Halmstad University
School of Business and Engineering

Sustainable Low-Cost Housing in Ethiopia

- A Study of CSSB-Technology

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Hållbara Lågkostnadshus i Etiopien

- En Studie av CSSB-Teknik

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(Foto från framsidan är tagen av Arash Afkari i April 2010, Kambataa regionen, Etiopien)

Abstract

This degree project is about sustainable low-cost housing in Ethiopia with a focus on CSSB-technology, which is one method of constructing houses. The project allowed me to visit Ethiopia during seven weeks in 2010, to observe, gather information and to perform tests regarding the specific subject. It is a sub-project to a larger research project initiated in 2002 at Halmstad University in an attempt to introduce low-cost housing technologies for the Kambaata Region in Ethiopia. The aim of the research project has been to develop and test new, sustainable, low-cost building technologies intended for the population, with regard to local traditions, needs and affordability.

Preface

This study has been carried out at Halmstad University with the support from SIDA (Swedish International Development Cooperation Agency). It is the bachelor thesis at C-level for my Bachelor in Science degree in Construction Engineering. Without the help from Halmstad University and the financial support from SIDA, this study wouldn't have been accomplished.

I would like to dedicate special thanks to Prof. Bengt Hjort, my supervisor at Halmstad University who have supported me throughout my work and who helped me during my initial stay in Ethiopia. Workneh Hechamo, my supervisor in field and his wife Hanna-Karin Stark Hechamo who were my hosts at the Swedish Lutheran Mission in Addis Abeba. Prof. Herbert Schmitz and Lecturer Tibebu Daniel Desta, my hosts at Addis Abeba University for providing me with material and for letting me take part in their project. Furthermore I would like to give great thanks to Selam Technical and Vocational Center in Addis Abeba for providing me with information and letting me use their facilities for my tests.

Summary

Ethiopia is one of the poorest countries in the world and is experiencing problems such as a rapid population growth rate, lack of education amongst the population, uncontrolled urbanisation, housing shortages and deforestation and erosion which directly affect the population's wellbeing. These problems are severe and the needs for sustainable solutions are growing. The overpopulated country is in a big need for recourses such as water, food, security, jobs, infrastructure and education. Furthermore there is a big need for sustainable low-cost dwellings for the population. It is important to develop and present technologies that are easily implemented with the available recourses in the different regions in Ethiopia. One of these technologies is the Cement Stabilised Soil Block-technique (CSSB).

The main component in CSSB is one of the most available building materials, used for centuries throughout the world; soil. The blocks also consist of water and cement; working as a stabiliser, mixed and compressed in a pressing machine. The method is very suitable for the population with a low income if they are manually produced and the production process is relatively easy to learn. There are however essential processes in the production which highly affect the quality of the blocks and require consideration. Choosing the right soil for the production is important and the soil need to be pulverized and screened before being mixed with the other components. The mixing is also essential and the blocks need to be pressed immediately after being wet-mixed. The blocks also need to be cured for approximately 28 days before being used in production.

One house that is being constructed with CSSB-technique is one of the demonstration houses in the town of Durame,in the Kambaata region, in Ethiopia. This project is a sub-project to the previous studies performed at Halmstad University with the aim of developing and testing new, sustainable and low-cost house building technologies intended for the population in the Kambaata region in Ethiopia. Before the blocks are to be produced for the project, different tests needed to be performed to ensure the quality of the blocks. In this report I have produced different test blocks with different contents of cement and sand in order to compare the blocks regarding their quality, compressive strength and water resistance. The result of the test was that the cement content affects the quality of the blocks. The blocks containing 4 % and 8 % cement resisted higher compressive strengths compared to the blocks not containing any cement. They also appeared to have a much better resistance to water than the blocks not containing any cement. The blocks with 4-8 % of cement met the requirements regarding their compressive strengths, according to CRATerre.

Although the test production only was at a small scale, it gave me a good view in what to consider when producing the blocks. Choosing the right soil for the production is important and can save a lot of time and money in the practice. Having preexisting knowledge and training is also of key essence. Achieving a good result with durable and high quality blocks relies a lot on the production team and their knowledge and routines during the production process.

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Definitions & Acronyms

Definitions

CSSB – Cement Stabilised Soil Blocks, containing Soil, Cement and Water

Adobe Blocks – Mud blocks, containing Soil, Grass and Water

Bottle test – A sedimentation test to measure different percentages of gravel, sand, silt and clay in a soil.

