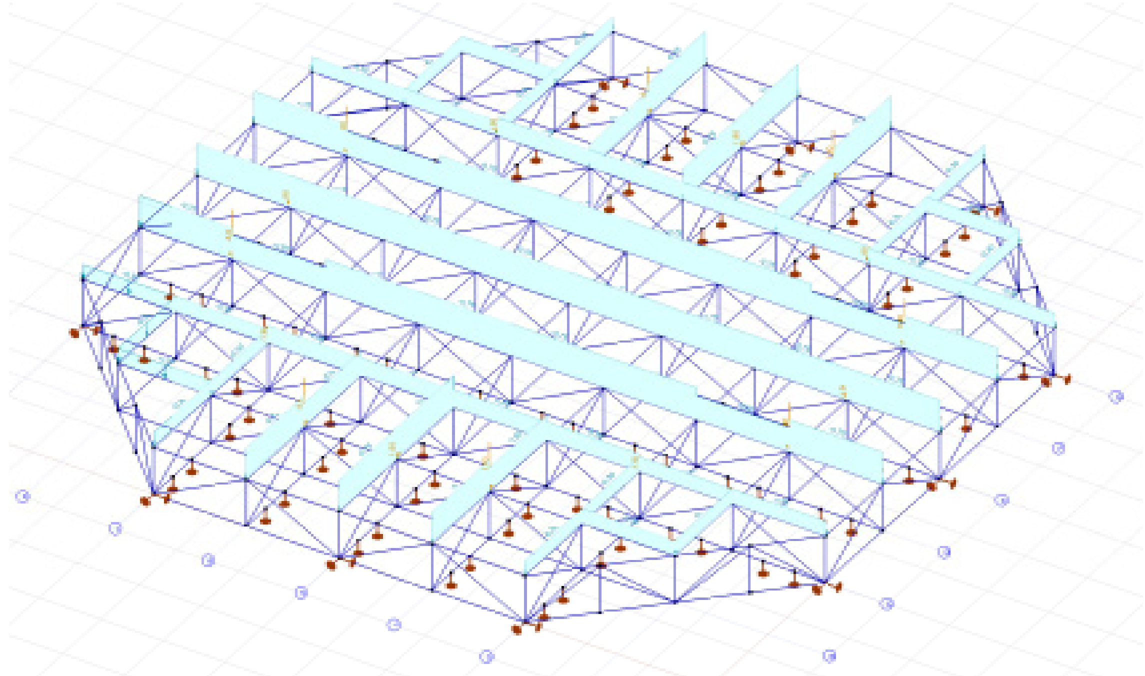
Load cases floating foundation (3D - model)



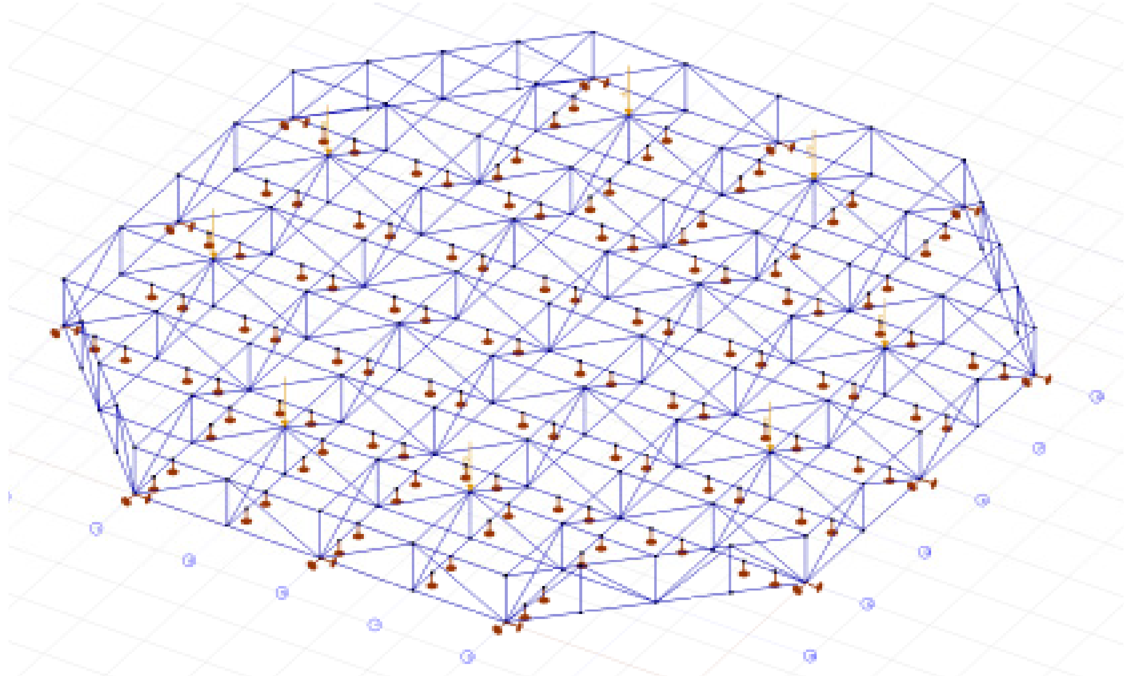
Load case 1 - own weight



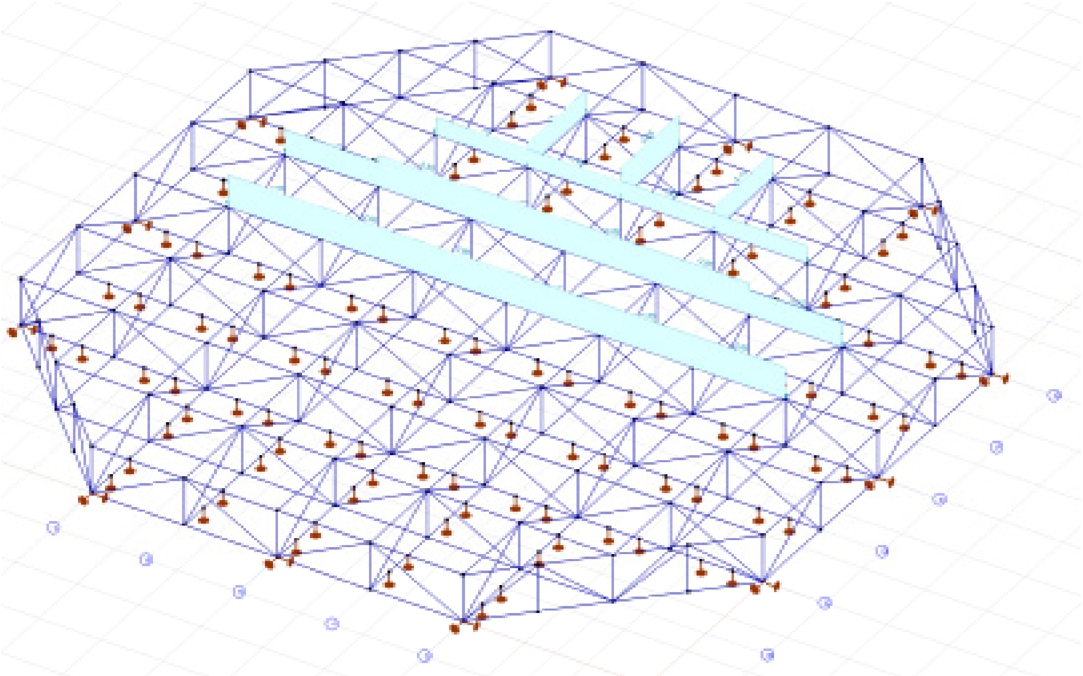
Load case 2 - live load classroom



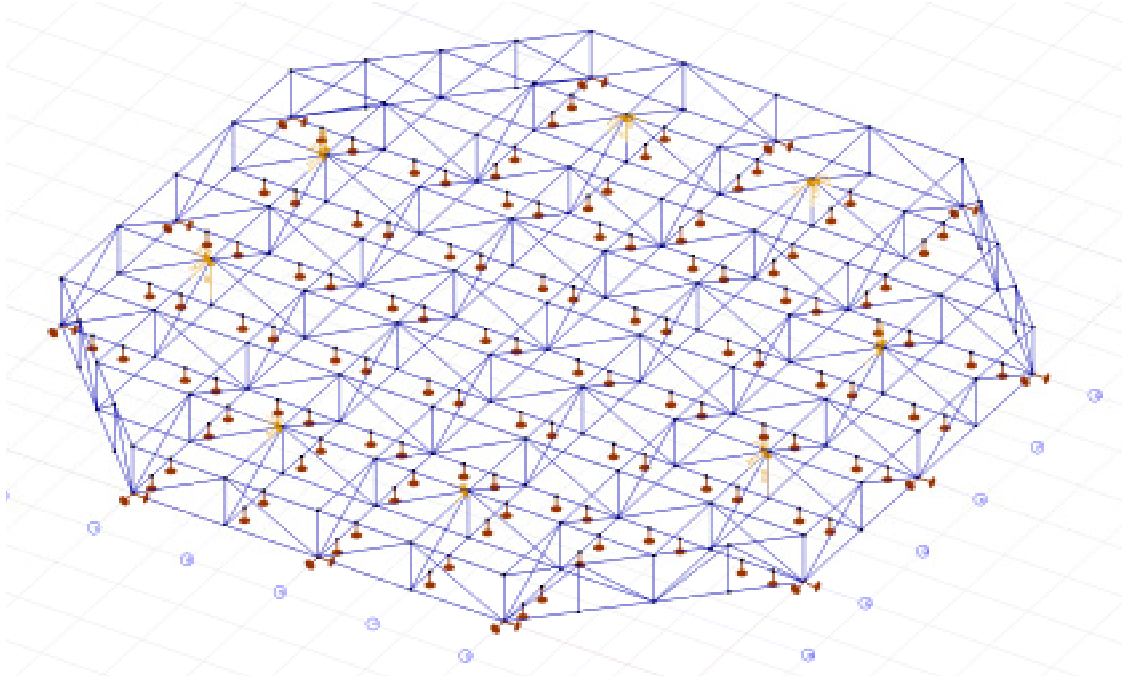
Load case 1 - dead load



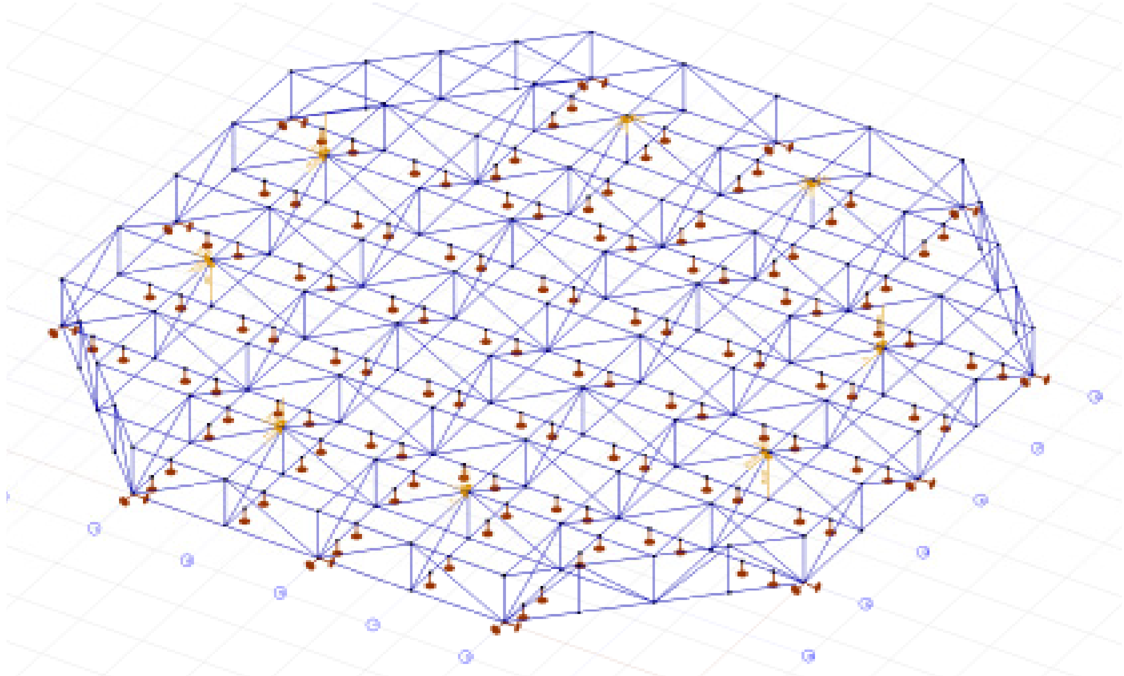
Load case 3 - live load roof



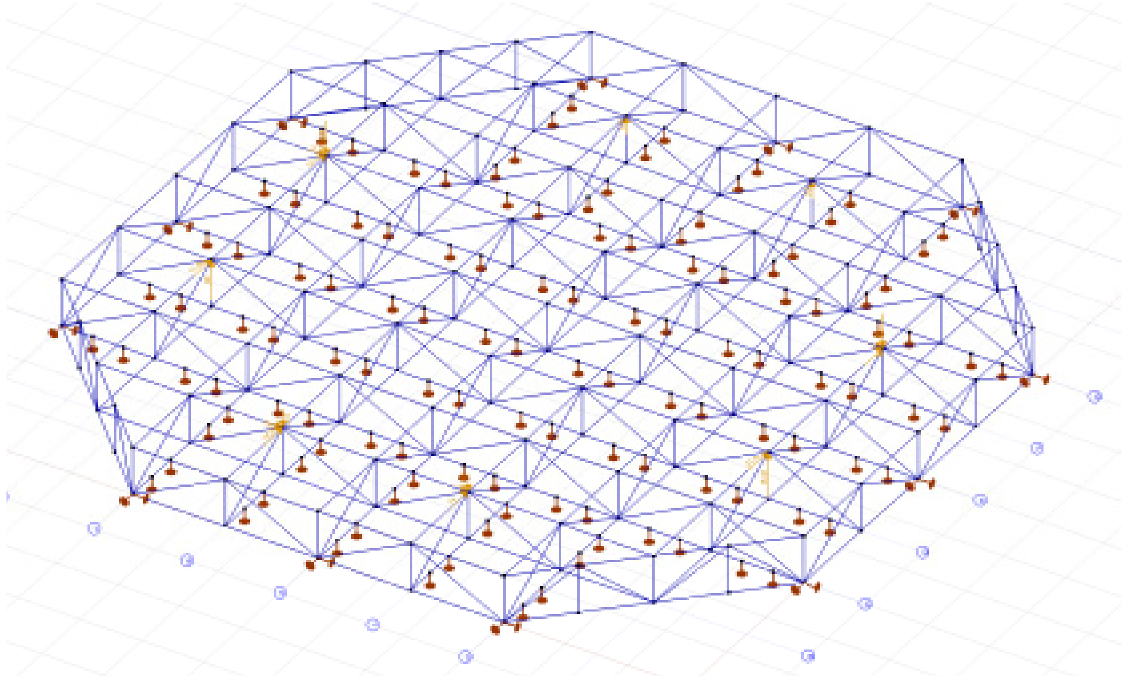
Load case 4 - live load classroom - half platform loaded



