Roof Truss Construction in Lwengo Basilla

A minor field study with focus on constructing and calculating required dimensions of roof trusses on a school in Democratic Republic of Congo

Byggnation av takstolar Lwengo Basilla

Tillverkning och beräkning av erforderliga dimensioner på takstolar för att uppnå en jämn och säker byggprocess i Demokratiska Republiken av Kongo

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The MFS Scholarship Programme offers Swedish university students an opportunity to carry out two months’ field work, usually the student’s final degree project, in a country in Africa, Asia or Latin America. The results of the work are presented in an MFS report which is also the student’s Bachelor or Master of Science Thesis. Minor Field Studies are primarily conducted within subject areas of importance from a development perspective and in a country where Swedish international cooperation is ongoing.

The main purpose of the MFS Programme is to enhance Swedish university students’ knowledge and understanding of these countries and their problems and opportunities. MFS should provide the student with initial experience of conditions in such a country. The overall goals are to widen the Swedish human resources cadre for engagement in international development cooperation as well as to promote scientific exchange between universities, research institutes and similar authorities as well as NGOs in developing countries and in Sweden.

The International Relations Office at KTH the Royal Institute of Technology, Stockholm, Sweden, administers the MFS Programme within engineering and applied natural sciences.

Erika Svensson
Programme Officer
MFS Programme, KTH International Relations Office
Abstract

This report is a part of a thesis in the department of “Construction engineering and Design” with specialization in “house building, planning and construction” at the Royal Institute of Technology in Stockholm, Sweden.

The report is about the construction of a roof for a school building in the village of Lwengo Basilla located in south eastern parts of Democratic Republic of Congo. The school project is funded by a non-profit organization in Sweden named “Elikia na Biso” headed by Miza Landström. The design and construction of the school has been put forth with the help of students from different departments of the Royal Institute of Technology (KTH). A group of students from KTH helped to lay the foundation and the walls of the school. The next group of students was sent to help with the construction of the school roof.

The focus of this report is to dimension and construct the roof of the school using local materials in an efficient way. The steps of constructing a mitre box (precision box), the sawing and nailing of the roof truss, and raising the roof trusses into place are all described in detail.

The timber used for the roof trusses was much more durable than what was expected, this ensures the stability and safety of the roof. The roof of the first school was finished, and the workers will build the roof of the second school by themselves with the experience they gained during the construction of the first school.

Key words:
- Roof truss
- Lwengo Basilla
- School construction
- Fink truss
- Eurocode
- Loads
- Wind loads
- Chords
- load combinations
Sammanfattning


Nyckelord:

- Takstol
- Lwengo Basilla
- Skolbyggnation
- Fackverkstakstol
- Laster
- Vindlaster
- Över ram
- Under ram
- Lastkombinationer
Preface

I never thought that I would be going to a village in the middle of Africa to work on my thesis when I first started at KTH. To live in the village of Lwengo Basilla for seven weeks was a once in a life time experience filled with unforgettable memories.

I want to thank all the people who helped me through this project, starting with Erika Svensson at MFS who manages the applications. Erika helped me with the difficult application process, and also introduced me to Carl Michael Johannesson who was in charge of recruiting students to the school project in Lwengo Basilla.

I also want to thank Miza Landström and “Elikia na Biso” for letting us take part in the project. I hope that her will and enthusiasm for creating a better world will grow even stronger with time.

Thanks to those who were involved in the project before us and were willing to share their information and experience with us. (Emma and Joel’s group as well as Alexander and Bashiri’s group).

The employees at Sodeico, especially Primé, in Kinshasa were very helpful with our transport and hospital visit, thanks to them.

Thanks to Jenny and Sven-Henrik for going out of their ordinary routines in order to help us take part in this unique project.

Thanks to Daniel and Arvid who helped me with the difficult decisions that had to be made during the construction, and made the whole trip more fun.

I want to thank my dear friend, Banoo Heewa, for revising this thesis several times.

Last, but not least, I want to thank my parents and my sister, Zhala, for always supporting me and my decisions.
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1. Introduction

Some sections of this thesis were written together with Arvid Nystedt and Daniel Hällqvist, authors of the report “Roof construction in Lwengo Basilla; A minor field study with focus on the attachment, columns and battens on a school in Democratic Republic of Congo”, because both reports are about the construction of different parts of the same roof in the village Lwengo Basilla.

1.1 Background

Democratic Republic Congo (DRC) is one of the poorest countries in the world and has constantly been in the bottom of UNDP list where income, health, and education is measured (UNDP, 2011). A big step to get out of poverty is to step into education. It is therefore important for all children to have the right and opportunity to go to school and get a proper education.

Miza Landstöm, who is the daughter of Rigobert Moupondo (the tribe leader in Lwengo Basilla), started a non-profit organization by the name "Elikia na biso." This organization was formed in order to collect funds in charity events to support a home for disabled children in Kinshasa, DRC. As time went by and the donations increased, Miza decided that some of the donations should be invested in the construction of a school in Lwengo Basilla, her home village. This village ( S 05.171494° E 018.625687° ) is located in the region Menikongo, 35 kilometers southwest of Kikwit. It is one of the thirteen villages around the area.

The buildings in Lwengo Basilla are often built with bamboo or wooden sticks which are then covered with clay. This is a very easy and cheap way of building houses, but the problem is that the walls need to be rebuilt every two years (Elofson, Persson, 2013), which is costly and time consuming. Some of the houses which belong to the "well-doers" of the village are made from locally manufactured bricks and thin brittle metal sheet roofs. These brick houses are more sustainable but much more expensive to build.

In 2013, Miza came in contact with Senior lecture, Carl-Michael Johanneson, from the Royal Institute of Technology (KTH) and started discussing the possibility of including KTH with the school project. In order to get financial support for the students from KTH who were going to get involved in the school project, they had to rely on Swedish aid work. Sweden sets aside a sum of its annual budget for aid work...
in the less developed countries around the world; some of this budget goes to Minor Field Studies (MFS). MFS gives their share of the budget, as scholarships, to students who are willing to travel to less developed countries and write their thesis on subjects similar to their field of study. The school project in Lwengo Basilla has been successful, partly because of MFS’ indirect investments. A large number of the students who have taken part in the school project received their scholarships through MFS.

In July 2013, two of Michael's students wrote a field study in DR Congo about the country’s school system and the feasibility of building two school buildings in Lwengo Basilla. This field study also included gathering information about local construction materials, the building site, and the knowledge in building constructions among the villagers (Elofsson, Persson, 2013). As a result of the study of materials, two simple clay press machines were bought to produce clay bricks for the walls. The villagers were also taught how to use these machines so that they would be able to produce their own bricks for the walls.

This was the basis for a group of Master students, Bashiri, Ekdahl, Egstam, Grimfeldt and Möllersted (2013) studying Industrial Design at KTH, who wrote a report on how to build a school with the report from Elofsson and Persson as a starting point. A number of requirements such as: the roof should be built with wood preservation timber, the walls must be built with tiles, and the school must be designed to resist the rainfall in the area (Bashiri et al, 2013), were set up for the schools.

The report from the group of Master students was written on the basis that a container with wood preservation timber was supposed to be shipped from Sweden sponsored by Svenska Träskyddsföreningen and it was presented with working process and blueprints for the buildings (Bashiri et al, 2013).