Acronyms

CSSB – Cement Stabilised Soil Block

STVS – Selam Technical and Vocational Center

GNP – Gross National Product

SIDA – Swedish International Development Cooperation Agency

ETB – Ethiopian Birr (currency)

SEK – Swedish Krona (currency)

UNICEF - United Nations Children's Fund

ETH – The Swiss Federal Institute of Technology

EiABC – The Ethiopian Institute of Architecture, Building Construction and City Development

SUDU – Sustainable Urban Dwelling Unit

1. Introduction

1.1 Background

Ethiopia is one of the poorest countries in the world and struggle with severe problems such as a high population growth rate, an uncontrolled urbanisation process, deforestation, erosion and housing shortages. The traditional methods of constructing houses contribute to the deforestation process and it is of significant matter to introduce sustainable building materials and building methods for the population. In previous reports performed at Halmstad Univerrsity two low-cost housing materials have been studied; Adobe blocks and CSSB which have been proven to have the potential of replacing the traditional way of building. This degree project has a primarily focus on one of the methods of block technology; CSSB-technology.

Three previous field studies at Halmstad University have been carried out by students at the Construction Engineering Programme regarding the main project; sustainable low-cost housing for the Kambaata region in Ethiopia. The first study was completed in 2002 and focused mainly on different low-cost housing materials that could replace the traditional ways of building. The second one included a study of two different block technologies and the design of an elementary school constructed with these technologies. In the third study *Low-Cost Housing for the Kambaata region, Ethiopia* performed by Johansson and Wartanian in 2008, numerous sites and low-cost housing projects were observed. The project resulted in a set of drawings and a cost calculation for houses intended to function as demonstration houses in the town of Durame in the Kambataa region. The results of these field studies have demonstrated that the research about the technology is relevant, essential and financially feasible.

1.2 Aim & Approach

The aim of this project has been to study, document, and evaluate the production process when constructing low-cost houses with CSSB-technology. During a 7 week field-study that was carried out in April-May of 2010 in Ethiopia, mainly two low-cost housing projects were in focus; The demonstration project in Durame and The SUDU-project at Addis Abeba University. These houses are intended to function as demonstration projects in order to introduce alternative building techniques and methods and hopefully spread the knowledge to the Ethiopian population.

The issues that this report has focused on can be summarised as the following:

- What are the fundamental reasons of CSSB-technology and what are the production procedures?
- What are the difficulties and obstacles when constructing houses with CSSB-technology?
- Is it possible to produce good quality CSSB using site soil from Durame?

The intention has been to collect soil from the site in Durame and produce test blocks with different contents of cement and sand in order to compare the blocks regarding their strength, water resistance and other factors of matter.

1.3 Methods

The methods used in this project have mostly consisted of qualitative research but also in some matters quantitative research. The qualitative research is an appropriate method due to the reports investigation on the specific area of “low-cost housing in Ethiopia” and the CSSB-technology. The project also uses a quantitative approach regarding the test production of CSSB; the different contents of cement and sand and the testings that have been done in the end of the project.

One of the significant methods of collecting information for this report is through the observations during the field study in Ethiopia. This is a suitable method due to the projects specific area of the Ethiopian region. The observations made during the field study have focused on the following:

- Gather information about the reasons behind low-cost housing projects in Ethiopia
- Gather information through interviews with people involved in low-cost housing projects, especially regarding CSSB-technology
- Study-visits of projects in Ethiopia

I have gained information through a prepared interview with someone experienced and with knowledge about CSSB-technology. I also have gained information about specific matters during spontaneous conversations with people involved in low-cost housing projects and with institutes that can provide knowledge and guidance related to CSSB-technology.

Prior to the field study I collected as much information as I could through literature and brought these with me to Ethiopia. I found it rather difficult to find literature with narrow and relevant information regarding the specific area of the project. However, with the help of some individuals I was able to achieve good references related to the specific area of low-cost housing and CSSB-technology.