Load case 6 - wind 2

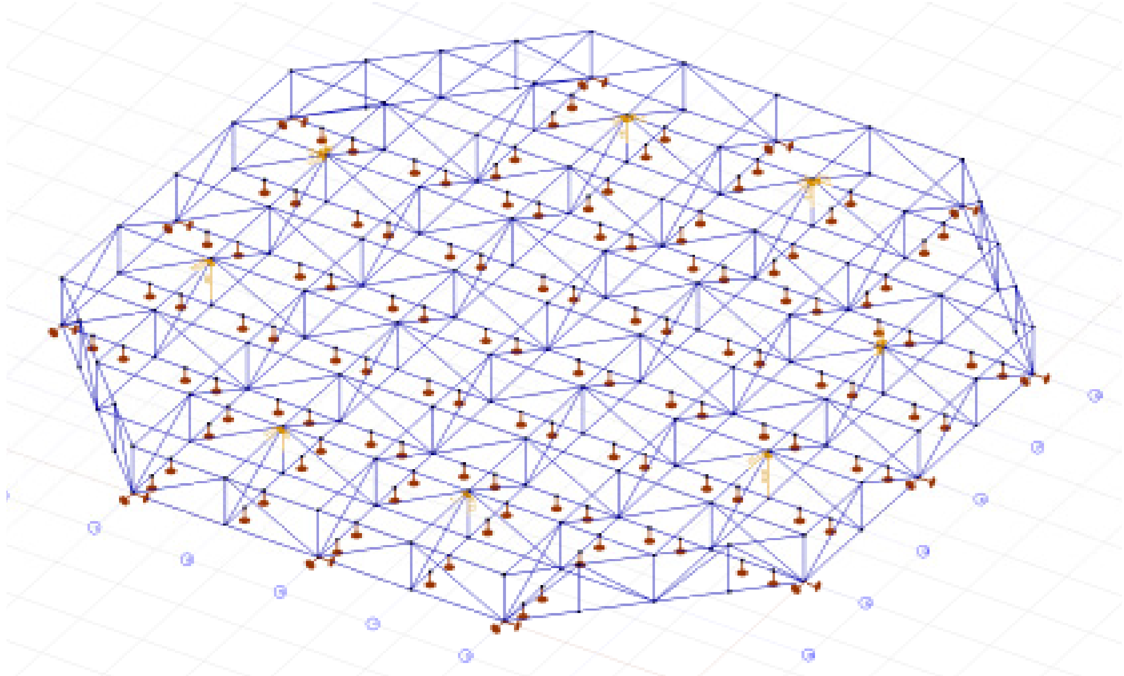


Load case 5 - wind 1

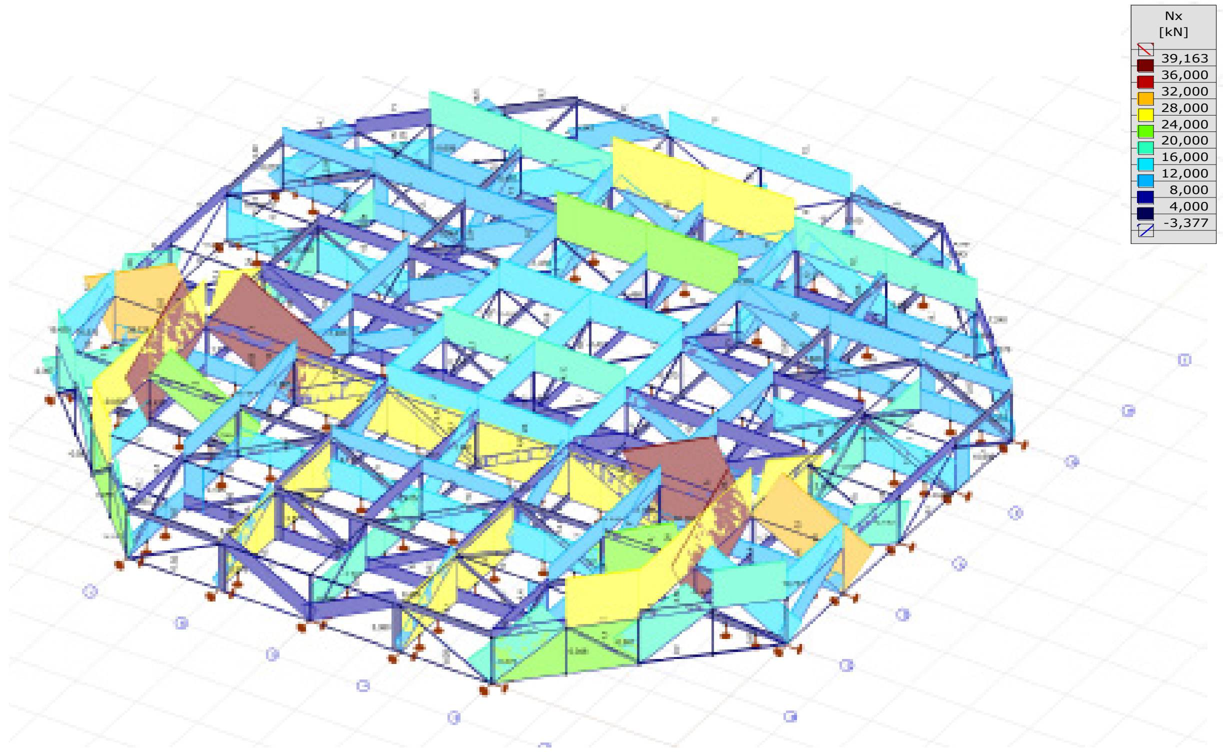


Load case 7 - wind 3

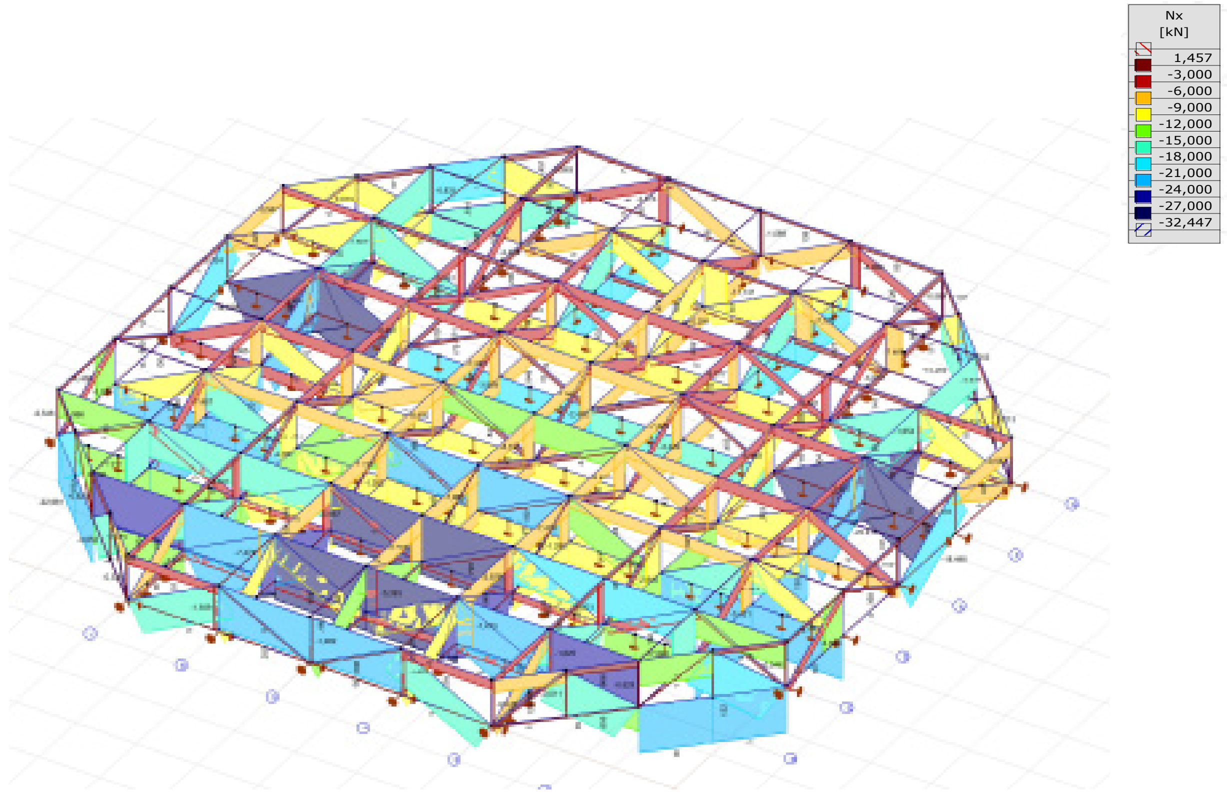
Results of structural calculations by Axis VM used for the floating foundation