Later on, as the project progressed, it was decided that the timber would be bought locally because the transportation costs were too high and it would be easier to teach out the use of local materials to the natives rather than the timber imported from Sweden.
1.2 Purpose

There are a couple of purposes why I’m taking part in this project. Our group will start with teaching the people a more efficient way of constructing schools that are safe and sustainable for a longer period of time by using local materials. The loads and dimensions of the roof trusses will be calculated in detail from a technical point of view. This thesis will also contain the layout of the roof trusses of the school in comparison to the roof trusses of some of the other buildings in the area in order to visualize the safety precautions taken during the construction of the school in Lwengo Basilla. There will be some information about why that exact type of roof truss was chosen for the school. An inspection of the first school building will be performed in order to improve the second school building. The greater purpose of this project is to increase the availability of education in the area of Lwengo Basilla, which will increase the self-dependency of the people in the future.

1.3 Objectives

One major objective that I will consider during all the phases of this project will be the effective use of materials considering the budget limitations of this project. A smart and effective solution will be taken forth during the construction process, with the help of my colleagues at the site, when problems occur. It will be explained in the report on what basis choices were made for the different parts of the project.

- Mitre box: I will focus on accomplishing the construction of the mitre box at first hand. A mitre box helps to cut precise angles of the roof truss. Once the mitre box is finished, we will be able to put together the roof trusses in exact angles.
- Roof trusses: Once the parts of the roof truss are cut out with exact dimensions and angles, the parts will be nailed together and form the roof truss.
- Raising the roof trusses: Once the roof trusses are raised on top of the wall, my colleagues will take over and attach the truss to the wall.
1.4 Method

1.4.1 Prior to the field trip

Prior to the field trip, a literature study will be performed to gather information about building techniques and materials that are available. All the loads that affect the roof will be calculated in order to provide a stable and solid roof. A quantity survey for the materials will be calculated so that the materials arrive at the construction site by the time of our arrival in order for us to start as soon as possible. A model of the mitre box, which will be used to get precise angles on each roof truss, will be drawn. A small 3D-model of the roof truss and the mitre box in a 1:200 scale will be cut out from a Styrofoam board in order to provide a wider point of view for the workers that will help us during the construction. This mitre box will also be built to scale at the site so it can be used as an accurate template for the school roof. A certain type of roof truss has been chosen for calculations from the book, “Trätakstolar till bostadshus,” (1972) by Wale and Jakobsson. An older version of the book has been chosen because they use wood plates in the joints instead of the more modern steel plates.

1.4.2 During the field trip

As the group of students arrives in Lwengo Basilla, the students will have an information meeting in which they will be explaining the procedures. The work will begin with the construction of the mitre boxes. It is important that the workers understand and learn the details of the work they do in order for them to use the experience they gain for future projects in their area. The building techniques will be taught through translators, sketches, and body language. There will also be a literature study on the effects of humidity on timber and the types of problems that might occur. A simple stress test of the acquired timber will be performed in the field once the timber arrives.
1.5 Limitations

The project is limited to the first school building so that the workers can build the second building with the experience they gain from the first building.

Another group will specify the layout of the roof battens and the attachment brackets, while this report will concentrate only on the roof trusses.
2. Current setting and situation

The village of Lwengo Basilla has a population of over 500 people. Most of the people live in small clay houses with roof made out of banana leaves. The people of the village spend their days with cultivating their crop fields. The construction site where the school project is located is adjacent to the village of Lwengo Basilla.

Since the circumstances of this project are very different from a building project in Sweden, we’ll have to be flexible with our ideas and find effective solutions to the problems we might encounter. For example, the lack of electricity will force us to work with simple tools which will reduce our pace of production. The lack of sufficient internet and books will limit our sources.

The limited budget for the project forces us to be resourceful with the usage of the materials during production. Since we don’t have any information on the quality of the local products used for the roof, we will assume that the materials have the lowest quality during our calculations. The population doesn’t generally speak any English, which means that we will encounter difficulties during translation.

The building site is in a remote area and lacks paved roads. This slows down the transport of materials. There are always plenty of workers that want to help with the construction of the school. Some are transporting rocks to the construction site so that another group of workers can crush the rocks into smaller sizes so they can be used for mixing concrete. Some of the workers are laying the bricks in order to finish the walls and some workers are assisting with the construction of the roof trusses.
3. Theoretical Framework

3.1 Types of roofs

Generally, there are four types of roofs that can be taken into consideration when constructing a building. The four types are Monopitched, Duopitched, Hipped, and Mansard roof.

3.1.1 Monopitched roof

Monopitched roofs are widely used on narrow houses, and are getting more popular on newly constructed buildings. Usually, the monopitched roof has a small slope. (Sandin, 2010, page 76)

![Figure 3.1 - Section of a monopitched roof by Shwan Delshad Raouf](image)

3.1.2 Duopitched roof

The most common roof type is the duopitched roof, because it has been used and perfected for centuries. The roof's simple and flexible construction is the reason why it can be found all over the world.

![Figure 3.2 – Section of a duopitched roof by Shwan Delshad Raouf](image)
3.2.3 Hipped roof

The hipped roof is very similar to the pitched roof. The only difference is that the gables are also sloped. The sloped gables are purely for aesthetic and architectural reasons rather than for practical ones. (Sandin, 2010, page 75)

![Figure 3.3 – plan view of a hipped roof by Shwan Delshad Raouf](image1)

3.2.4 Mansard roof

The Mansard roof type consists of two slopes on each side of the ridge. The first slope, which extends from the wall, is very steep, while the second slope, which reaches the ridge, is very shallow. The Mansard roof is very practical if there is a need for furnishing and extra floor level. (Schunck et al. 2003. p 107)

![Figure 3.4 – section of a mansard roof by Shwan Delshad Raouf](image2)
3.2.5 Roofs categorized by their slopes

The types of roofs can also be categorized according to their slopes; steep, shallow, and flatbed roofs. A roof with a slope larger than 14° (1:4) is categorized as a steep roof. One of the advantages of a steep roof is that water and snow run off easily. This makes the roof less vulnerable to water damages. The steep roof gives another advantage of installing roof tiles, because the water runs off instead of penetrating the tiles, which otherwise could also result in water damages. (Sandin, 2010, page 75)

Any roof with a slope between 4° (1:16) and 14° (1:4) is called a shallow roof. The shallow roof must have a higher resistance against water penetration since the water doesn't run off as fast as it does on a steep roof. (Sandin, 2010, page 75-76)

A flatbed roof can also be called a terrace roof because it has a slope of less than 4° (1:16). The roof has to be completely waterproof since water can become stationary on the roof and create high pressure on the top of the roof resulting in water damages. (Sandin, 2010, page 75-76)
3.2 Types of roof trusses

The purpose of a roof truss is to transfer the loads affecting the roof to the walls. There are three general types of roof trusses that are commonly used: Collar, Purlin, and Fink truss.

3.2.1 Collar roof truss

The Collar is generally used in smaller houses with a span between 6-12 meters. The steep slope of the Collar truss allows the highest floor level to be furnished. The spacing between the centers of two Collar trusses (spacing), is usually 1.2 meters. The Collar truss is self-supporting, but there is also an older version of the Collar truss called the Swedish truss, which is not self-supporting. (Schunck et al. 2003. p 62-64, Sandin page 78)

Figure 3.5 - section of a collar roof truss by Shwan Delshad Raouf
3.2.2 Purlin roof truss

Another type of a roof truss which isn't self-supporting is the Purlin truss. The Purlin truss usually rests on several walls or a concrete joist.