1.4 Limitations

The limitations in this report can be described as the following:

- This report is merely focused on methods suitable for ordinary people; meaning low-income groups in Ethiopia.
- This report has preliminary focused on CSSB-technology.
- Focus is on the construction process of demonstration projects in Ethiopia and on producing test blocks with CSSB-technology

2. A brief description of Ethiopia

2.1 Geography

Ethiopia is officially known as the Federal Democratic Republic of Ethiopia and is located in the northeast part of Africa. With a population of approximately 79 million people, it is the second-most populous country in Africa and the tenth largest by area with its 1,100,000 km² of land. The capital is Addis Abeba which is situated in the centre of the country on an elevation of about 2300 meters above sea level. Ethiopia is landlocked and the bordering countries are Sudan in the west, Kenya in the south, Somalia in the east and Djibouti and Eritrea in the north. [6]

Ethiopia is one of the most mountainous countries in Africa with some of Africa's highest mountains as well as some of the world's lowest points below sea level. It contains of two regions of vast highland separated by the Great Rift Valley and a vast low-lying region that roughly divides the country in half. The country's irregular elevation level is of significant factor affecting the climate, vegetation, soil composition and settlement patterns of every region in the country. The highlands generally receive 1000 mm of rainfall per year and experience moderate to cool temperatures. Situated in the highlands is Addis Abeba with an average temperature of 15ºC and an average annual rainfall of 1250 mm. The lowlands experience a much dryer and hotter climate and usually receive less than 500 mm of rain per year. These areas are situated in the north-central and eastern parts of the country and the population is far less dense than on the plateaus. Ethiopia's irregular elevation also makes regional communication and transportation difficult, but has also kept the country protected from invaders historically. [7]

The varied amounts of rainfall and the rugged terrain have resulted in a great variety of vegetation and animal life. In the driest areas in the lowlands, only occasional bushes and specific grassroots are to be found. The cooler and wetter highlands have a greater range of vegetation such as eucalyptus and yellowwood trees. Some regions in the south western areas are home for rainforests and it is here that some of Ethiopia's famous coffee is produced. There are a wide range of reptiles, mammals, birds and fish to be found. The grasslands are home for the hyena, gazelle, antelope, leopards and lions. Baboons and monkeys are usually found in forested areas. The Great Rift Valley is recognised for its birdlife, which include eagles, hawks and flamingos. [5, 7]

Picture 1. *Great Rift Valley, Awash National Park.* [5]

2.2 Population & Health

The population was in 2007 estimated to around 79 million people, making Ethiopia the second most populous country in Africa. This figure is however very unsure due to the difficulty of estimating the population in third world countries such as Ethiopia. The country has a high population growth with an average annual growth rate of 2.6 % between 1994 and 2007. The distribution of the population by broad age is illustrated in figure 1. It shows that the proportion of the young population under the age of 15 is as high as 45 % and the proportion of population aged 65 years and over is just 3.2 %. The life expectancy at birth was in 2007 estimated to 48 years for men and 51 years for women. [6]

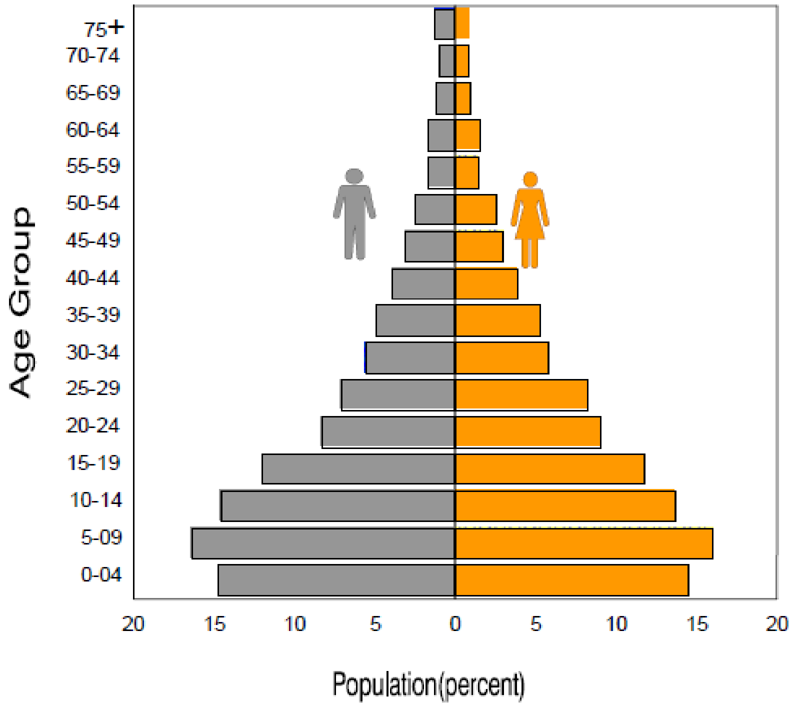


Figure 1. *Population pyramid of Ethiopia 2007.* [6]

Ethiopia has about 75-80 different indigenous languages, with Amharic and Oromo as the main languages. The country is divided into 9 ethnically based regions and 3 larger cites with the majority of the people living in rural areas mainly in the highlands.