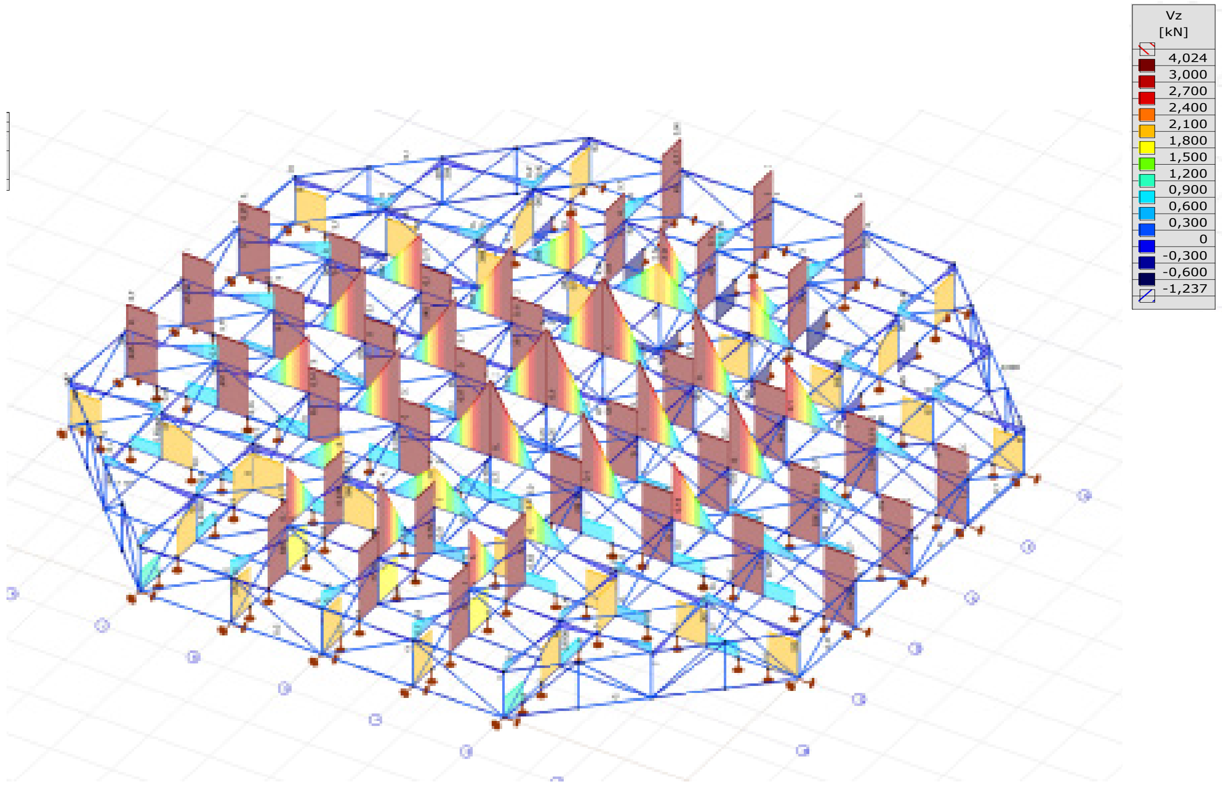
Load case 8 - wind 4



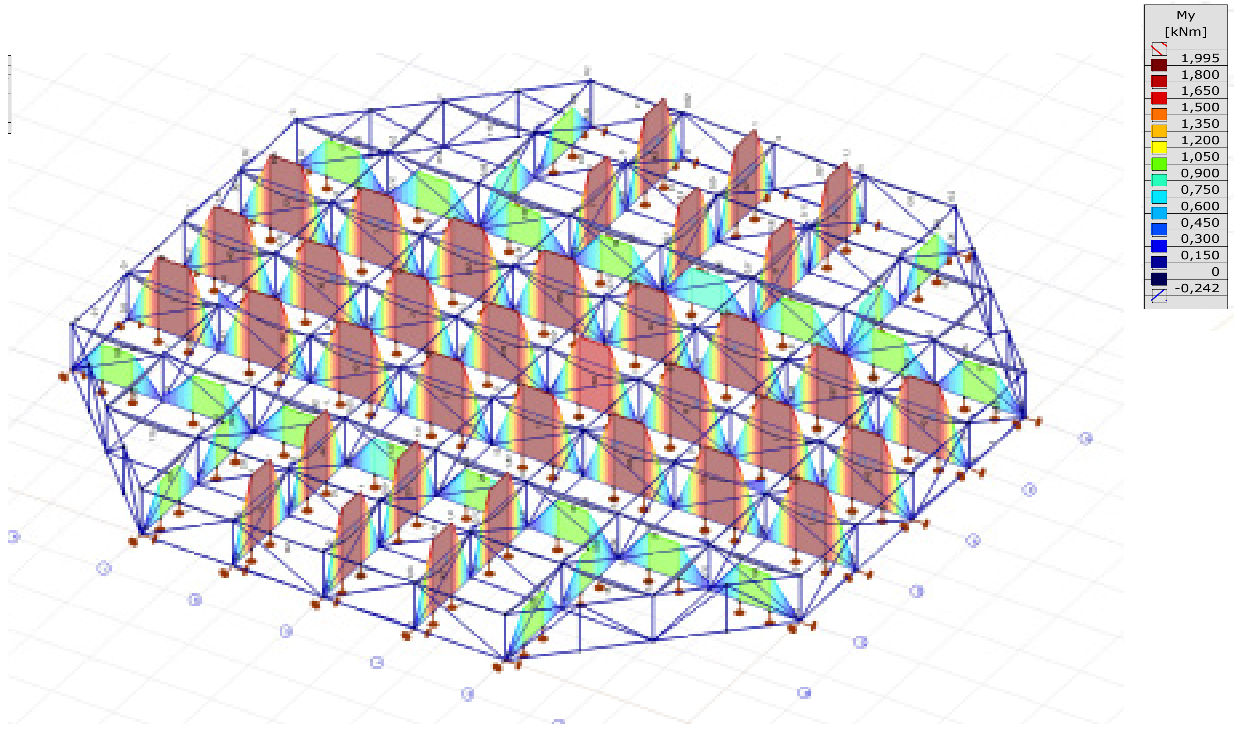
Nx,max



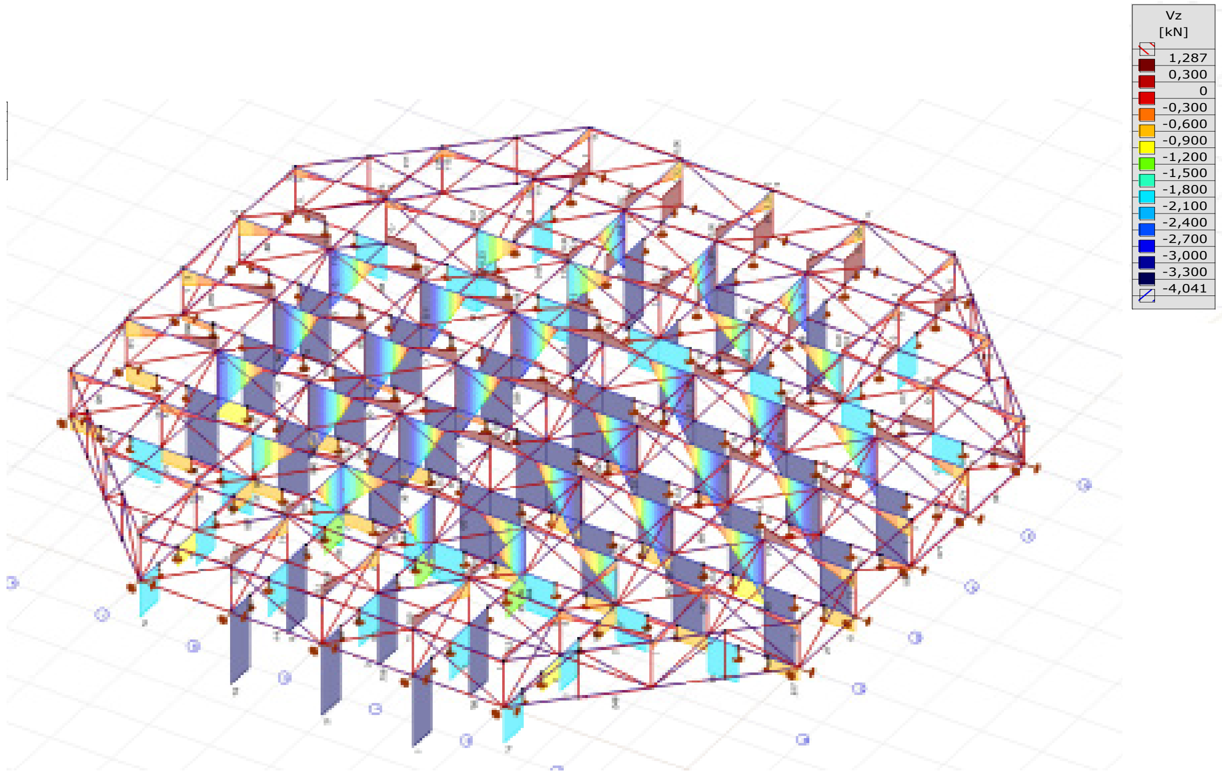
Nx,min



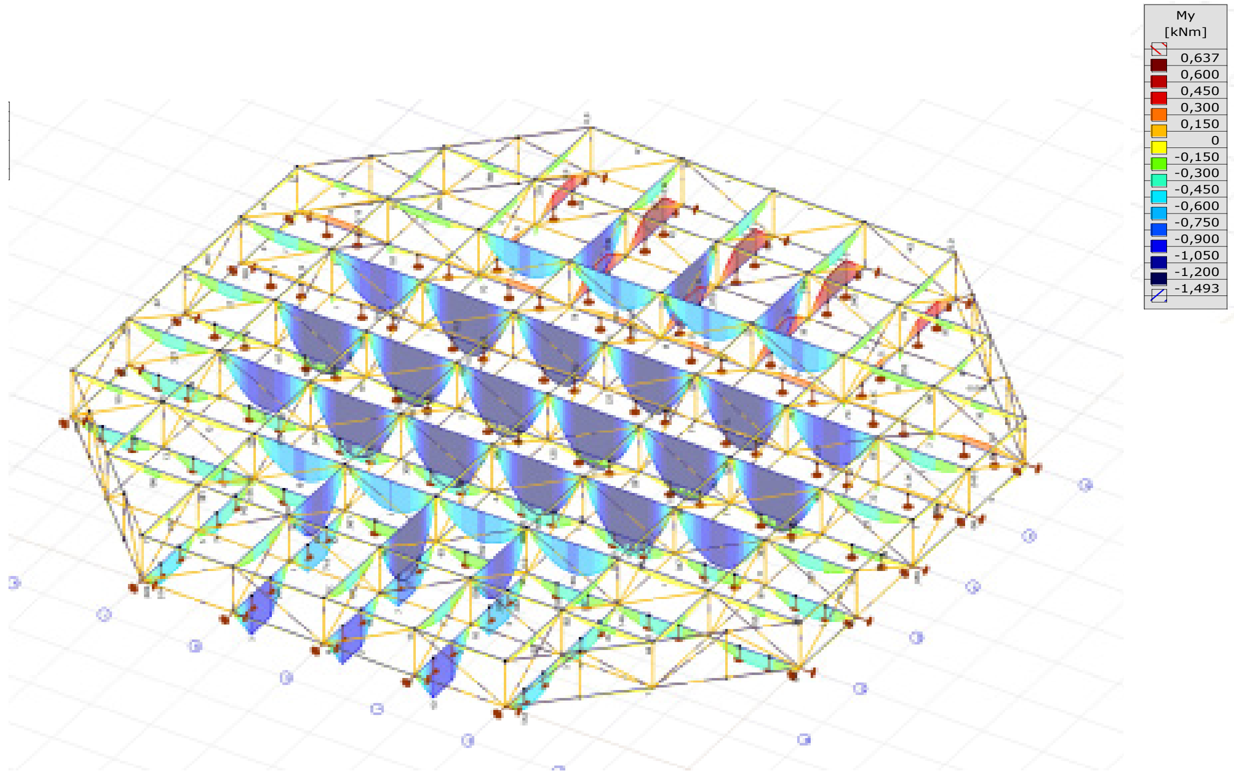
Vz,max



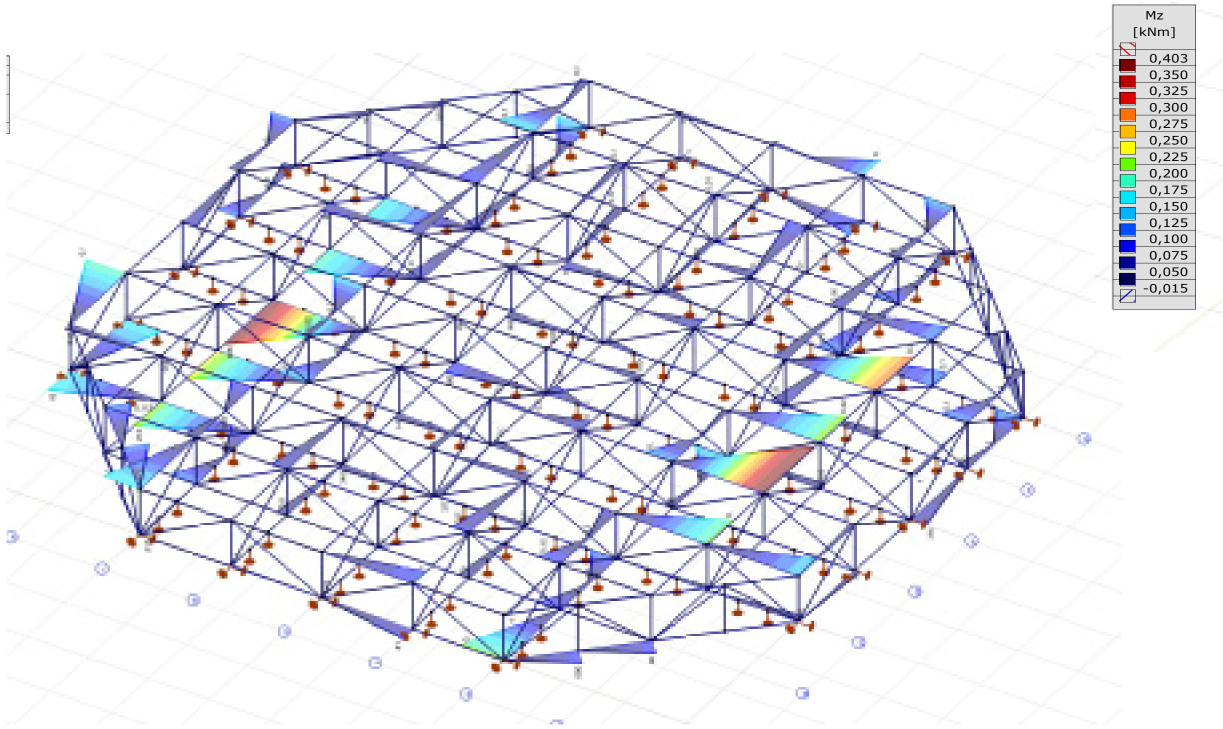
My,max



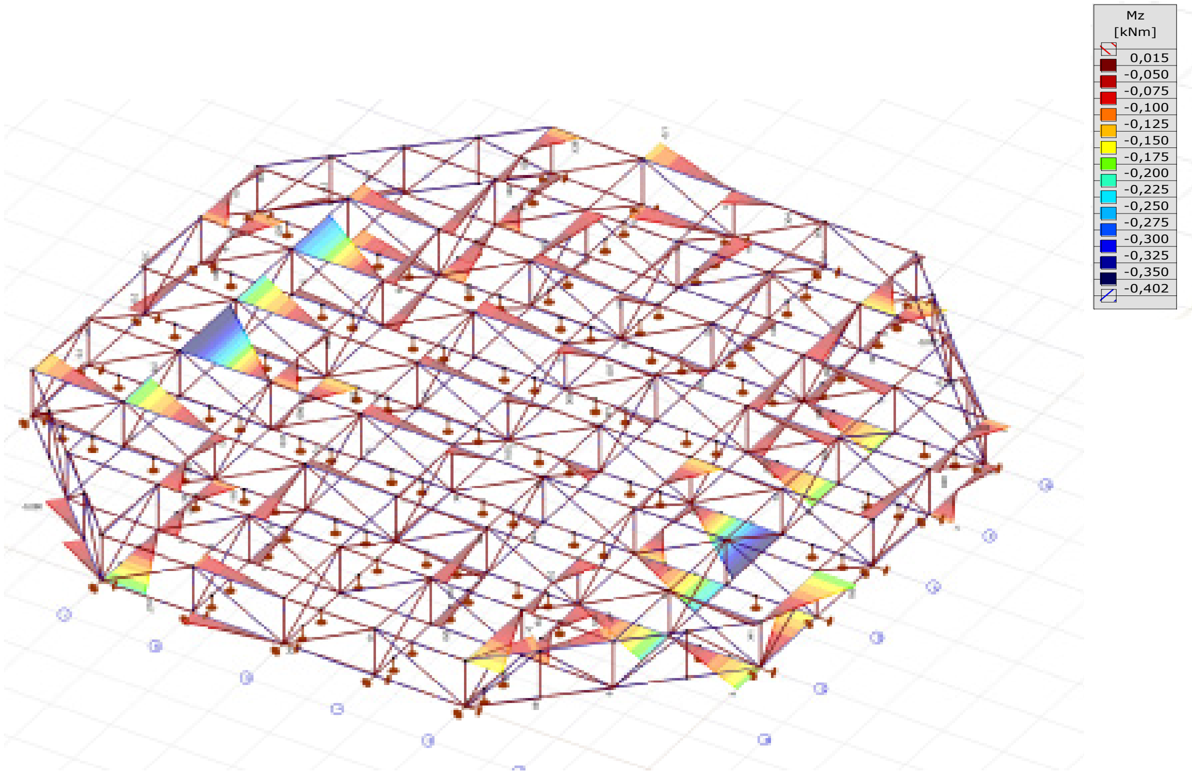
Vz,min



My,min



Mz,max



Mz,min

Stabilization wall control element 6

	N force =	4,4	kN						
	Moment in Y =	0	kNm						
	Moment in Z =	0	kNm						
	Ly =	1000	mm						
	Lz =	1000	mm						
	w =	50	mm	A =	3150	mm^2			
	h =	63	mm						
	W_y =	33075	mm^3	I_y =	1041863	mm^4			
	W_z =	26250	mm^3	I_z =	656250	mm^4			
	i_y =	18,2	mm	λ_y =	55,0				
	i_z =	14,4	mm	λ_y =	69,3				
6.21	$\lambda_{rel,y}$ =	0,95		bc =	0,2				
6.22	$\lambda_{rel,z}$ =	1,20							
6.27	k_y =	1,02		Strenght					
6.28	k_z =	1,31		pressure $\sigma_{c,o,d}$ =	1,40	N/mm^2	≤	U.C.	0,11
6.25	$k_{c;y}$ =	0,72		tension $\sigma_{m,y,d}$ =	0,00	N/mm^2	≤	U.C.	0,00
6.26	$k_{c;z}$ =	0,54		tension $\sigma_{m,z,d}$ =	0	N/mm^2	≤	U.C.	0,00
Stability									
6,23	0,15	≤	1	OK					
6,24	0,20	≤	1	OK					