![Figure 3.6 - section of a purlin roof truss by Shwan Delshad Raouf](image)

There are three main set-ups of the Purlin truss: the monopitch, the outward duopitch, and the inward duopitch. The Purlin truss can be used in almost all types of buildings. (Schunck et al. 2003. p 62-64)

3.2.3 Fink truss

The self-supporting Fink truss can be classified as a beam because of its rigid layout and its way of distributing the loads. The rigidity of the Fink truss allows it to have a span up to 15 meters. The slope of the truss is usually between 14° and 17°. The Fink truss has been chosen for the roof of the school in Lwengo Basilla because of its safe and simple structure. In Sweden, the standard spacing between the Fink trusses are set to 1.2 meters, in order to fairly distribute the massive loads from the roof insulations and coverings. (Schunck et al. 2003. p 62-64)

![Figure 3.7 - section of a fink truss by Shwan Delshad Raouf](image)
3.3 Joint connectors

The two types of materials generally used as connectors are either wood or steel. Joint connectors can be used to connect two beams together or to strengthen the weak point of a beam. The steel plate is used more often today because of its tensile strength, long term sustainability and its thinner dimension compared to the timber. The connection plates can be either nailed or screwed together with the beams. The screw is preferred because of its ability to attach itself to the timber.

Picture 3.1- picture of a joint connector by Shwan Delshad Raouf
3.4 Eurocode

Eurocode is a European standard issued by the European Committee for standardization (CEN). Based on article 95 in the "Treaty of Rome" (1957), the now called European Union decided to begin a program to develop a standard for its members. This standard wasn’t just supposed to make dimensioning and trading between countries easier, but also to ensure the stability and bearing capacity of buildings. (SS-EN 1995-1-1:2004)


EN-1990 is more general then the other documents and is thought to be used together with the rest of the documents. It contains principles and demands of safety, usability and stability of structures.

EN-1991, Action and structures, is a guide when dimensioning. It contains dead loads, imposed loads and density of materials as well as methods when searching for characteristic values.

EN-1995, Design of timber structures. This chapter covers bearing structures made of timber and is divided into two parts, one is more general about timber and the other specifies on bridges. EN-1995 shows the demands of bearing capacity, stability and resistance against fire in the structures of timber.
3.5 Loads

There are several types of loads, such as dead load, imposed load, snow load, wind load etc. that have to be taken into account when calculating the dimensions of a roof.

3.5.1 Dead Loads

Dead loads are permanently in existence. The weights of the materials that compose the roof are considered as dead loads. (Schunck et al. 2003. p 46)

3.5.2 Imposed loads

Loads that are temporary or change over the course of time are called imposed loads. Imposed loads occur both as distributed and point load. For example, a snow load distributed evenly over a roof provides a distributed imposed load [kN/m²] to the roof, while a person standing on one spot of the roof provides a point imposed load [kN]. Roofs with a slope less than 40° are generally subject to imposed loads, because a person can easily walk on the roof during maintenance and impose a point load on the roof. (Schunck et al. 2003. p 46)

3.5.2.1 Snow Loads

Snow loads are a type of imposed loads, because it only arises during the colder seasons. The snow load is usually a distributed load but it's not necessarily evenly distributed since some sections of the roof might get covered with a larger amount of snow, because it is facing the direction of the snow. Another example of unevenly distributed snow is when some sections of the roof have a higher elevation than the rest of the roof; this difference in elevation results in piled up snow where the lower roof meets the wall of the elevated roof. The Eurocode has specified several snow zones all over Europe, because the amount of snowfall differs from one place to another. One can simply look up the area of the construction site and take out the snow load for that specific area, and use it during load calculations. (Schunck et al. 2003. p 46)
3.5.2.2 Wind loads

Wind loads can be considered as an imposed load, since it's not always present, but what separates wind loads from imposed loads is the wind's speed and change of direction. The wind speed is directly proportional to the load it thrusts upon a surface. The aerodynamics of a building plays a big role when wind loads are present. The speed and direction of the wind creates pressure on one side of a surface and suction of the other side of the surface. (Schunck et al. 2003. p 46)

3.5.2.2.1 Internal and external wind pressure

Wind loads arise on a surface when there is either external or internal wind pressure. These two types of wind both result in exerting a load or suction on a surface and are referred to positive (load) or negative (suction) pressure depending on their direction. (1991-1-4:2004; chapter 5)

![Figure 3.8 - External and internal pressure exerted on a roof](image-url)
External and internal wind pressure can be calculated with the help of these two formulas from EN-1991-1-4 chapter 5.2:

External wind pressure: \( w_e = q_p(z_e)c_{pe} \)  [Formula 3.1]

Internal wind pressure: \( w_i = q_p(z_i)c_{pi} \)  [Formula 3.2]

**Symbols:**

- \( w_e \) External wind pressure [kN/m²]
- \( q_p(z_e) \) External peak velocity pressure [kN/m²]
- \( c_{pe} \) External pressure coefficient
- \( z_e \) External reference height
- \( w_i \) Internal wind pressure [kN/m²]
- \( q_p(z_i) \) Internal peak velocity pressure [kN/m²]
- \( c_{pi} \) Internal pressure coefficient
- \( z_i \) Internal reference height
3.5.2.2.2 How to determine the external and internal peak velocity pressure

The external and internal pressure coefficient is determined with the help of three elements; the reference height \([Z]\), the basic wind velocity \([v_b]\), and the terrain category.

The reference height is the height of the building which wind loads are exerted upon. \(Z_e\) and \(Z_i\) are equal to the height of the structure. (EN-1991-1-4, chapter 7.2.9).

The basic wind velocity is a function which depends on measuring two factors 10 meters above ground. The two factors being wind direction and the time of year. (EN-1991-1-4 chapter 4.2)

The roughness of the terrain in which the building is constructed, is taken into consideration and is divided into five categories. (EN-1991-1-4 chapter 4.3.2)

### Terrain categories

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Sea or coastal area that is exposed to the open sea</td>
</tr>
<tr>
<td>I</td>
<td>Lakes or flat and horizontal area with negligible vegetation and without obstacles</td>
</tr>
<tr>
<td>II</td>
<td>Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights</td>
</tr>
<tr>
<td>III</td>
<td>Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)</td>
</tr>
<tr>
<td>IV</td>
<td>Area in which at least 15% of the surface is covered with buildings and their average height exceeds 15 m</td>
</tr>
</tbody>
</table>