The country is much affected by diseases such as Malaria, AIDS and other communicable diseases caused by malnutrition and poor sanitation. The infant mortality rates are very high, as over 11% of infants die shortly after or during birth. This rate has however decreased in the last decades due to governmental efforts in education and training. Another problem affecting the health of the population is the lack of medical doctors and proper medicine. Due to the lack of modern medical training, less reliable"healers" have been common, mainly in rural areas. In 2009 the World Health Organisation estimated an average annual figure of 1809 physicians working in the country between 2000 and 2009, which comes to about 2.3 per 100,000. [8, 9]

2.3 Economy

Ethiopia is considered one of the poorest countries in the world and this is easily observable when travelling in the country. In the 2009 census, Ethiopia was ranked high at the top list of the countries with the lowest GDP (Gross Domestic Product) in the world and the youth unemployment was measured to as high as 70%. Ethiopia has however shown an improving economy in the last years with a growing annual GDP and becoming the fastest growing non-oil-export-dependent African nation in 2007 and 2008. Regardless of these efforts, rural and urban poverty is of important matter in the country. [10, 11]

The economy is currently based on a mixture of state control and private enterprise. The former regime extended state control over economy in the mid- to late 1970s but the government that took power in 1991 began releasing many of these controls. Many governmentally owned properties have since been transferred to governmentally owned enterprises. State control is nevertheless still apparent in the country with telecommunications remaining a state monopoly as well as the financial bank system. The Ethiopian constitution also prevents its citizens to own, mortgage or sell their land as belonging "*only to the state and the people*". Citizens are however able to lease the land up to 99 years. [12]

Agriculture is without a doubt the most significant sector of the Ethiopian economy. It accounts for more than 45 % of the GDP, 80 % of foreign exchange earnings and constitutes approximately 80 % of the total employment in the country. It is the most promising resource in which many economic activities rely on such as export of agricultural products. The main crops are coffee, beans, oilseeds, cereals, sugarcane, vegetables and the mild narcotic *Khat*. The well-known Ethiopian coffee is currently the largest export commodity and main income for many farmers. Other exports include livestock, leather products and gold. [7]

The manufacturing industry contributes to about 5 % of the economy and is mainly concentrated in Addis Abeba and Dire Dawa. The goods that are produced are mainly for the domestic market and include food and beverages, textile, wood products, steel and cement. The mining sector contributes to about 1% of the economy. Deposits containing platinum, limestone, copper and iron have been discovered but gold is currently the main mineral mined on larger scale. The most important resource of energy is from hydropower, deriving approximately 90 % of the generated electricity. This heavy reliance has made the country vulnerable to lengthy droughts and the national electrical-grid is currently still undeveloped. [7]

3. Problems that Ethiopia are facing related to this project

3.1 The population growth rate

With a rapid annual population growth rate, the Ethiopian society is one of the fastest growing worldwide and at the same time one of the poorest around the globe. Ethiopia was in 2008 home for approximately 79 million people and the population is expected to grow rapidly in the upcoming years. In 2025 the population could reach more than 125 million and it is important to find answers on how they can be housed in a humanitarian way. The people are in a big need for firewood and building materials and it is important to present sustainable solutions. The housing question is furthermore not the only issue to consider. An overpopulated country is also in a big need for recourses such as water, food, security, jobs, infrastructure and education. These issues must be carefully considered and consistent solutions must be presented to prevent a difficult and intolerant future. [6]

3.2 Lack of education

Ethiopia faces many historical, social, cultural and political obstacles that have limited the education process for many decades. There is a common statement in the country, especially in the country's rural areas, that work is more important than education. It is customary for children to start working at young age with little to no education handed to them to support their families economically. Studies conducted by UNICEF in 2003-2008 show that only about 37% of males and 24% of females are enrolled in secondary school. It also suggests that the largest single reason for non-attendance to secondary school was that parents could not afford to pay school fees for their children. Other identified obstacles were lack of funds for educational supplies, children staying home to do housework or having too far to walk to their schools. [13]

The lack of education isolates the country and its people and prevents new knowledge and ideas to come to existence. It prevents the spread of new techniques such as alternative low-cost housing methods and encourages conservative ways of thinking in different subjects. Despite governmental efforts and major campaigns during the last years, the lack of education is still a major issue in current Ethiopia.