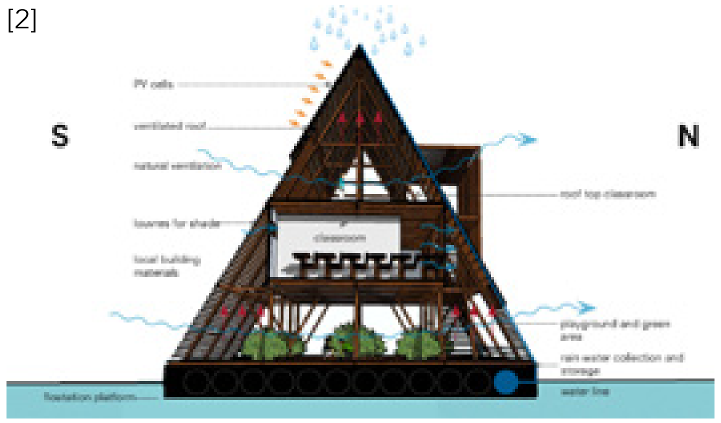
Case study: Makoko Floating school

LOCATION	Location:	Lagos, Nigeria
	Climate:	Tropical climate Average temperature 26,4 degrees, warmest 33 degrees, coolest 21 degrees.
INDOOR COMFORT	Shape and dimensions:	Triangular, the platfrom is 10x10 meter and 10 meter high.
	Floorplan:	Ground floor: open green space, planting area's, toilets, services area, also surves as an community space in the after hours First floor: classrooms. Second floor: open air classrooms [4]
	Ventilation:	Natural ventilation in the form of cross ventilation.[2]
	Shading devices:	Bamboo louvre's
	Fenestration:	A linked open pattern of wooden slats on the facade which offers some privacy for the school activities and the passage of daylight and breezes.
	Shading objects:	There are no schading objects around the Makoko school
	Water and restroom facilities:	Rainwater storage barrel that is been located between the other floating barrels (ideal roof drainage shape) and a compost toilet
CONSTRUCTION	Materials:	AKUN wood, aluminium roofing sheets, bamboo furniture
	Building theory:	The triangular shape provides a low center of gravity which makes the construction stable even in heavy winds.
	Construction details:	Beams and columns are made from a composite wooden profiles that are connected in the corner points by means of steel bolts on a wooden strip that serves to connect the different corner points to each other [3]. The structure is kept in place cross chained by anchors.
	Floating foundation:	The floating foundation consists of 16 wooden modules each containing 16 barrels. (256 barrels)
SCHOOL	No. of classrooms:	4 closed classrooms, 2 open air classrooms.
	No. of students:	+/- 60 students
	Noise control between classrooms:	The classrooms are divided by aluminum or bamboo walls which don't offer a lot of sound insulation

IMPRESSIONS

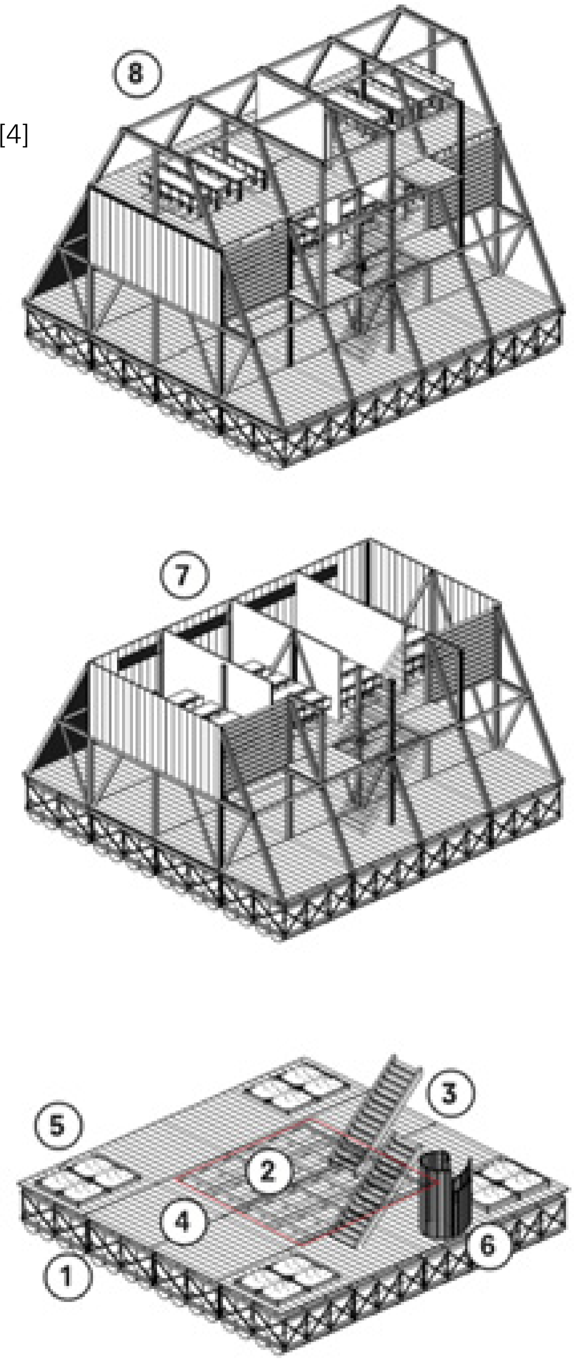
[1]

[2]



[3]

[4]



(1) flotation platform, (2) services area
(3) accessibility, (4) open green space
(5) planting area's, (6) toilet
(7/8) classrooms

Figures x: Imressions of the makoko floating school (NLE, 2016)

Case study: Makoko Floating school

The Makoko school collapsed in 2016 due to deterioration from a lack of proper maintenance and collective management. *"It was built quickly, with some improvisations and the quality of construction and materials were yet to be perfected. It was built with the collective goal of learning from the local environment, for educating and improving the building system through product development. The project team was constantly aware of the imperfections and collectively worked to devise locally appropriate and innovative solutions. The imperfections may have triggered events that led to the collapse but these did not directly cause the collapse. Had the management decision to repair or dismantle the structure been made soon after it was damaged, its lifespan would have been prolonged or it would not have collapsed." (NLE, 2016)*
NLE decided to go on developing the concept of the Makoko school and formed the MFS II, MFS III, and MFS IIIX3. In the report of the collapse and regeneration plans for the Makoko school, NLE describes some of the most significant improvements that they want to make after analyzing the collapse of the Makoko school.

Technical Improvements

Prefabrication process off-site

Fast paced assembly

Screen printed marine board facade

Steel-to-wood designed connections

Stronger corners for anchoring

Sturdy steel connection elements

Securely moored to poles

Widely used mooring method

Case study: Finch Floating Home

LOCATION	Location:	Macababe, the Philippines
	Climate:	Warm and humid Average temperature 26,6 degrees, warmest 33,2 degrees, coolest 21 degrees.
INDOOR COMFORT	Shape and dimensions:	Square plan, the house is 4,8x4,8 meter and 5,3 meter high and has a veranda around the house which is 1,3 meter wide.
	Floorplan:	Consists of three main zones; Living area: visitors seating, dining area and kitchen Sleeping: attic floor Bathroom
	Ventilation:	Natural ventilation in the form of wind driven ventilation and buoyancy driven ventilation (stack effect)
	Shading devices:	Eaves and overhangs + verandah around the house
	Fenestration:	The openings shutter are two layered; one with fenstrations and the outer one is a solid shutter
	Water and restroom facilities:	The bathroom is connected to the septic tank which is located inland.
CONSTRUCTION	Materials:	Meranti wood
	Building theory:	The house is inspired from the traditonal bahay kubo. The hip roof gives a better shape for the wind flow. The prefabrication helps to reduce the construction time, more adaptable and easier maintain and repair. Bamboo poles are provided around the perimeter to support and stop the building from drifting away.
	Construction details:	The builiding is made of prefabricated components and rests on a floating foundation. Floor panels: 8 no.s screwd together. 1.2 m x 2.4 m. Plates are fixed on top. Wall panels: 8 no.s with dimensions 1.2 m x 2.2 m Plates are fixed to frames. Openings are constructed in similar way with shutters Roof panels: Rafters and battens are connected to make the frame, considering the openings. Insulation and roofsheets are connect to the frame.
	Floating foundation:	9 foundation modules of dimensions 2.5 m x 2.5 m It has wooden frame and has 16 recycled drums in one module which are connected together, as well connected to wooden trusses. The modules are connected together to form the floating platform. Steel bolts are used.

IMPRESSIONS

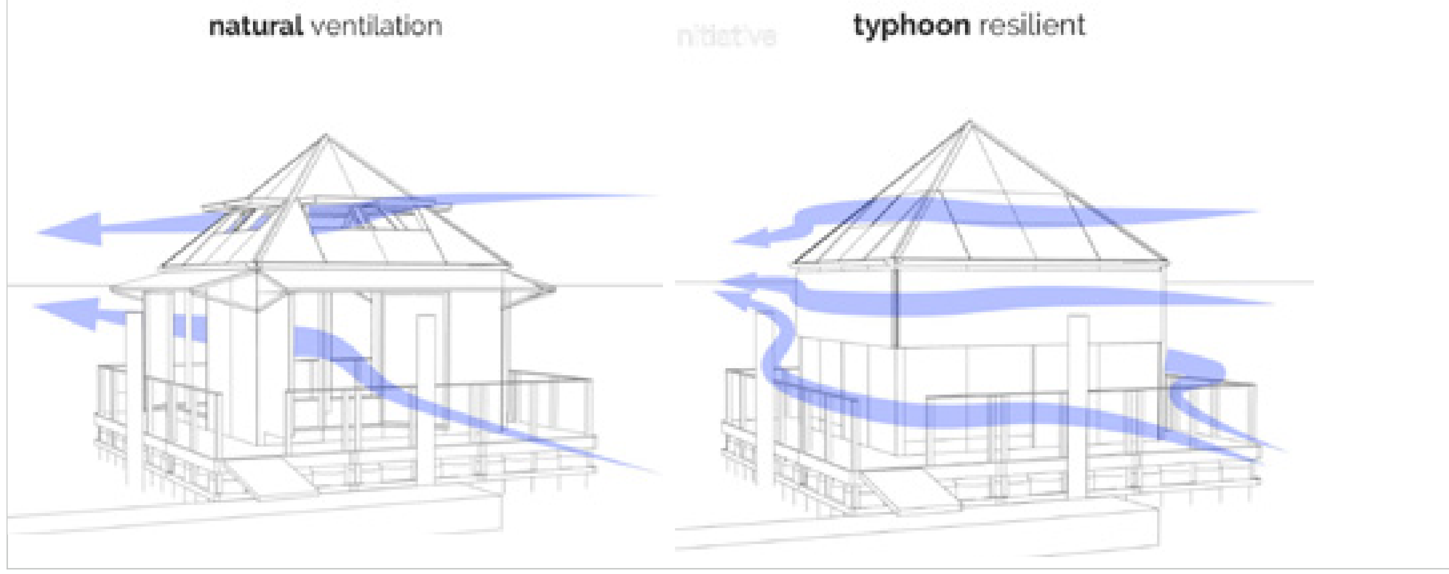


Figure x: Photo's of the construction of the FINCH and concepts of the building (Presentation Finch 2017)

A.2 Case study: Finch Floating Home

Interview with Joran van Schaik and Pieter Ham - About the construction proces of the finch floating home

Construction methods

Did you have any problems with assembling all the different prefabricated parts on-site?*Some of the parts had a small deflection, which caused the problem that some parts did not well fit together. These deflection were already in the parts when delivered on side. Also some beams where curved, bended and beams with same dimensions had a significant difference in weight. Some beams needed to be bended straight with the help of other beams tension. In front we shoudl have done a quality control on side at the local contractor and pick the materials by ourself. We could say as tip don't use beams with a signifanct length because how longer they are how more deflection they will have. During construction the walls were placed later causing the frame to stand allot bit under an angle.*

While you were, there, did you see any other options for the floating foundation instead of using barrels which you may reconsider for the next house? And thought of some ideas to reduce the number of barrels? *There were not many other options that had the some benefits as the barrels. The barrels cost 10 euro's a piece and have a quitte thick wall which shouls ensure they got a longer life span. And maybe the idea of a catamaran to reduce the amount of barrels so the design becomes more cost effective.*

Transportation

Where there any problems with transportation? Maybe because of the size of the prefabricated parts? *The foundation module was the toughest part to get on location. Also because of the size and the carrying into the water worked well with the help of 8 man in total.*

Costs

If the house has to be built again, what changes would you make regarding to save costs? *Configurations to let houses share the same platform in this way you can save on the barrels.*

Time

How long did it take to assemble them all on-site? *Due to the hot weather the efficiency was less so that did cost us time. Transportation from the truck to the site took some time and not everything was in hand reach which caused for situation that you had to wait for certain things.*

Did you have any delay because of some unforeseen problems which you can prevent for the next time? *Prepare the building site before you actually start building so everything goes more smooth.*

What are the working hours of the local construction workers? *4 workers on daily basis (8 hours)*

How big was the team you were working with? *Mainly 6, Pieter and Joran, Ricky the main constructor with 3 co workers. And sometimes people from the Netherlands came over to help us with building.*

Questionnaire with students of schools in and around Macabebe, Philippines for the design of the floating classroom.

TUDelft

Name (pangalan): .... Grade (grado): ....
Age (edad): .... School (paaralan) ....