Table 3.1 – Terrain categories from EN-1991-1-4:2004 chapter 4.3.2

### Peak velocity pressure

<table>
<thead>
<tr>
<th>höjd</th>
<th>(v_b = 22 \text{ m/s} \cdot \text{Terrängtyp})</th>
<th>(v_b = 24 \text{ m/s} \cdot \text{Terrängtyp})</th>
<th>(v_b = 26 \text{ m/s} \cdot \text{Terrängtyp})</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0,60 0,52 0,39 0,35 0,32</td>
<td>0,71 0,62 0,46 0,41 0,38</td>
<td>0,84 0,73 0,55 0,49 0,44</td>
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<tr>
<td>4</td>
<td>0,70 0,63 0,50 0,35 0,32</td>
<td>0,83 0,75 0,59 0,41 0,38</td>
<td>0,98 0,87 0,69 0,49 0,44</td>
</tr>
<tr>
<td>8</td>
<td>0,81 0,74 0,61 0,43 0,32</td>
<td>0,96 0,88 0,73 0,51 0,38</td>
<td>1,13 1,03 0,85 0,60 0,44</td>
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<tr>
<td>12</td>
<td>0,87 0,81 0,69 0,50 0,35</td>
<td>1,04 0,96 0,82 0,60 0,42</td>
<td>1,22 1,13 0,95 0,70 0,49</td>
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<td>16</td>
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<td>1,10 1,02 0,88 0,66 0,48</td>
<td>1,29 1,20 1,04 0,78 0,56</td>
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<tr>
<td>20</td>
<td>0,96 0,90 0,78 0,60 0,45</td>
<td>1,14 1,07 0,93 0,72 0,53</td>
<td>1,34 1,26 1,10 0,84 0,63</td>
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<tr>
<td>25</td>
<td>1,00 0,94 0,83 0,65 0,49</td>
<td>1,15 1,12 0,99 0,77 0,59</td>
<td>1,40 1,32 1,15 0,90 0,69</td>
</tr>
</tbody>
</table>

Table 3.2 – Peak velocity pressure from HS1008 Konstruktionsteknik; V13Formler och tabeller – Laster by Lars Holmgren och Sven-Henrik Vidhall
3.5.2.2.3 How to determine the external pressure coefficient $C_{pe}$

The external pressure coefficient is presented in chapter 7.2 of EN-1991-1-4 and is divided into two sections; $C_{pe,1}$ is for small elements with an approximated area of 1 m$^2$ and $C_{pe,10}$ is used for load bearing objects larger than 1 m$^2$. The $C_{pe}$ for duopitched roofs can be found in chapter 7.2.5 of EN-1991-1-4. The roof is divided into sections, each with a designated alphabetical letter. Each section is affected in a different way when wind pressure is exerted upon the roof. (EN-1991-1-4:2004, chapter 7.2.5)

3.5.2.2.4 How to determine the internal pressure coefficient $C_{pi}$

There are two ways to calculate the internal pressure coefficient. If one of the building’s faces has more openings than all the other facades of the building together, it will be called the dominant face and is calculated using some specific formulas that won’t be shown in this report. Those buildings which don’t have a dominant face have their own way of calculating the internal pressure coefficient with the help of comparing the opening ratio of the openings in the building. (EN-1991-1-4:2004, chapter 7.2.9)

$$\mu = \frac{\sum \text{Opening area with } c_{pe} \leq 0}{\sum \text{All area openings}}$$ \hspace{1cm} \text{[Formula 3.3]}

3.5.2.2.5 Calculating the wind force for a roof

The most unfavorable scenario of external and internal wind pressure is chosen during calculations. Wind friction can be disregarded when the side of the roof being exerted with wind pressure is smaller than four times the total area of the roof. The formulas are presented below. (EN-1991-1-4:2004 chapter 5.3)

- External force: $F_{we} = c_s c_d \cdot \sum \text{Surfaces} \cdot w_e \cdot A_{ref}$ [kN] \hspace{1cm} \text{[Formula 3.4]}
- Internal force: $F_{wi} = \sum \text{Surfaces} \cdot w_i \cdot A_{ref}$ [kN] \hspace{1cm} \text{[Formula 3.5]}
- Summed up forces: $F_{w} = F_{we} + F_{wi}$ [kN] \hspace{1cm} \text{[Formula 3.6]}

**Symbols**

$c_s c_d$ is a structural factor which is equal to 1.0 if the height of the building is less than 15 meters.

$A_{ref}$ is the reference area of an individual surface.
3.5.3 Load combinations

When calculating the dimensions of a roof truss, both the Service Limit State (SLS) and Ultimate Limit State (ULS) have to be calculated in order to select the appropriate dimensions of the roof truss.

3.5.3.2 Service Limit State (SLS)

The SLS is a measure on how much load should be exerted on a certain component, i.e. the floor of a building, in accordance with certain requirements. A requirement could be the avoidance of long term deformations.

<table>
<thead>
<tr>
<th>Load</th>
<th>characteristic</th>
<th>frequent</th>
<th>Quasi-permanent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent</td>
<td>$G_k$</td>
<td>$G_k$</td>
<td>$G_k$</td>
</tr>
<tr>
<td>Variable loads</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Main load</td>
<td>$Q_{k,1}$</td>
<td>$\varphi_{1,1} \cdot Q_{k,1}$</td>
<td>$\varphi_{2,1} \cdot Q_{k,1}$</td>
</tr>
<tr>
<td>Other loads</td>
<td>$\varphi_{0,j} \cdot Q_{k,j}$</td>
<td>$\varphi_{2,j} \cdot Q_{k,j}$</td>
<td>$\varphi_{2,j} \cdot Q_{k,j}$</td>
</tr>
</tbody>
</table>

Table 3.3- Formulas for calculating SLS from HS1008 Konstruktionsteknik; V13Formler och tabeller – Laster by Lars Holmgren och Sven-Henrik Vidhall

3.5.3.3 Ultimate Limit State (ULS)

The ULS is a measure on how much load can be exerted on a building component until it reaches breaking point. The ULS is calculated with the help of equation 6.10.a and 6.10.b.

<table>
<thead>
<tr>
<th>Load</th>
<th>Equation 6.10.a</th>
<th>Equation 6.10.b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent unfavorable</td>
<td>$\gamma_d \cdot 1.35 \cdot G_k$</td>
<td>$\gamma_d \cdot 0.89 \cdot 1.35 \cdot G_k$</td>
</tr>
<tr>
<td>Permanent favorable</td>
<td>$1.00 \cdot G_k$</td>
<td>$1.00 \cdot G_k$</td>
</tr>
<tr>
<td>Variable main load</td>
<td>-</td>
<td>$\gamma_d \cdot 1.5 \cdot Q_{k,1}$</td>
</tr>
<tr>
<td>Cooperative variable loads:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the largest load</td>
<td>$\gamma_d \cdot 1.5 \cdot \varphi_{0,1} Q_{k,1}$</td>
<td>-</td>
</tr>
<tr>
<td>Cooperative variable loads:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>other loads</td>
<td>$\gamma_d \cdot 1.5 \cdot \varphi_{0,j} Q_{k,j}$</td>
<td>$\gamma_d \cdot 1.5 \cdot \varphi_{0,j} Q_{k,j}$</td>
</tr>
</tbody>
</table>

Table 3.4- Formulas for calculating ULS from HS1008 Konstruktionsteknik; V13Formler och tabeller – Laster by Lars Holmgren och Sven-Henrik Vidhall

21
3.5.4 Safety classes

The Swedish government’s sector for building and planning has added safety classes to ULS calculations in the Eurocode. These safety classes have $\gamma_d$ as symbol and are used in equation 6.10.a and 6.10.b. (Tillämpning av europeiska konstruktionsstandarder; EKS 8)

<table>
<thead>
<tr>
<th>Safety class</th>
<th>Definition</th>
<th>partial coefficient [$\gamma_d$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (low)</td>
<td>Low risk for serious injuries</td>
<td>0.83</td>
</tr>
<tr>
<td>1 (medium)</td>
<td>medium risk for serious injuries</td>
<td>0.91</td>
</tr>
<tr>
<td>1 (high)</td>
<td>high risk for serious injuries</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 3.5- The types of safety classes from Tillämpning av europeiska konstruktionsstandarder, EKS 8