3.3 Urbanisation

Ethiopia is one of the least urbanised countries in the world but most recent trends suggest that the urbanisation rate is rising hastily. Many of the people in rural areas of the country seek hope of better living conditions in larger cities such as the capital Addis Abeba. Although all of Ethiopia suffers from poverty, the living conditions are far better in the cities than in rural areas. There is better access to education and health, use of improved water sources is greater and the death rates are significantly lower in the larger cities. This increase in urbanisation is straining the governments' capacity to provide its people with basic services. It also decreases the productivity in the agriculture sector and results in fewer people to grow food for the population. By being aware of these issues, solutions must be presented to attain a sustainable future regarding housing for the population. [14]

3.4 Housing and Infrastructure

Due to the rapid population growth and urbanisation, housing shortages and overcrowding are major issues in Ethiopia. Homelessness is a major problem especially in the urban areas. It has been estimated that 80 % of the inhabitants in Addis Ababa are homeless or live in low-grade dwellings. The majority of the people live in city slums with poor housing solutions and sanitation. Improving the housing conditions in both rural and urban areas of the country would considerably improve the population's wellbeing. [15]

Lack of building laws and urban planning is also considered a big problem. There is an absence of federal and regional building laws as well as guidelines and codes regarding urban planning. The lack of urban planning is highly visible in Addis Abeba; a city that has been developed with an unusual geographical pattern where luxury hotels are right next to city slums. The fortunate inhabitants in the city slums construct their dwellings using the materials that are available, with walls of mud or wood and roofs of waste metal. There is a growing need for sustainable low-cost housing alternatives in the rural and urban areas of Ethiopia and these ideas should be integrated in the framework for building and urban planning codes.

The electricity is generated from two sources; hydroelectric power plants and thermal power stations and is connected to national grids which cover the main cities. The main cities also have public water supply systems but both grids are very underdeveloped and vulnerable resulting in deficiency of electricity and water. The rural areas of the country are less covered, and as the population is increasing the demand for an improved water and electricity system is rising. [7]

Picture 2. *Housing solutions in the centre of Addis Abeba.* [5]

3.5 Deforestation and Erosion

Deforestation is the process when forests are cleared, either by cutting down tree-plants or burning woodlands, and changing the form of the land to suit different uses. This is a major concern in Ethiopia and is the outcome of the populations needs, for example for fuel, housing developments and agriculture. The cleared land is often used as grazing land for livestock, plantation and settlements for the population. Timber is also used in larger scale as building material both in rural and urban areas of the country.

Ethiopia has been broadly covered with forests and vegetation because of the rugged terrain and the annual rainfall. The accelerated deforestation in the last years has resulted in an immense decrease of land covered with forests, from 30 % in the late nineteenth century to less than 4 %. [16]

The existing eco-system is highly affected by the process of deforestation and will often result in the land being eroded. Erosion is the natural process of breaking down and removal of soil and rock. The removal of tree-plants and vegetation, which anchors the soil to their roots, results in the soil being vulnerable to both wind and water erosion. During heavy rainfall the soil will often be washed away, leaving a degraded land with little to none vegetation. This is also of major concern in today's Ethiopia, especially in the northern areas of the country. A high population growth, farming on steep slopes, deforestation, and overgrazing are the main factors that accelerate soil erosions in Ethiopia. The annual rate of soil loss in Ethiopia is higher than the annual rate of the soil formation rate. Studies performed in 2008 suggest that Ethiopia loses over 1.5 billion tons of topsoil from the highlands to erosion. This soil could have added about 1.5 million tons of grain to the country's crop production. This should be of good indication that soil erosion is a very serious threat to food security of the population and requires urgent attention. [17]

Picture 3. *Erosion of the land in the Kambaata region.* [5]