Questionnaire (palatanungan)

1.) What do you think of the **temperature** in the classroom? *(Ano sa tingin mo ang temperatura sa silid-aralan?)*

Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
-3	-2	-1	0	+1	+2	+3
☐	☐	☐	☐	☐	☐	☐

2.) What do you think of the **light quality** in the classroom? *(Ano sa palagay mo ang kalidad ng ilaw na pumapasok sa silid-aralan?)*

Very low	Low	Neutral	High	Very high
-2	-1	0	+1	+2
☐	☐	☐	☐	☐

3.) Do you prefer **natural light** or **artificial light** inside the classroom? *(Mas gusto mo ba ang natural na ilaw o artipisyal na ilaw sa loob ng silid-aralan?)*

Natural light ☐ Artifcial light ☐

4.) Do you feel disturbed by **noises** from outside or other classes? *(Nararamdaman mo ba na nabalisa ka ng mga ingay mula sa labas o sa iba pang mga klase?)*

Very low	Low	Neutral	High	Very high
-2	-1	0	+1	+2
☐	☐	☐	☐	☐

5.) Do you prefer **windows open** or **airconditioning** inside the classroom? *(Mas gusto mo bang bukas ang mga bintana o air conditioning sa loob ng silid-aralan?)*

Windows open ☐ Airconditioning ☐

6.) Do you have enough **space** inside the classroom? *(Mayroon ka bang sapat na puwang sa loob ng silid-aralan?)*

Very low	Low	Neutral	High	Very high
-2	-1	0	+1	+2
☐	☐	☐	☐	☐

7.) What would you to like to improve about the classroom? *(Ano ang nais mong pagbutihin ang tungkol sa silid-aralan?)*

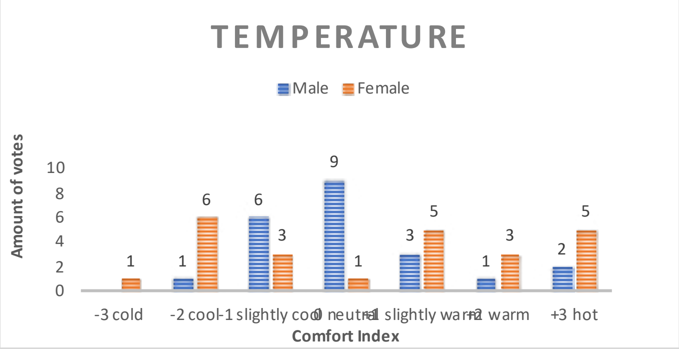
8.) What do you think is missing in the classroom? *(Ano sa palagay mo ang nawawala sa silid-aralan?)*

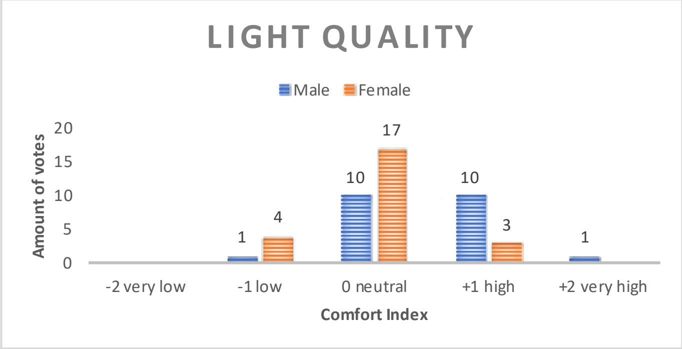
B.2 Results from questionnaires

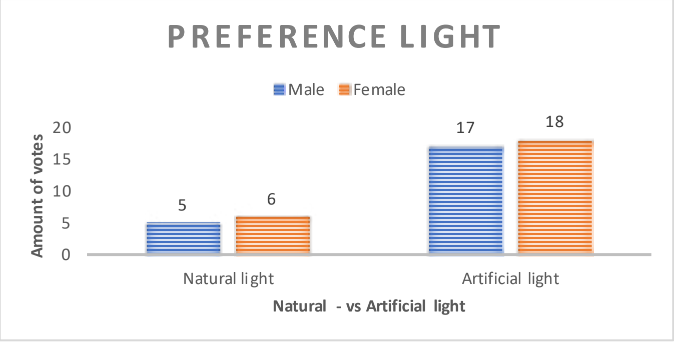
The tables below show the results of the interviews that were conducted at the different schools.