3.5.5 Strength classes

Timber can be classified into different strength classes depending on their tensile, bending, compression and shear forces. Softwood types have been assigned the letter C. For example, in C24, the C shows that the wood is a softwood species and the 24 shows that the timber is capable of handling loads up to 24 MPa (Mega Pascal). The letter D is assigned to hardwood and GL is assigned to Glulam. (EN-1995-1-1)

3.5.6 Service classes

The effects of moisture need to be taken into account when dimensioning timber. Three service classes have been established in Eurocode 5 in order to classify the moisture amount in timber. The environmental conditions below are measured at 20°C. (EN-1995-1-1:2004, chapter 2.3.1.3)

<table>
<thead>
<tr>
<th>Service class</th>
<th>Average moisture content</th>
<th>Relative humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>≤ 12</td>
<td>65%</td>
</tr>
<tr>
<td>2</td>
<td>≤ 20</td>
<td>85%</td>
</tr>
<tr>
<td>3</td>
<td>&gt; 20</td>
<td>&gt; 85%</td>
</tr>
</tbody>
</table>

Table 3.6- The types of Service classes from EN-1995-1-1:2004, chapter 2.3.1.3
### 3.5.7 Load duration classes

The duration of a load on a surface has been divided into five different classes as presented below. (EN-1995-1-1:2004, chapter 2.3.1.2)

<table>
<thead>
<tr>
<th>Load duration class</th>
<th>Order of accumulated duration of characteristic load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent, P</td>
<td>More than 10 years</td>
</tr>
<tr>
<td>Long-term, L</td>
<td>6 months - 10 years</td>
</tr>
<tr>
<td>Medium-term, M</td>
<td>1 week - 6 months</td>
</tr>
<tr>
<td>Short-term, S</td>
<td>Less than 1 week</td>
</tr>
<tr>
<td>instantaneous</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.7 - The types of load duration classes from EN-1995-1-1:2004, chapter 2.3.1.2

With the help of the load duration and service classes, $k_{mod}$ can be defined. $k_{mod}$ is a modification value used during ULS calculations for timber. (EN-1995-1-1)

### 3.5.8 Size factors

The impact from the size and volume of timber has to be taken into account when ULS is being calculated. The factor $k_h$ is used during calculations. (EN-1995-1-1:2004, chapter 3.2-3.4)

<table>
<thead>
<tr>
<th>Solid timber</th>
<th>Glulam</th>
<th>LVL (Laminated veneer lumber)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_h = \min \left{ \left( \frac{150}{h} \right)^{0.2}, \frac{150}{1.3} \right}$</td>
<td>$k_h = \min \left{ \left( \frac{600}{h} \right)^{0.1}, \frac{600}{1.1} \right}$</td>
<td>$k_h = \min \left{ \left( \frac{300}{h} \right)^{5}, \frac{300}{1.2} \right}$</td>
</tr>
</tbody>
</table>

Table 3.8 - Formulas for calculating the size factors from EN-1995-1-1:2004, chapters 3.2-3.4
3.6 Climate

There is a big difference when building houses in DR Congo and Sweden. In Sweden the houses are built to have an indoor climate that can vary a lot from the outdoor climate. Swedish houses are often constructed to have many layers of different materials to ensure a stable inner climate and to control the movement of humidity through the climate shell. There should be a lower indoor pressure to prevent the flow of air through the walls and roof. If the indoor air, which is often more humid than the outside air, penetrates the wall, the relative humidity will arise and there will be a risk for condensation since the colder air can’t contain as much moisture as the warmer air.

The outer climate in Sweden differs a lot throughout the year, from warm summer with a low relative humidity to very cold winters with higher relative humidity. In DR Congo the difference of the indoor and outdoor climate does not differ so much in most houses. The temperature varies from 25-29 degrees Celsius throughout the year with three dry months from June to August (NASA Langley Research Center Atmospheric Science data Center, New et al. 2002)
4. Fact Sources

The restricted access to internet due to the lack of network coverage and electricity has forced us to take advantage of the books we have with us and the observations we can make with the naked eye and simple tools. The language barriers restricts the depth of information required for this thesis.

All sides and parts of the school building were measured using a measuring tape the day after arrival in order to adjust the abstract pre-calculations of the roof to the real dimensions of the constructed building.

The sources used during the calculations of the roof trusses are listed below:

- Svenskstandard SS-EN-1995-1-1:2004 (contains information about all the types of loads that need to be used during calculations. it also contains calculation guides for the joint connectors.)
- EN_1991-1-4:2004, European Committee for Standardization, 2004, first edition (contains information about all the types of loads that need to be used during calculations.)

The sources used during research of the Theoretical Framework are listed below:

- Roof Construction Manual; Pitched Roofs by Schunk, Oster, Barthel and Kiessl, 2003
- Praktisk husbyggnadsteknik, Sandin, 2010
- Svenskstandard SS-EN-1995-1-1:2004
5. Procedure

5.1 Preparations

Usually, the first task of an engineering student at a construction site is observation of the work progress and understanding why certain decisions are made in different situations. The challenging and unique part of this project was that three engineering students would manage the whole project. Managing a project requires crucial decision making where different solutions are compared and the solution with the best outcome is chosen. This type of decision making requires years of experience which we did not have. To compensate for the lack of experience we had to study the different parts of the project from every angle. The project being located in a remote part of the world required careful preparations prior to the trip since there was insufficient access to electricity and internet. In this chapter, the construction progress of the 19 roof trusses including the decisions which had to be made will be presented.

Since the annual temperature in Lwengo Basilla is usually warmer and has a small range of degree difference, there is no need for insulation and several layers of roof coverings. This loss of roof weight allows for a wider spacing between the trusses, and therefore has a spacing of 1500 mm been chosen instead of 1200 mm. The houses in Lwengo Basilla which have roof trusses usually have a spacing width of 3 meters between two trusses. The schools outer dimensions were 28340 × 6440 mm and the school was divided into three identical classrooms. The position of the separating walls between the classrooms was some centimeters out of place. This
situation forced the spacing between two trusses to expand to 1610 mm. Seven of the 19 trusses were placed over the first classroom, 5 trusses were placed over the middle classroom and the last seven trusses were placed over the third classroom.
5.2 Dimensioning the roof truss

In order to have a stable roof truss, the loads exerted upon the trusses have to be compared to the capacity of the materials.

5.2.1 Wind loads

The wind loads creating downward pressure on the roof were calculated for the roof trusses with 1500 mm spacing in pre-calculations as well as 1610 mm spacing in post calculations.

Wind load 1500 mm spacing: 0.495 kN/m
Wind load 1610 mm spacing: 0.532 kN/m

5.2.2 Ultimate limit state

The ultimate limit state was calculated with wind loads set as main loads. The ULS was calculated for both types of spacing in the pre- and post-calculations.