3.6 Termites

As mentioned in the previous chapter, the usage of timber as building material is very widespread in Ethiopia. The commonly used sorts of timber are Eucalyptus, Zigba, Karraro and Sombo and they are all very sensitive to termite attacks. Termites are a group of insects that feed on dead plants, wood, leaves, soil and animal droppings. Due to their wood-eating behaviours, many termite species can do significant damage to unprotected buildings and other timber structures. The damages in the structures are often discovered at a late stage, due to the insect's habits of remaining concealed. Due to lack of termite protection and high usage of sensitive timber, the traditional houses in Ethiopia are very vulnerable to termite attacks resulting in a decreased lifespan. The replacement of damaged timber often leads to additional use of timber in the traditional houses which is not a sustainable approach for the future. It is therefore of high importance to spread the knowledge regarding termite protection and present new sustainable materials which can replace timber as construction material. [1, 3]

4. Cement Stabilized Soil Blocks (CSSB)

4.1 Introduction

The problems that are described in the previous chapter mutually contribute to a great need for sustainable low-cost housings in Ethiopia. This need is growing rapidly and solutions need be presented for the population and spread throughout the country. The technologies that are presented also need to be developed so that they are easily implemented with the available recourses in the different regions in Ethiopia.

A great deal of the costs in housing construction is directly linked to building materials. The building techniques used in the western world is highly expensive and requires an intense amount of energy. The methods may not be suitable for implementation in third world countries such as Ethiopia. By using appropriate technology suitable for the region and available recourses that are offered locally, the costs for building materials may be cut down significantly.

One of the most available building materials, used for centuries throughout the world, is soil. Earth construction has been the most effective way of building homes for the population in third world countries and has shown promising results for an economical solution of the housing problems. Soil is however often considered a low-grade material and people in general prefer modern materials such as concrete. Examples of poorly constructed and maintained soil buildings can easily discourage the population in need of sustainable low-cost houses. The knowledge regarding modern soil techniques in Ethiopia are poorly spread throughout the regions and this encourages traditional ways of building which may not be sustainable and can cause harm to the natural environment.

There have been a great number of researches that has been carried out regarding modern soil techniques to improve the housing conditions for the population in third world countries. One is research regarding compressed soil blocks and in this chapter the methods of Cement Stabilised Soil Blocks (CSSB) will be in focus. [18]

Picture 4. *Interlocking CSSB at Selam Technical and Vocational Center, Addis Abeba.* [5]

4.2 Components

A CSSB is a building block made from soil, water and cement; working as a stabiliser, mixed and compressed in a pressing machine.

4.2.1 Soil

Soil is the main component that the CSSB consist of. There are soil of different qualities and disposition, depending on where it comes from and it is important that the soil has the right composition before being mixed with the cement and water. Before producing CSSB, the soil must be tested to determine if it is suitable for the CSSB-production (more of this in chapter 6.5)

The ideal soil for the CSSB contain 50-75 % of coarse sand and fine gravel, 20-40 % of silt and fine sand and 5-10 % of clay. Pure sand may be added to the soil to obtain the right proportions of the soil but should be avoided due to the costs of purchasing sand and the transportation costs. The finer fractions of the soil such as the clay and silt contribute to the fresh block not falling apart while the sand and gravel reacts with the cement to stabilise the cured and dry block. Soil containing humus should not be used since it opposes the cement and it is therefore important not to use the topsoil (30-40 cm). The pH level is also of important factor; soil having a pH level below 4.5 or over 10 should be avoided as well as soils containing more than 2 % of sodium and potassium salts. [18, 19]

4.2.2 Cement

The cement works as a stabiliser and prevents the blocks from being decomposed when in contact with water. By adding cement, the blocks will have further improved durability, strength and volume stability due to the chemical reactions taking place between the cement and the soil. The effects will be in proportion to the cement quantity and the strengths of the blocks will generally increase linearly with the cement content, but at different rates for different soils. There is no need of adding more cement than needed for the purpose of the soil blocks due to the high costs of cement. The recommended cement rate is normally at a rate of 4-10 % (weight) depending on the type of soil. [18]

4.2.3 Water

Soil contains pores filled with air and water and these spaces will be reduced during compaction. By adding more water to the mixture the grains will be lubricated and air voids will be replaced making it easier for the grains to slide past one another. Water is also necessary in the hydration process of the cement. It will together with the silt and clay make the fresh block not fall apart after being pressed. The amount of water varies depending on the dryness of the soil. [18]

4.3 Production process

The CSSB can give an impression of being a high quality construction material although being based on simple production methods. The blocks are suitable for the population with a low income and the resulting building costs may be cut down significantly if the blocks are to be manually produced. The following production process is related to small scale production using manual machines and labourers. The different processes are illustrated in Figure 2.