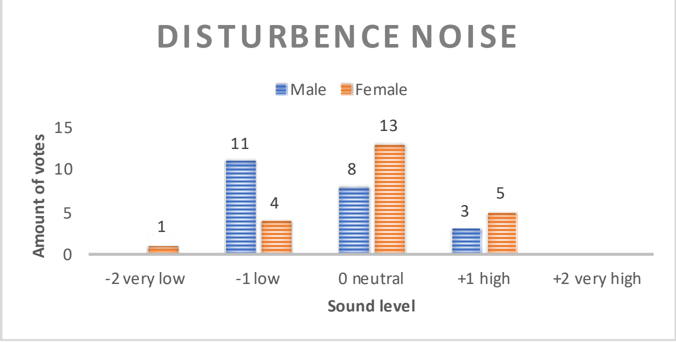
B.2.1 Collegio de San Lorenzo

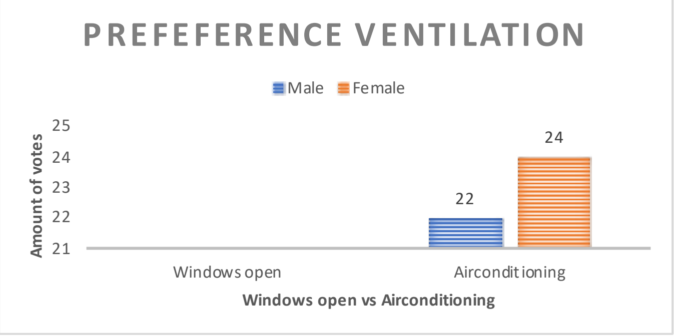
Grade 7 - 22 male and 24 female

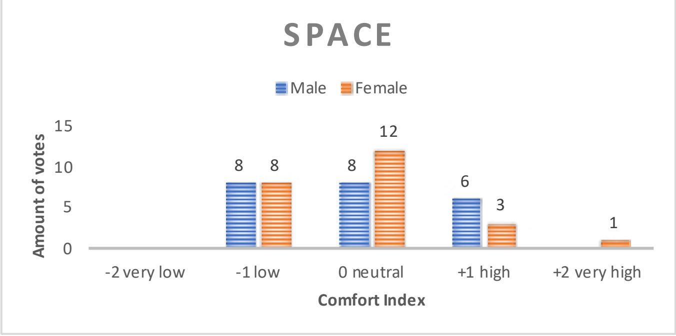






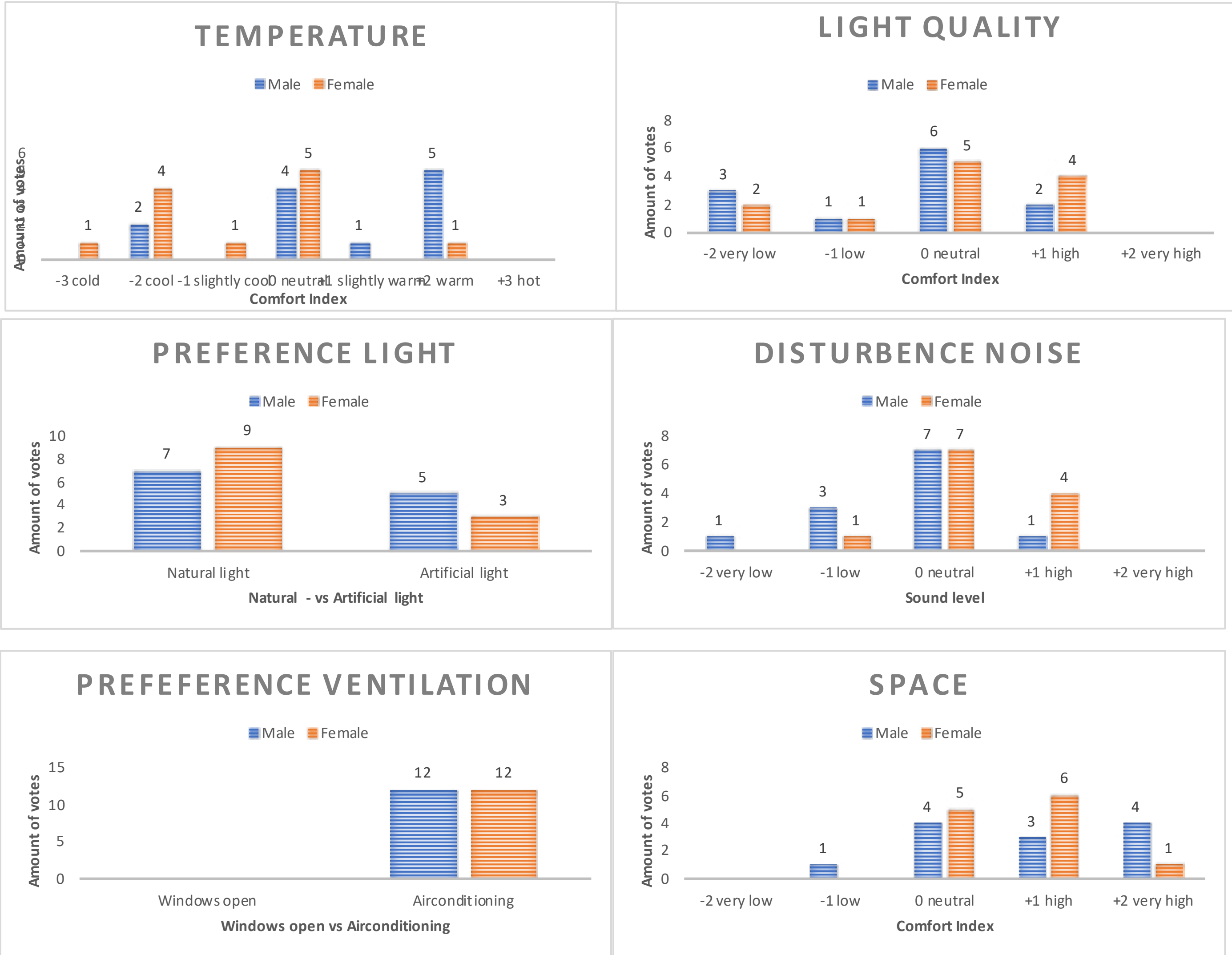


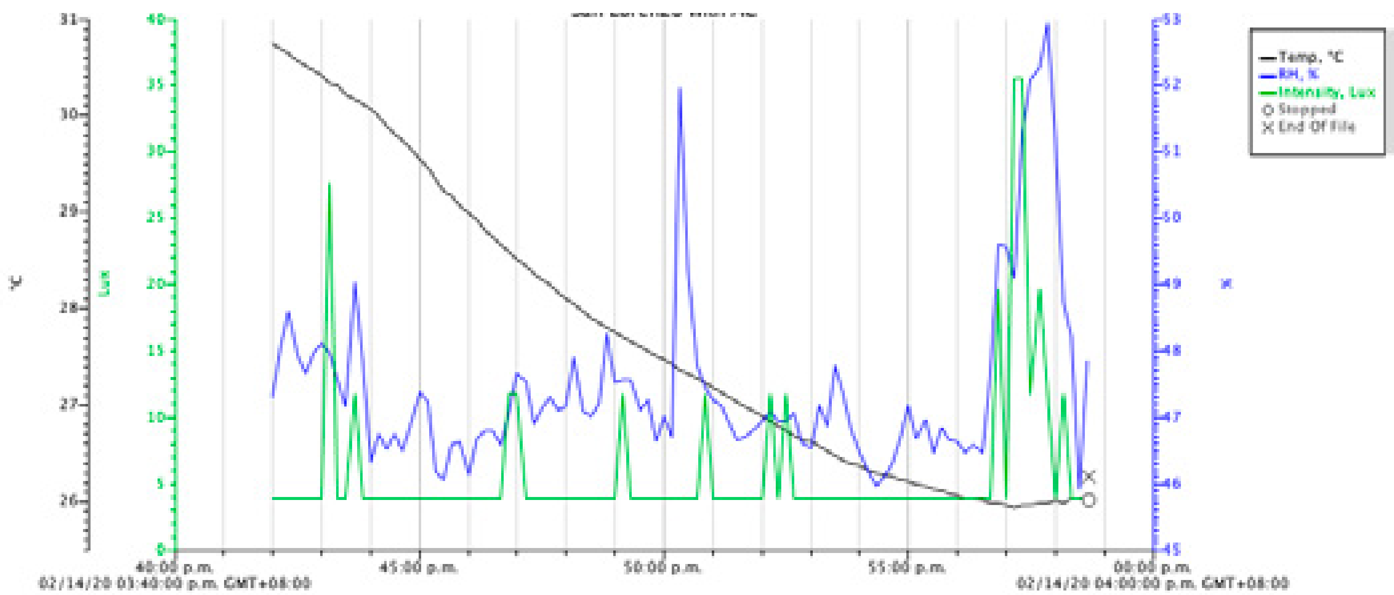




B.2.1 Collegio de San Lorenzo

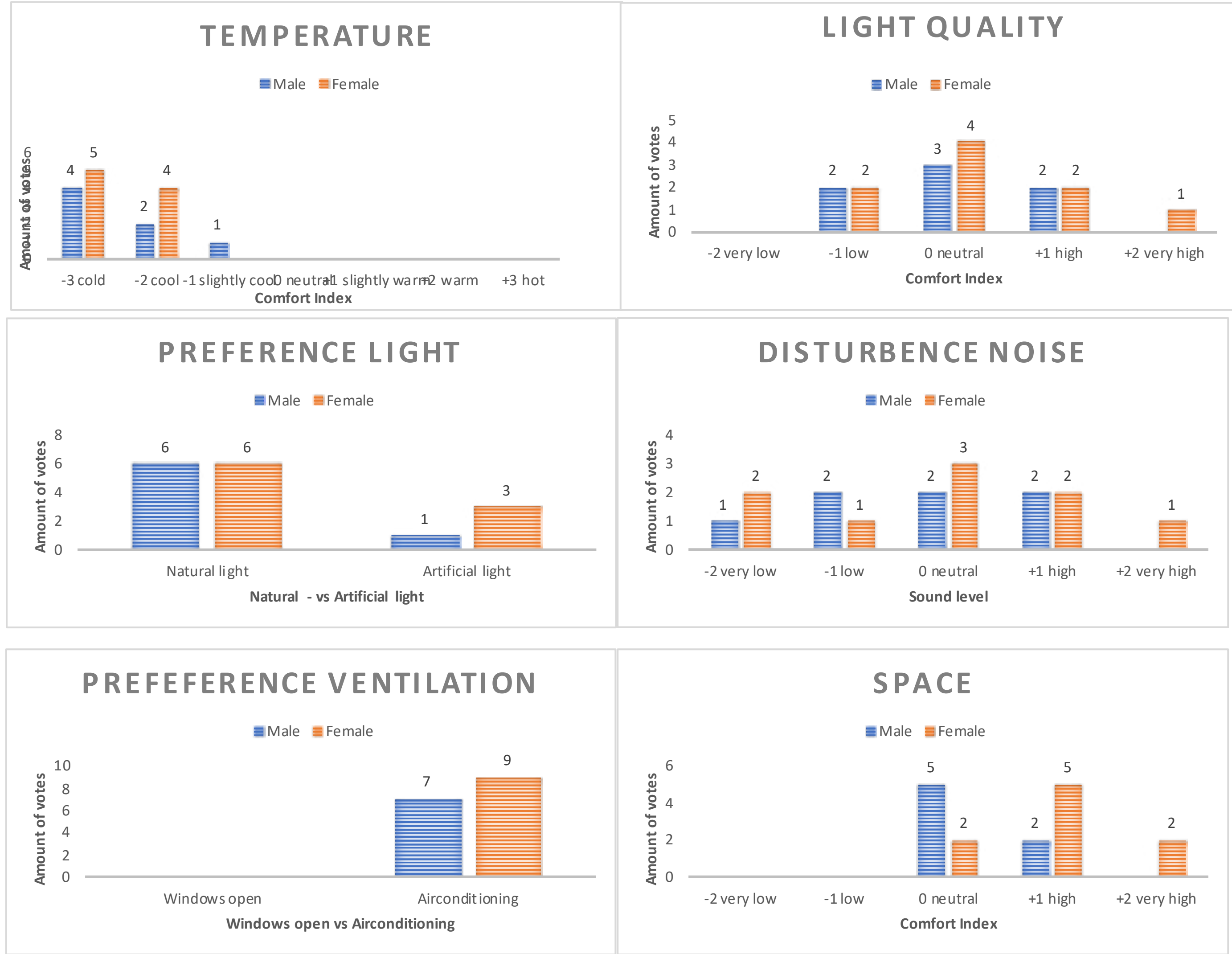
Grade 10 - 12 male and 12 female

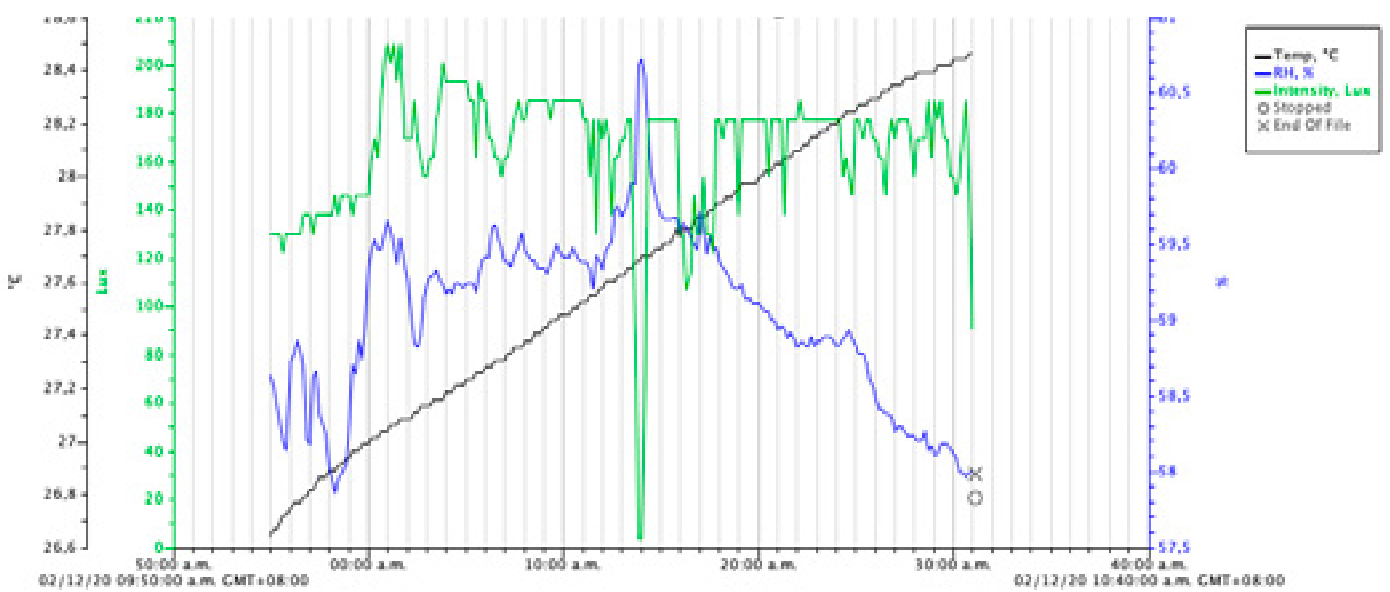




B.2.1 Collegio de San Lorenzo

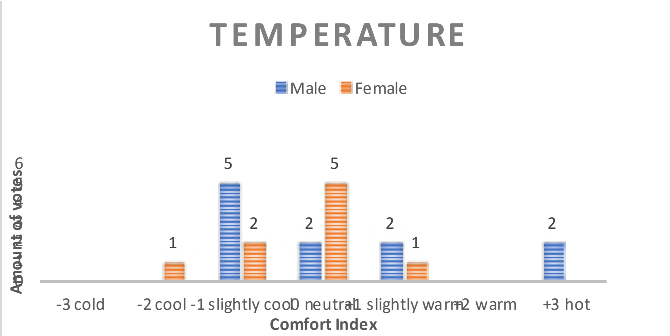
Grade 12 - 9 male and 9 female

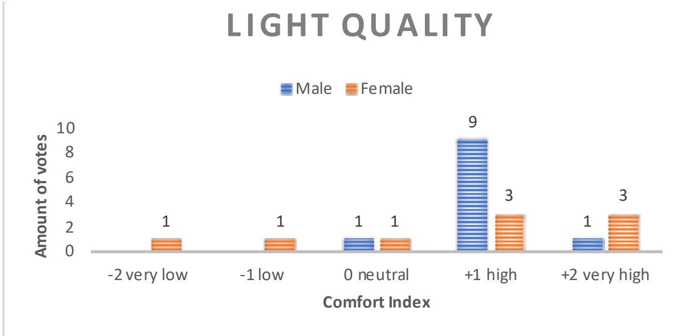


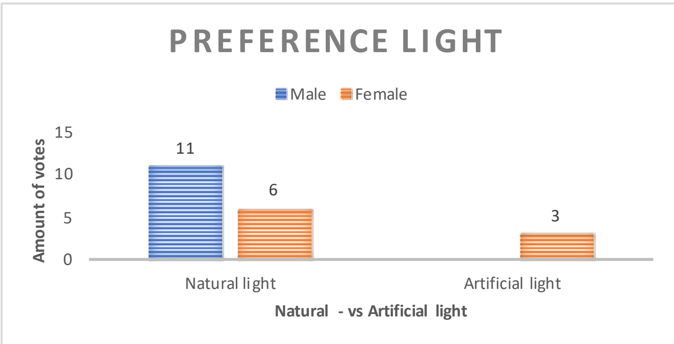


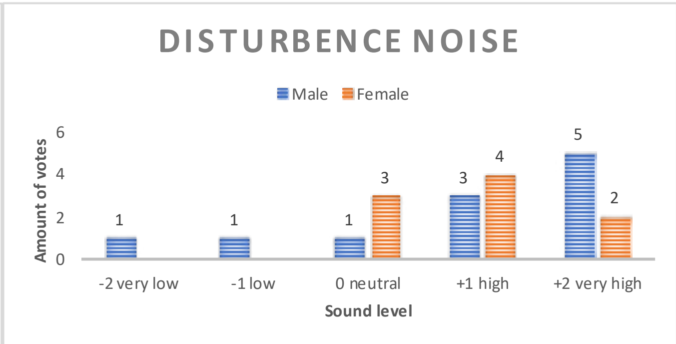
B.2.1 Macabebe High School

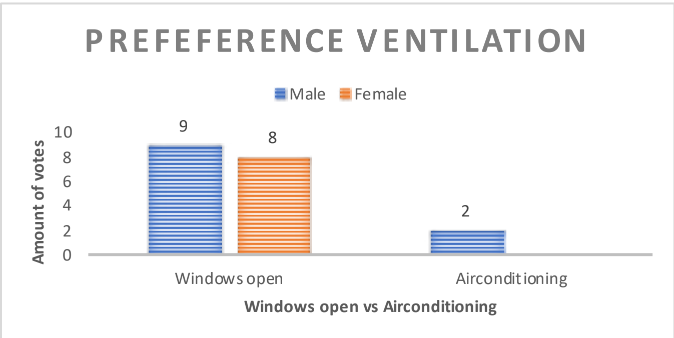
Grade 7 - 11 male and 9 female

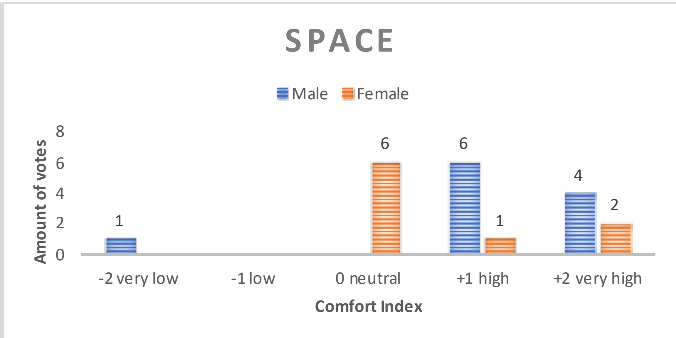


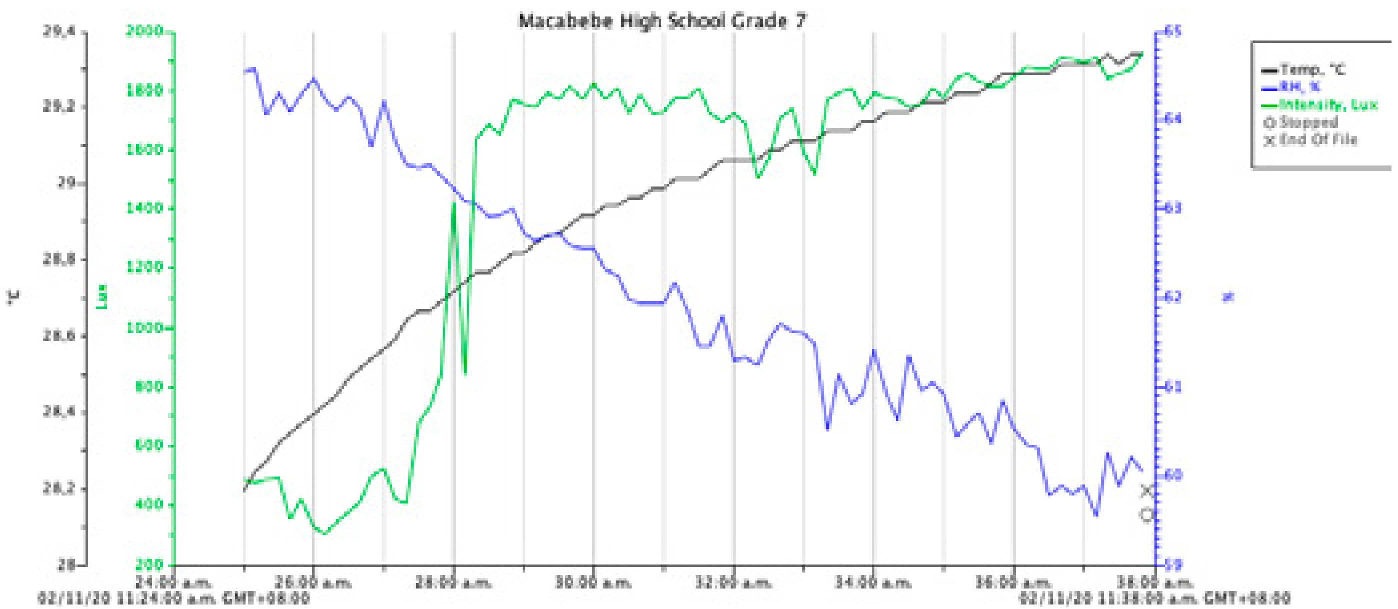






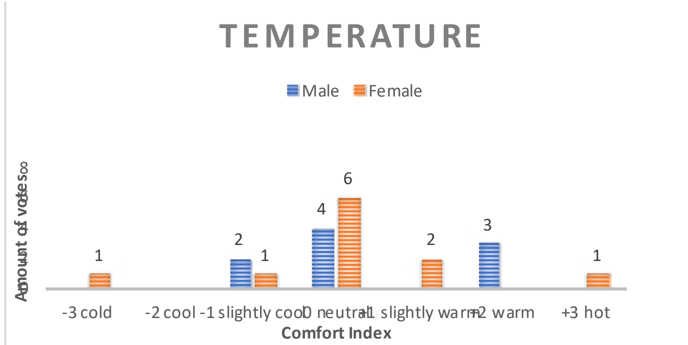