ULS pre-calculation: 0.937 kN/m
ULS post-calculation: 1.001 kN/m
5.2.3 Lumber capacity

The loads exerted on the roof were compared to the capacity of a type of lumber with the strength class C14. After the density of the lumber was determined by measuring the volume and mass of a piece of the lumber used during construction, the loads were compared to the capacity of the real lumber which had a strength class between D60 and D70. (see attachments for calculations)

Pre-calculations:

Bending capacity:
- Design load: 6.77 MPa
- Load capacity (C14): 7.54 MPa

Shear force capacity:
- Design load: 1.08 MPa
- Load capacity (C14): 1.615 MPa

Post-calculations:
- Design load: 7.92 MPa
- Load capacity (D60): 32.3 MPa
5.3 Mitre box (precision box)

A mitre box is a tool used to cut out precise angles on any piece of wood. The box has three sides and an open top. The walls of the box guide the saw in the path of the required angle as shown in the picture below.

Figure 5.3 – Sketch of the mitre box used for sawing the roof trusses by Arvid Nystedt, NTS

In order to get the exact length and angle on every piece of the roof truss, another version of the mitre box had to be invented where the length and angle of the parts could be preset. The first concept taken into consideration was very large and complex. It consisted of several connecting mitre boxes that could be joined together into the shape of the roof truss. The first concept was scrapped because the idea was farfetched, impractical and required a large work force. During the design of the second concept, practicality and simplicity were the main goals for the mitre box. The second concept was a 6 meter long mitre box where all the chords of the roof truss could fit in.
The mitre box was used for the top and bottom chords of the roof truss, while a template was used for cutting the web of the roof truss. The pieces of lumber were put into the box one by one in order to get the exact angles at the right length.

Picture 5.1 - the six meter long mitre box is being used for cutting the lumber by Arvid Nystedt
5.4 Cut the Lumber

The mitre box was only used for the top and bottom chords. The top chords were sawed off in a $14^\circ$ angle and the bottom chords at a $76^\circ$ angle. Since the bottom chord was too long (6.5 meters) to be produced in one piece, the manufacturer wanted to deliver two 5 meter lumbers which could be sawed off and then joined together in the middle with a joint connector. Two 4 meter lumbers were suggested in order to decrease the waste of materials, but because of some special circumstances that the manufacturer pointed out, which we did not understand to the fullest extent, it was easier to deliver a 5 or 6 meter lumber instead of a 4 meter piece.

Figure 5.4 - Top Chord 6m by Shwan Delshad Raouf, Not to scale (NTS)

Figure 5.5 - Top Chord 4m by Shwan Delshad Raouf, NTS
Figure 5.6 - Bottom Chords by Shwan Delshad Raouf, NTS

Picture 5.2- The chords being placed into their positions by Daniel Hällqvist
5.5 The first roof truss

The first materials which arrived were the lumber for the chords, but the web of the truss was delayed. This difficult situation didn’t allow for the construction of the first roof truss to be started since some parts were missing and time was ticking. The lumber for the chords was twice the size of the web, so the decision was made to create the web of the first truss from the chord lumber. The original web was be nailed on both sides of the chords but the web for the first truss was only be nailed to one side of the chords because this web was twice the size of the original web.

5.6 The web of the roof truss,

Once the first roof truss was raised successfully, the rest of the chords were sawed with the help of the mitre box. The lumber for the web of the roof truss arrived shortly after, and was delivered in 5 meter pieces with the dimensions of $100 \times 25$ mm. The web, which was nailed on both sides of the Chord, consists of four parts in a formation similar to the letter “W”.

A 5 meter piece of lumber could be cut into one “W” and one trapezoid shaped joint connector (This type of joint is explained on the next section of this chapter).
5.7 Joint connectors

Timber joints and nails were used instead of steel plates on screws during the roof construction of the school in Lwengo Basilla, because of the lower cost and availability. The timber is also a better choice considering how the relative humidity can corrode the steel plate over time.

There was a total of eight joint connectors on each roof truss; four on each side. Two joint connectors \((100 \cdot 25 \cdot 800 \text{ mm})\) were used to connect the two pieces of the bottom chord together.

![Picture 5.3 – Bottom chord joint connector by Shwan Delshad Raouf](image)

Four joint connectors \((100 \cdot 25 \cdot 800 \text{ mm})\) were used to connect the bottom and top chords on each side.

![Picture 5.4 – Joint connector between bottom and top chord by Arvid Nystedt](image)
Two trapezoid shaped joint connectors were used to connect the top chords together at the ridge of the roof truss. These connectors are allowed to have a maximum length of 300 mm and they should fit in tightly between the ends of the connecting parts of the web in order to transport the loads easily between the chords and the web.

Picture 5.5 – Joint connector between the top chords by Arvid Nystedt
5.8 Nail the parts to form a roof truss

When all the parts of the roof truss were sawed and laid out in an organized manner, the process of nailing the parts together started. The positions of the nails were marked out on the parts of the roof truss with pencils in order to fulfill the Euro code’s standards for distribution of nails. The nails had to be laid out in a pattern where the possibility of hammering nails between the same fibers was decreased. The nails have to be a distance of 10 times the diameter of the nail away from the ends of the timber joints, in this case 38 mm. The nails had to be 20 mm away from the edges of the timber joints. These precautions were taken in order to avoid the formation of cracks in the material. As the nails were laid out according to the standards, the aesthetic and symmetric aspects of the roof truss were taken into consideration during the layout of the nails. (EN 1995-1-1:2004, chapter 8.3)

The nailing of the second truss started after the layout of the first couple of joints was marked out. The two parts of the bottom chord were first to be joined together, then followed the connections between the top and bottom chords. The web came next and was nailed to both sides of the chords at the same time; held together by clamps.
The last piece to be nailed was the trapezoid shaped joint connector by the ridge of the truss. The last piece had to be sawed of right before it was to be nailed onto the truss because the last piece would take up all the marginal errors that arose during the sawing and nailing process. It was easier and less time consuming to adjust two small plates instead of the whole roof truss. The trapezoid shaped connector which could have a maximum length of 300 millimeters was adjusted accordingly with each roof truss. All the trapezoid connectors of the 19 roof trusses had a length between 290-305 millimeters. (svenska takstolar)

The amount of nails was adjusted once because of the size of the nail itself. The first roof truss had a total of 196 nails as suggested by the Swedish roof truss manual “svenska takstolar”. The only difference was that the size of the nails delivered to the construction site had a diameter of 4mm instead of 3.4mm as suggested by the manual. Since the diameter of the nails was larger than what had been ordered, the amount of nails had to be decreased in compensation. The new amount of nails for one roof truss was decreased to 156 nails in total.

As the second truss was finished, an assembly line was formed. One group was marking the parts of the roof truss; another group was transporting all the pieces of the roof truss to a designated area and then prepared the pieces for the last group which was in charge of nailing the pieces together.
5.9 Raise the roof truss

Once the roof trusses for the first classroom were nailed together, they were to be raised. A set of Scaffolding needed to be assembled, both on the inside and outside of the classroom walls, in order for the trusses to be raised. The scaffolding inside the classroom was in the form of a vertically inverted letter “Z” as shown in the picture below.

Figure 5.7 – Inside and outside scaffolding setup by Shwan Delshad Raouf, NTS
The roof trusses were carried into the classroom by the help of 7-8 people. The truss was raised on top of the Z-shaped scaffolding. The scaffoldings had a height of ca. 2000 mm and could be used as a resting zone for the truss so the workers could catch their breath. Once the truss was resting on the scaffolding, the workers could get into their positions on the scaffoldings both on the outside and inside of the classroom.

Figure 5.8 – Roof truss resting on top of the scaffolding by Shwan Delshad Raouf, NTS
The next step was to raise the truss up from the scaffolding onto the walls of the class room as illustrated in the picture below.