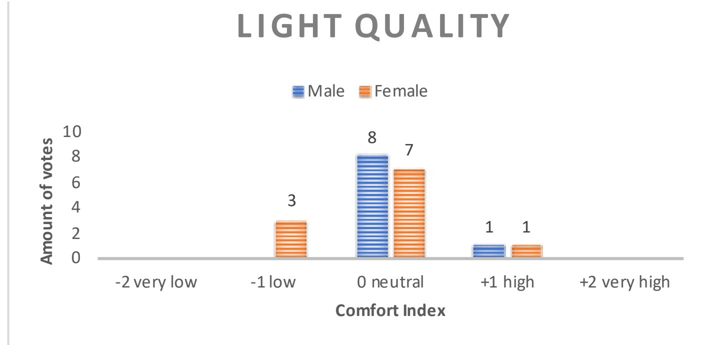


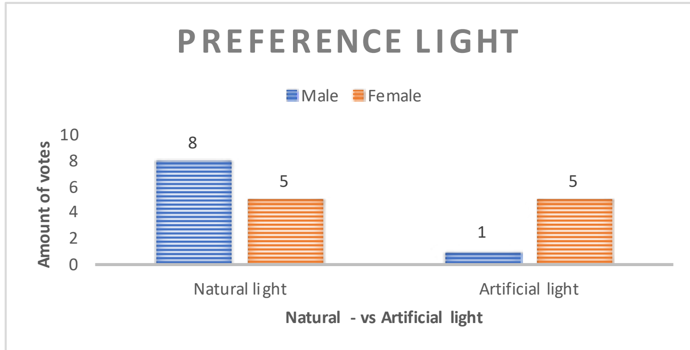


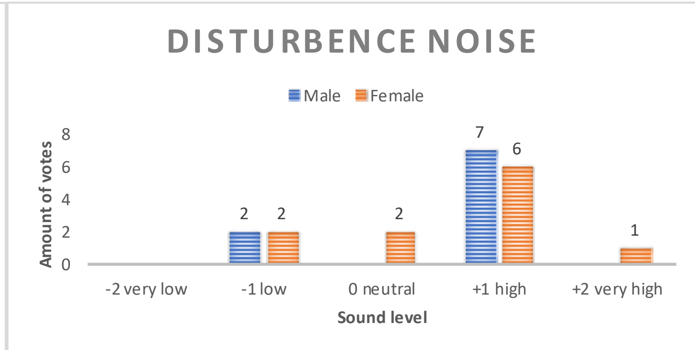
B.2.1 Macabebe High School

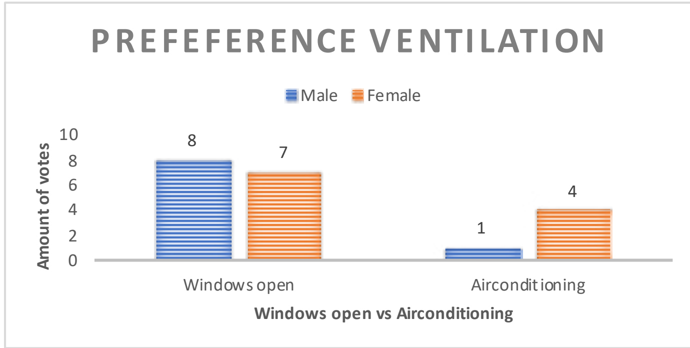
Grade 10 - 9 male and 10 female

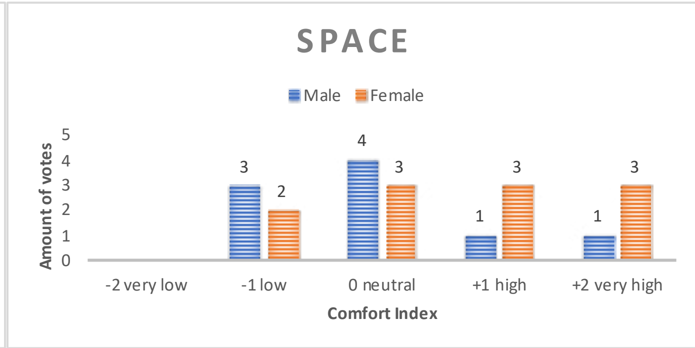


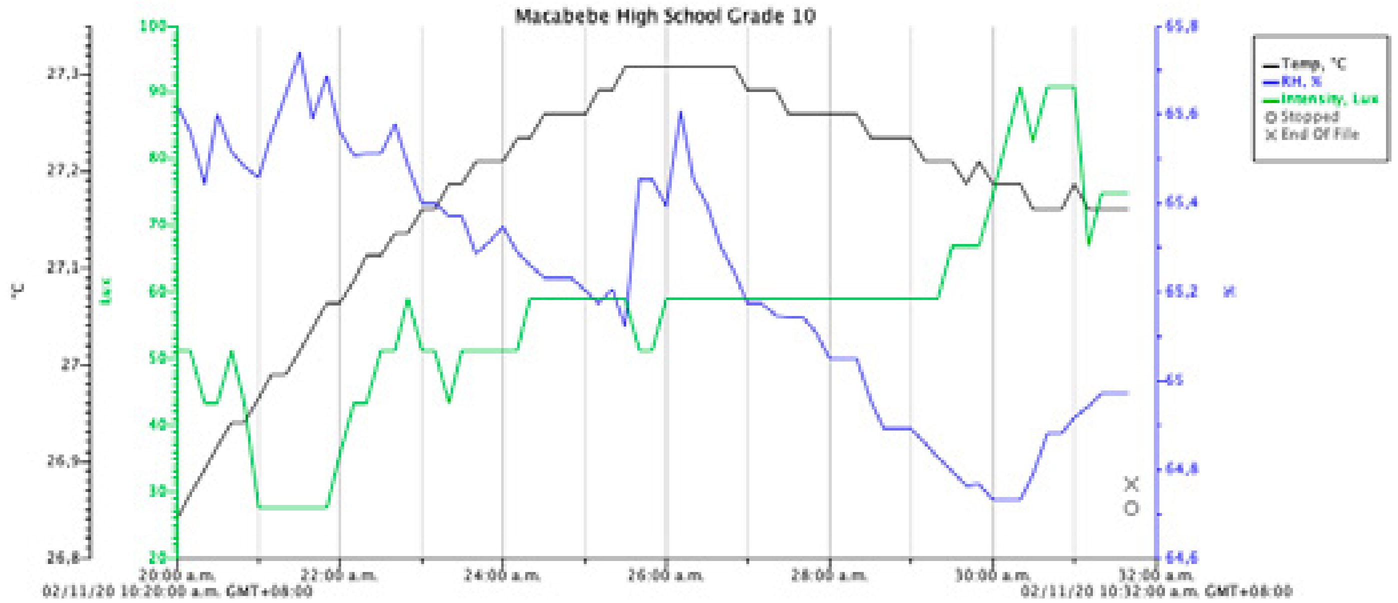






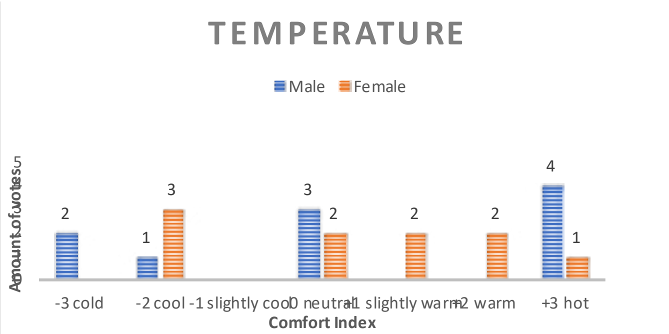


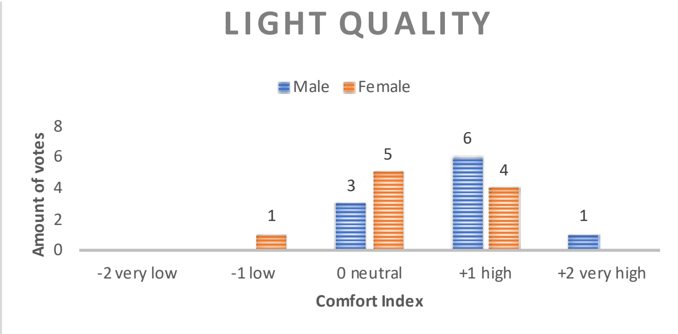


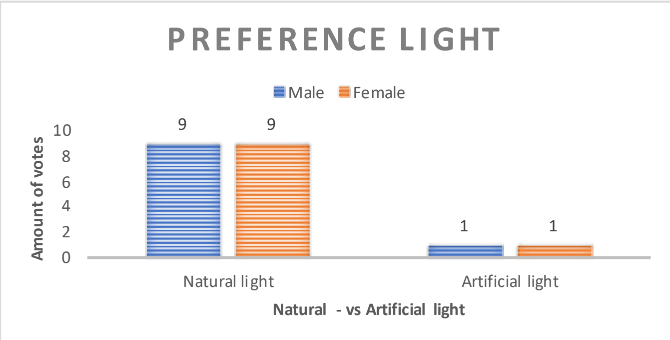


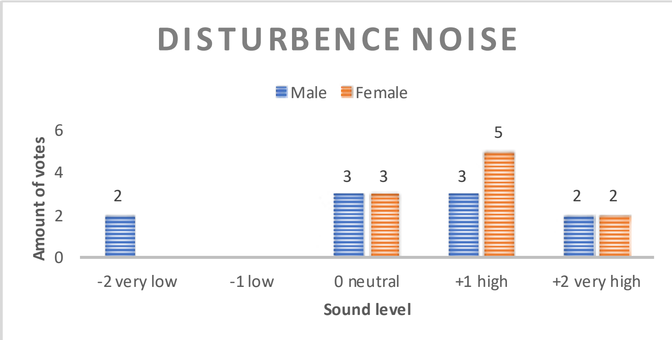
B.2.1 Macabebe High School

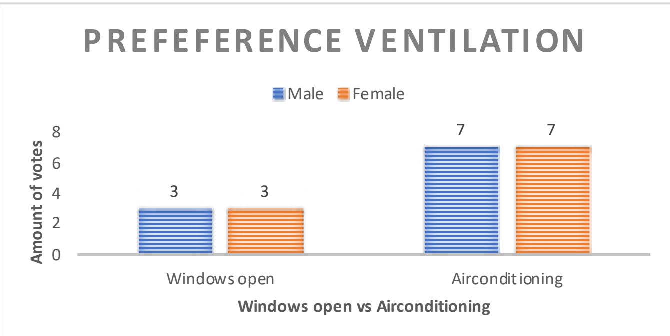
Grade 7 - 10 male and 10 female

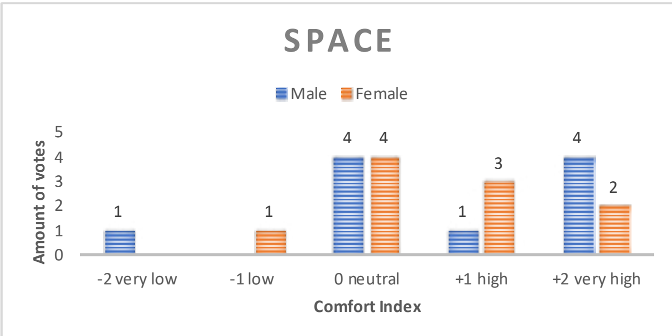


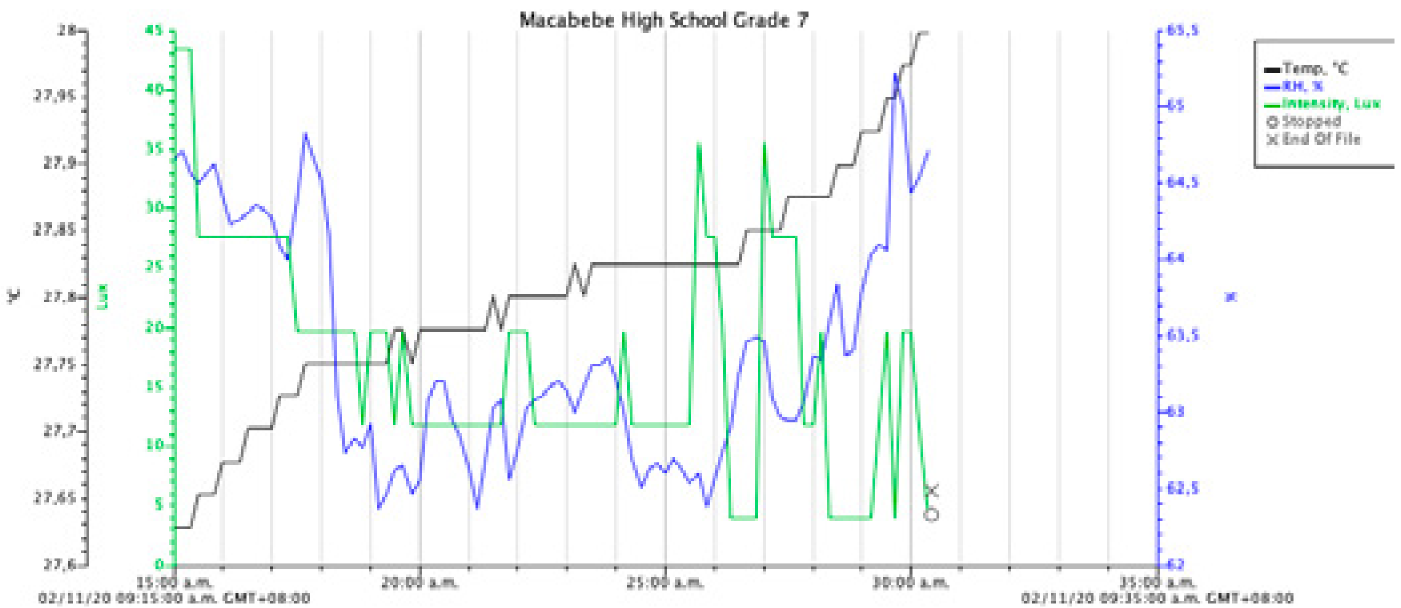






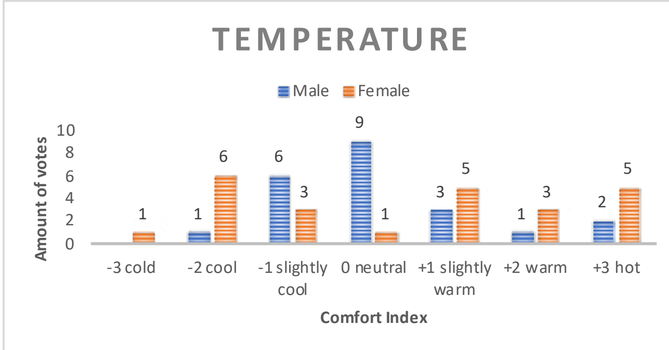


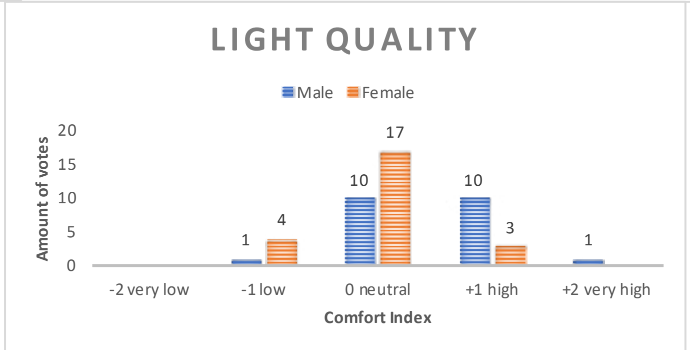


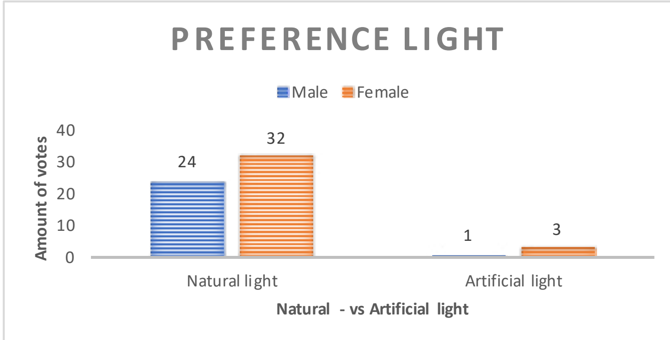


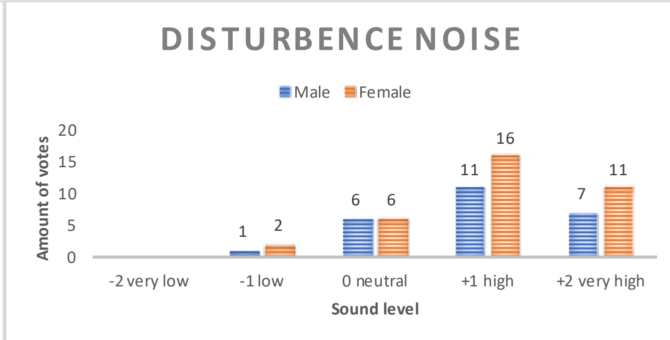
B.2.1 San Francisco San Vincente High School