Figure 5.9 – Roof truss resting on top of the walls by Shwan Delshad Raouf, NTS
The truss would be raised into the upright position and then moved to one side of the classroom until all the trusses were raised up on the walls for the whole classroom using the same procedure.

Figure 5.10 – Roof truss raised into upright position by Shwan Delshad Raouf, NTS
When all the trusses for the first class room were raised, the process of spreading the trusses out to their assigned positions started.

Figure 5.11 – Roof truss spread out into their assigned places by Shwan Delshad Raouf, NTS
The process of nailing together the rest of the trusses continued and all the trusses for both classroom 2 and 3 were raised together. In order to save time and material, no scaffolding was raised inside of the third classroom, because all the trusses could be transported through classroom two and then raised over the separating wall and then moved on top of the walls of classroom three. The scaffoldings next to the separating wall between classroom 2 and 3 had to be modified and reinforced so it could compensate the extra loads emerging during the transportation of the trusses over the wall. All the 19 roof trusses including the mitre box were sawed, nailed and raised in 15 days.

Figure 5.12 - Layout of the 19 roof trusses by Shwan Delshad Raouf, NTS
5.10 Materials and workforce

The materials used during the production of the trusses are listed below:

- 2 saws
- 3 hammers
- 1 level
- Markers
- 3 clamps
- Measuring tapes
- 1 angle protractor
- 2 L-squares
- 1 Crowbar
- 1 rasp

The work force dedicated to the construction of the roof consisted of 10-11 men. A usual workday started from 8:00 a.m. until 5:30 p.m. with a 1-2 hour lunch break.

Picture 5.7 – picture of school with all 19 trusses raised by Daniel Hällqvist
6. Analysis

6.1 Snow loads

Snow loads are generally the main imposed load in Sweden when the dimensions of a roof truss are to be determined. First, it was decided that snow loads would be calculated into the equations as the main imposed load and wind loads would be taken as a secondary imposed load. As the knowledge about DR Congo increased, it was decided that snow loads would be left out, since it never snows in the area where the building is located. This decision made it obvious that the main imposed load would be the wind loads.

6.2 Wind loads

Since the basic wind velocity \( (v_b) \) of the areas in DR Congo could not be determined at the site or be found on the internet, the highest basic wind velocity in Sweden was chosen to be used in the calculation. The decision of taking the highest \( v_b \) was made because there was no real information about the severity of the wind loads in the area.

6.3 Nails

The thickness of the nails ordered for the roof trusses were 3.4 mm, but the nails delivered were 4.5 mm and circa 3.8 mm. Since the sizes of the nails were larger, the amount of nails had to be decreased. The total amount of nails per roof truss was decreased from 196 nails to 156 nails. The decrease in nails also decreased the possibility of cracks in the timber, while the nails still had the same durability.

6.4 Curves

Every lumber for six meter long top chord of the roof truss was a bit curved when they got delivered probably because of the capabilities of the cutting machine. Since the lumber could not be returned or straightened out, they had to be nailed to the other parts of the roof truss with the curves facing the same direction in order to have a similar pattern along the roof.
6.5 Cracks

When the first roof truss was to be nailed together, the 4.5 mm thick nails were used, but because of their thick dimension, it created small cracks in the joint connectors, but none of the cracks were noteworthy. In order to dodge the cracks in the coming roof trusses, the thinner 3.8 mm nails were used. The nails were a success and it also showed the natives that just because an object is larger, it is not necessarily better.

6.6 Calculations

The calculations showed that even if the lumber used for the roof truss had the lowest strength class (C14) in the Eurocode, it wouldn’t have been a problem. The loads exerted on the roof truss were only 90% of what the roof truss was capable of handling. The fact that the lumber delivered to the construction site had a strength class between D60 and D70 shows that we only used ca. 24.5% of the total capacity. The results of the calculations are shown in chapter 5.2.3 in this report. (The complete calculations are in the attachments) (Byggformler och tabeller, 2011)
7. Conclusion

7.1 Technical conclusion

The roof trusses were constructed with local materials which saves the transportation costs. All the extra pieces of lumber were used as joint connectors or as parts of the scaffolding in order to minimize the wastage. The minor problems that occurred during the construction phase were solved from an engineer’s point of view, where different solutions were compared and the solution with the best outcome was chosen.

The loads and dimensions were calculated in order to get a technical perspective of the roof trusses as well as a safety perspective of the roof trusses considering the different loads that are exerted on the roof.

The mitre box was a success as it showed how easy one could get the precise angles for every roof truss instead of marking out every lumber by measuring every side and angle of each roof truss.

The 19 roof trusses were sawed, nailed and raised on the roof in 17 days, which was an amazing accomplishment considering the lack of resources.

7.2 Reflective conclusion

Building a school in the DR Congo is vital since the lack of schools in the area have limited the availability of education for children. The enthusiasm of the natives in the area for the school was overwhelming. It showed that they had a profound understanding for what education could do for an individual as well as a nation. The normal assumption of a westerner for most of the countries in Africa is that the people are hungry for food because they want to live another day. The fact was that they were hungrier for education, because the natives know that they have a country full of riches that is being exploited while they are left with nothing. They had realized that the only way to solve these problems were by increasing the populations awareness so that they can draw new conclusions and choose better paths for themselves and their country instead of taking the same paths as their ancestors. This school project is only the genesis of an idea and my hope is that it will inspire future students of the civil engineering department to lend a helping hand to those who need it the most.
8. Recommendations

8.1. Recommendations for the second school building in Lwengo Basilla

A list of recommendations and guidelines were left for the carpenter and those who assisted us during the construction of the roof. Below are two of the main recommendations for the construction of the roof of the next school.

8.1.1 Bottom chord

The bottom chord consisted of two identical parts joined together. The two parts were each cut from a five meter lumber. For the next school they can order a six meter long lumber from which both parts of the chords can be sawed from.

8.1.2 Curves

If the timber for the six meter lumber is curved, make sure that all the curves are facing the same direction so the whole roof gets a similar pattern

8.2 Recommendations for the non-profit organization “Elikia na Biso”

“Elikia na Biso” should continue to collect donations for constructing schools in other parts of DR Congo. They should use the school in Lwengo Basilla as an example of their accomplishments, because people usually want a concrete proof of where their donations go.

8.3 Recommendations for the department of “Construction engineering and Design” at the Royal Institute of Technology

The department of “Construction engineering and Design” should encourage their future graduating students to take on tasks on a global level in order to spread their knowledge about construction in different parts of the world while at the same time they gain a life changing experience. To be a part of a project that helps close the gap between developed and impoverished countries isn't just a humbling act, but also gives the engineering students a new level of respect and admiration for their profession. It is therefore highly recommended that the construction department gives out more information to the students about minor field studies and how they can engage in future projects.
9. Bibliography

- Tillämpning av europeiska konstruktionsstandarder; EKS 8, Boverket, 2011
- Eurocodes:
10. Attachments

10.1 Calculation of wind loads

- External wind loads \( \theta = 0^\circ \)

\[
E \leq \begin{cases} 
\text{b} = 27.340 \text{ m} \\
\text{2h} = 7.68 \text{ m}
\end{cases}
\Rightarrow E = 7.52 \text{ m}
\]

**Assumptions**

- \( V_b = 26 \text{ m/s} \)
- Terrain Type II
- \( h = Z = 3.790 \text{ m} \)
- \( b = 29.1340 \text{ m} \)
- \( \alpha = 14^\circ \)

\[
f_p(z) = \left( \frac{0.41 - 0.55}{z} \right) + 0.95
\]

\[
f_p(z) = 0.6753 \text{ kN/m}^2
\]

**Four different cases of wind load can be chosen for examination**

1. 
2. 
3. 
4. 

\[
\begin{array}{c|c|c|c|c}
\text{Case} & \text{F} & \text{G} & \text{H} & \text{I} & \text{J} \\
\hline
\text{CF}_{1,0} & 0.18 & 0.18 & 0.0 \text{ } 0.02 \\
\text{CF}_{2,0} & -0.02 & -0.04 & -0.13 & -0.04 & -0.05 \\
\hline
\text{W}_{12} & 0.72 & 0.72 & 0.72 & 0.0175 \\
\text{W}_{21} & -0.72 & -0.72 & -0.72 & -0.0175 \\
\hline
\end{array}
\]
Case 3 of external wind loads will be used for dimensioning the roof truss.

**External wind loads** $\theta = 90^\circ$

\[
\begin{array}{c|c|c|c}
\text{zones} & F & G & H & I \\
\hline
C_{p_{10}} & -1.33 & -1.7 & -0.61 & -0.951 \\
C_{w_{10}} & -0.892 & -0.836 & -0.172 & -0.394 \\
\end{array}
\]

The wind pressure from a $90^\circ$ angle will be ignored since it only applies suction on the roof.

**Internal wind pressure**

\[
\frac{h}{d} = \frac{3.29}{0.440} = 7.489
\]

\[
U = \Sigma \text{openings area with } C_{p_{i}} < 0 \\
\Sigma \text{ Total area of openings}
\]

\[
\text{area}_E = 1.3 \times 0.85 \times 12 = 13.26 \text{ m}^2
\]

\[
\text{area}_D = 1.3 \times 0.85 \times 2 + 2,10 \times 0.85 \times 3 = 11.925
\]

\[
U = \frac{13.26}{11.925 + 13.26} = 0.525
\]
with the help of \( h/d \) and \( u \)
the value of \( C_p \) can be determined
by looking at Figure 7.13 in EN 1991-1-4

\[ C_p (\frac{h}{d}) = 0.09 \]

\[ C_p (\frac{h}{d} < 0.25) = 0.14 \]

\[ \frac{C_p (\frac{h}{d} > 0.25)}{C_p (\frac{h}{d} < 0.25)} = 0.14 - 0.09 \]

\[ 0.78 \times 0.09 = 0.0708 \]

\[ \frac{q_p (z_1)}{q_p (z_0)} = 0.675 \text{ kN/m}^2 \]

\[ w = 9.08 \times 10^{-6} \times 0.0708 = 0.07 \text{ kN/m}^2 \]

\[ \text{internal area} = 27.24 + 5.94 = 163 \text{ m}^2 \]

Total wind load \( (F_{w}) \)

\[ F_{w} = (0.122 + 0.122 + 0.135 + 0.1) \times 1.5 = 0.398 \text{ kN/m} \]

\[ F_{w1} = 0.0729 \times 1.5 = 0.109 \text{ kN/m} \]

\[ F_w = 0.398 + 0.109 = 0.509 \text{ kN/m} \]

Laminar flow \( (S_{ fax}) \)

\[ F_{w2} = (0.122 + 0.122 + 0.135 + 0.1) \times 1.61 = 0.415 \text{ kN/m} \]

\[ F_{w1} = 0.0729 \times 1.61 = 0.117 \text{ kN/m} \]

\[ F_w = 0.415 + 0.117 = 0.532 \text{ kN/m} \]
10.2 Capacity pre-calculation of the roof truss
Moment Capacity

\[ F_{m1} = \frac{V_{mod}}{f_{ck}} \]

Service Class: 3
Load duration: Short

\[ V_{mod} = 0.70 \]

\[ f_{ck} = 35 \text{ MPa} \]

\[ f_{ck} = 3 \text{ MPa} \]

Desired AC Unit Shear

\[ V_{d} = 70.8 \text{ kN} \]

\[ F_{v1} = \frac{F_{v1} \cdot f_{ck}}{f_{ck}} = \frac{3.0}{1.3} = 2.31 \text{ MPa} \]

\[ V_{d} = \frac{V_{d} \cdot f_{ck}}{f_{ck}} = \frac{16.7}{1.3} = 12.8 \text{ kN} \]

\[ f_{ck} = 0.89 \text{ kN/m}^2 \]

\[ f_{ck} = 90.9 \text{ kN/m}^2 \]

\[ V_{d} = \frac{V_{d} \cdot f_{ck}}{f_{ck}} = \frac{1700}{0.925 	imes 0.1} = 1808 \text{ MPa} \]

\[ < 1.615 \text{ MPa} \]
10.2 Capacity post-calculation of the roof truss

Post calculation: Roof truss

Dead load:
- Corrugated metal sheet 0.22 m
  \[ G_k = 0.02 \cdot 1000 \cdot 1.610 - 1.610 = 0.112 \text{ kN/m} \]
- Roof truss: \( (0.01 \cdot 0.05 \cdot 0.5) = 0.00375 \text{ kN/m} \)
  \( (0.00 \cdot 0.025 \cdot 0.5) = 0.00125 \text{ kN/m} \)
  \[ G_k = 0.112 + 0.0375 + 0.0125 = 0.16875 \text{ kN/m} \]

Wind load (1/6.10 m SPACER):
\[ G_k = 0.572 \text{ kN/m} \]

Moments:
\[ q_1 \cdot C = 9 \text{ kN/m} \]
\[ M_{A-B} = N_B \cdot C = 4 \frac{1}{256} \cdot 9 \cdot 0.5 \]
\[ M_{B-D} = 12 \cdot 0.5 \cdot C \cdot L^2 = -12 \cdot 0.5 \cdot 1.001 \cdot 0.5^2 = -0.330 \text{ kN/m} \]

\[ \sigma_{max} = \frac{M_{E-M}}{W} \]
\[ \sigma_{max} = \frac{300}{100^2} = 1.417 \text{ MPa} \]
Choose C16

\[ f_{\text{c}} = 0.70 \times f_{\text{c}}' = 0.70 \times 16 = 11.2 \text{ MPa} \]

C16 class would have been enough

Weighness of timber used during construction of the roof truss:

Volume: \( V = 0.002382 \text{ m}^3 \)

Weight: \( m = 1995.5 \times 1.985 \text{ kg} \)

Dead weight of timber: \( f = 1995.5 \times 9.82 = 19198 \text{ N} \)

\[ \frac{19198}{0.002382} = 8057.65 \text{ N/m}^2 = 8057.65 \text{ kN/m}^2 \]

Density: \( \rho = \frac{1995}{0.002382} = 8220.74 \text{ kg/m}^3 \)

\( f(D60) = 700 \text{ kN/m}^2 \)

\( f(D70) = 900 \text{ kN/m}^2 \)

\( D60 < \text{timber used for roof truss} < D70 \)

\[ f_{\text{c}} = 0.70 \times f_{\text{c}}' = 0.70 \times 16 = 11.2 \text{ MPa} \]

Approximating degree of utilization:

\[ \frac{11.2}{19198} = 0.0006 \text{ or } 0.06\% \]