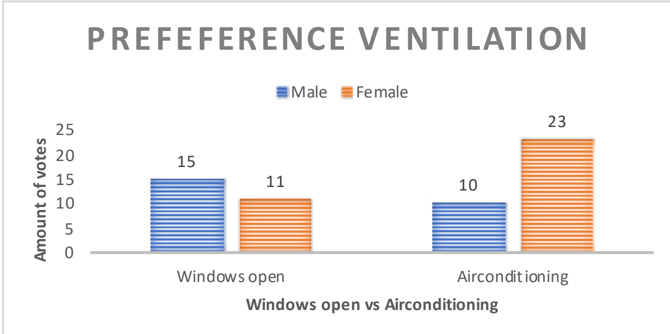
Grade 11 - 25 male and 35 female

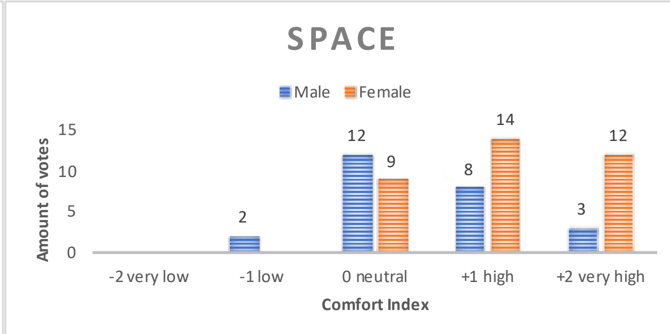


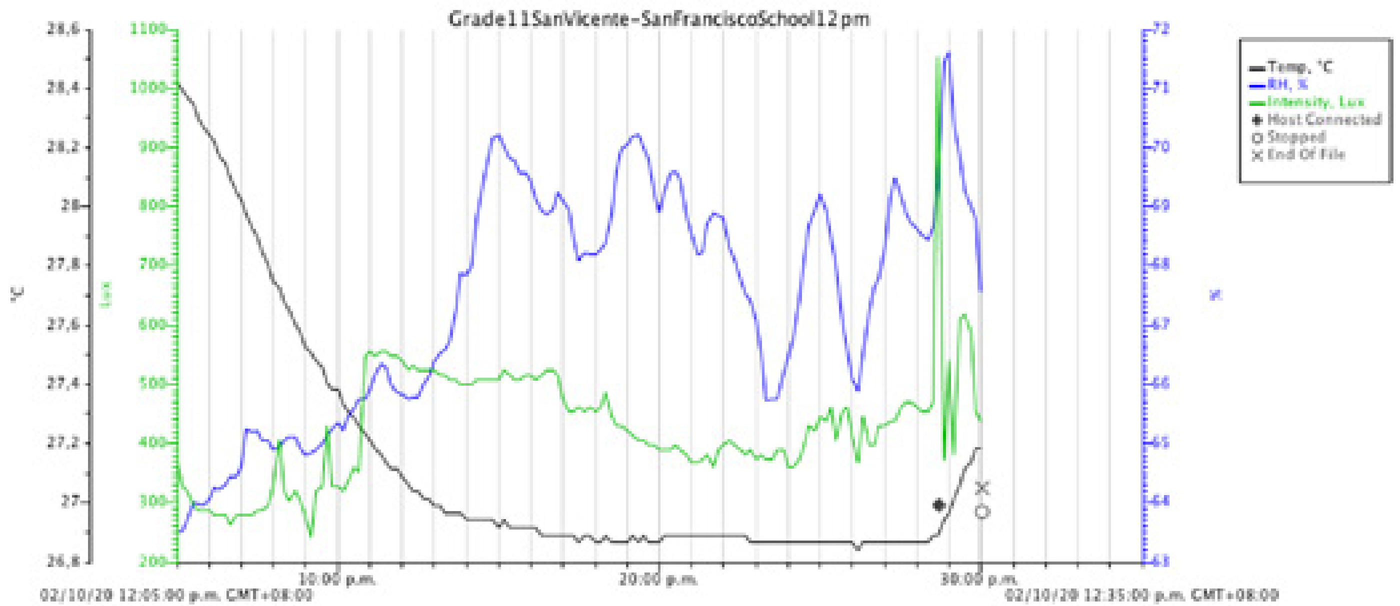












Interviews with teachers of schools in and around Macabebe, Philippines for the design of the floating classroom.

The purpose of this research project is to design a classroom that offers students living in a typhoon and flood sensitive area in South- East Asia, a safe learning environment. This research is conducted by Wietse de Haan at the Delft University of Technology.

Your participation contributes to the collection of information that contributes to the course of this research. The information collected will be kept confidential and will be used only for the research purpose.

The interviewed:
Name:
Age:
Grades in teaching: Grade 6 to 10 English

School building:
Name: SVSF High Shool

Theme: General

1. What are the current conditions of schools in Macabebe ? (continue questioning the given answer)
Floods for a month or two during the raining season, which leads to the suspension of classes. So If we would have classes that are elevated from the ground, this will help us against the suspension of classes. During last year we got two months of suspension of classes in total.

2. What are the greatest needs for schools (in general) in Macabebe and Philippines ? (continue questioning the given answer)
Elevated classrooms and proper water disposal systems, around the classrooms and the whole Macabebe.

3. Is the school building being used as another function besides an educational environment for students?
As far as I remember, we only use this building as a school building; maybe our covered court is being used for other functions.

Theme: School design

4. What aspects of your school building and classroom do you wish you could improve or need to be improved?
From my point of view, I want better ventilation of the classrooms; we only use electrical vans now. I prefer the building to be naturally ventilated, but we cannot have the natural air, especially during summer from March we have hot temperatures and not any more wind. The buildings around it do not block the wind, but during summertime, we do not have wind anymore.

5. What aspects of your school building works well to facilitate learning ?
Our new classrooms now work well for learning because they're wider and safer for students. More spacious. What could be better is more chairs for students who are left-handed most of the chair+table combination are for right-handed students.

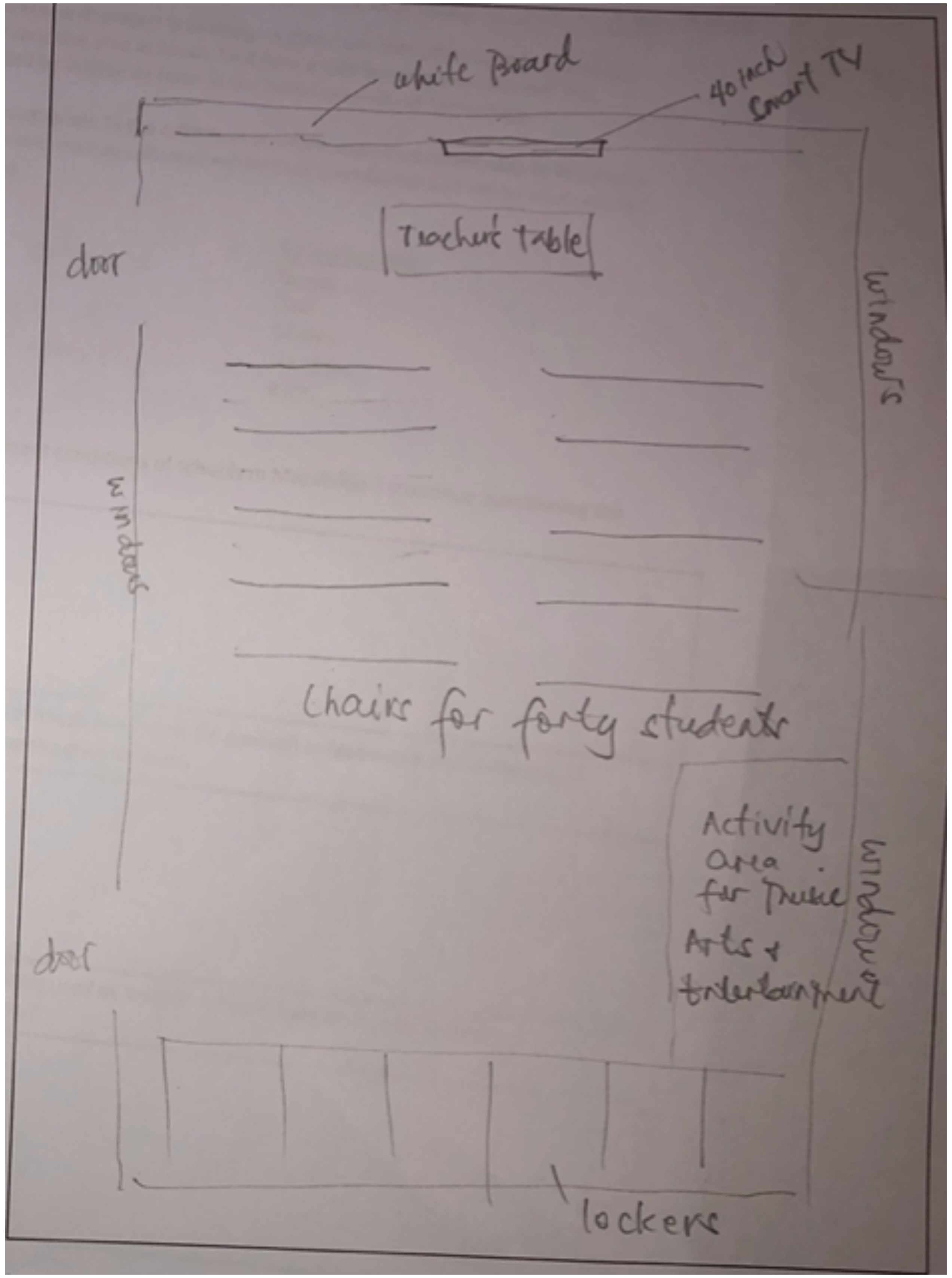
6. How many students are there in a classroom?
The most is 39, and the least is 32 only for this year, in the past, we had 70 students and one time I even had 100 students. They were sitting on the floors for two weeks, and then they were distributed to other schools.

7. Is the current classroom able to accommodate this number of students?
This is fine because now we have a limited amount of students because there are many schools in this area, unlike in the past when there were fewer schools around Macabebe. The most amount of students we have now is 50.

8. For what kind of activities do you use the classroom besides teaching, such as group activities and how important do you think this flexibility is?
We have discussions sessions were we talk about our problems and solutions for those problems with the students. One time I had a demonstration and moved all the chairs aside, so the middle part was free, which the students really liked.

9. What different kind of areas would you like to create in a classroom? (area with couches, area for exercises etc…)
We had a program of that in which in a classroom each corner had another function, like for example on was with sports equipment, one for music, writing, reading but we cannot have that in our school right now because of lack of finance. Cause it will cost if every classroom, for example, has one set of instruments but if we do have the finance the fond this kind of ideas it would be nice. Thirty-six classrooms in the school right now.

10. What is the best way to furnish a classroom according to your believes and what equipment should be available (like a sink, shelve, etc…) (room for a sketch if he or she is open for that idea)



11. How do you experience that the colours in the classroom are affecting the students ? What colours do you think are the best for stimulating the children?
We cannot change the colours of the classroom because the DepEd specifies that. If you ask me for another colour, different tints will affect students. It will affect the children if there are a variety of colours, especially the younger ones.

12. Are there any windows towards the corridor ? What you do you think about that? And why?
Yes, but I put curtains because it is distracting. And I also put the curtains because sometimes it is hot because the sun gets in and also to keep it more private.

13. How big is the need for any independent study places, in your opinion? If yes should this be inside the classroom or outside?
In my classroom, I don't have difficulties with students creating their own space; they can even lay down because there is space enough. But in other classrooms with less space, this can become a bigger issue.

14. What do you think should be provided in a schoolyard? (playground, vegetation, sport activities etc..) And why?
We have our playground, which is only our covered court which is mended for our sports activities. We also have our different gardens like the science garden, math garden there are some chairs there so then can study.

15. What do you think about contact between the classrooms and the outdoor environment ? Why?
Green is good for the students and also not close to the road cause it can lead to distractions.

16. What is your opinion about a flexible place to be able to give classes outside?
In my class, there are some activities which we are doing outside to observe nature and everything. I Show theme through our window or from our terrace, but we do not go out. We have one covered place outside which we use for our performances.

Theme: Indoor comfort

17. What do you think about your working environment considering the temperature and humidity ? And how do you think this affects the students?
In my classroom, it's okay because we have at least six working electric vans and at the same time it is very cool because it is in the first floor, but in our classrooms, it is very hot mostly because of the size. And most of my classes are during the afternoon, and it's very hot at that time. Even with the use of the vans, it is still hot because there is direct light from the sunlight in the classroom. And the curtains are very thin, so they don't work very well.

18. How does your school address to this in terms of shading devices and ventilation?
I would like to have longer curtains so they will be abstracting the sunlight and the glare.

19. What do you think about the working environment considering the quality of air? And how do you think this affects the students?
Honestly speaking fresh air we cannot have it because there is still floodwater from our backyard which gives some smell. So after the flood goes away some classrooms still keep the smell of the floodwater.

20. Do you think there is enough natural light in the classroom ? Do you think it's important to have natural light in the classroom? Why? Do you prefer it above artificial light?
Our classrooms have eight fluorescent bulbs. (tl light) But if we need some extra light, we will open up our curtains. I prefer natural light.

21. How do you consider the noise level inside the classroom ?
Inside, according to English teachers if there is no noise during your classroom there is no learning. We have the allowable noises level. And noises from outside we don't like it so what we do is we close our windows.

22. (if the noise level is considered high) What effect does this have on the learning environment?
If it's noisy learning will become less effective. So it is much better to become hot instead of hearing the noises outside (effect of closing the windows)

23. Are there any strategies or measures being used to reduce this noise level?
We don't have something like that.

Theme: Floodings

24. How does your school respond in the occasion of floodings?
Answered in the first part.

25. What are the most significant problems that occur with the classrooms and the school building during a flood?
Answered in the first part.

26. Have adjustments been made to the building against the floods?
Answered in the first part.

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