4.3.1 Grinding and pulverisation

The soil must initially be pulverised to obtain uniform mixing of the components. Lumps and larger pieces of soil are broken up usually by being pressed between two surfaces. Grains with a homogeny structure such as stones and gravel must be left unbroken and separated from the soil. The grains having a composite structure such as clay must be broken up so that at least 50% of the grains are less than 5 mm in diameter.

There are different types of machines for this purpose. It is on the other hand easy to obtain a uniform pulverised soil by manual pounding without acquiring expensive machinery for this purpose. The easiest way of preparing the right soil mixture is by moulding it with the feet or using animal power. The soil will be easily crushed and pulverised when being moist. It is however very important that the soil is properly dried before being mixed. Wet or moist soil will react sooner with the cement before being properly mixed, resulting in inferior qualities of the pressed blocks. [5, 18]

4.3.2 Screening

This is a necessary part of the process and is essential when the pulverisation has been incomplete and there are large particles in the soil. To separate them from the soil, a fixed screen is set up at an angle or is suspended. Although there are mechanically available machines for this job, the operation is easily carried out manually. Raw soil is thrown with a shovel at the top of the fixed screen. The screened soil is then loaded onto a wheelbarrow and is ready to be mixed with the other components while the larger unscreened material is rejected. It can be used for other purposes or can be further grinded and pulverised and once again be screened. In most cases grains up to 10 mm are passed and obtained during this process. [5, 18]

4.3.3 Mixing

The importance of proper mixing should not be underestimated in the production process. It ensures the succeeding quality of the product and of the structure itself. It also guarantees that the blocks are built economically in the case that it optimises the proportions of the components. As mentioned before, only dry materials and liquids can be mixed. Mixing dry and moist materials will create certain problems especially in the case when a stabiliser such as cement is included. The dry soil and cement should be mixed properly until it is of a consistent colour and no dissimilar layers can be seen in the mixture. The amount of water is added afterwards by progressive sprinkling of small amounts. Too much water will reduce the strength of the blocks hence it is important to use the right amount. Right amount of water has been added to the mixture when a sample, that being squeezed in the hand, stick together without any water seeping out.

The planning of the mixing is important; mixing of soil is very different to the mixing of concrete, because while concrete is not cohesive, soil is. There is a risk of formatting of lumps and crumbs that could reduce the strength of the blocks. The most economical way to perform this operation is by manual mixing. This is carried out usually by one or two individuals using a shovel, mixing the amounts on a hard surface. The mixture must be pressed without delay after water has been added to the soil and cement mixture due to the danger that the cement may set prematurely. [5, 20]

4.3.4 Pressing

A pressing machine is loaded with the right amount of the wet mixture of soil, cement and water. There are currently different kinds of presses available on the market both manual and mechanical. The best-known press worldwide is the manual Cinva-Ram, developed in Colombia. There are other types of presses that are similar to the Cinva-Ram and many imitators are available on the market. The advantages of these types of presses are that they are light, manually operated, low-cost, have a simple sturdiness and are easily produced and prepared. The disadvantages are that they only have a single moulding module, are low pressured and have a low output compared to the mechanical presses. The average output is approximately 150-300 blocks per day.

The press will compress the mixture, shaping it into a block. Different shapes such as angular or interlocking blocks can be produced by changing the form of the pressing mould. The pressed blocks need to be transported to a storage room, preferably at a close distance to the pressing machine. [5, 20]

4.3.5 Curing

It is important to protect the pressed blocks from rain and sunlight. The curing shall therefore take place in a rain protected storage space for at least four weeks. The blocks can be carried to the curing area by hand. It is best to use a flat board to lift and carry the blocks because this prevents any damage to the blocks. The blocks need to be cured in shade on a clean and levelled area and should be stacked no more than 5 blocks high until they are fully cured. Spaces should be left for air to pass between the blocks.

Curing is the process of the blocks getting stronger and setting hard and this process is divided into two parts; wet and dry curing. During the first 7 days the blocks should be watered, preferably sprinkled once per day and covered with plastic sheeting. If the blocks are not kept moist, there is a possibility that they will crack or be weakened due to the shrinkage of the clay in the soil. After 7 days the plastic sheet should be removed and the blocks will start their dry curing for at least 21 more days before being used. The curing phase is essential for the blocks future strength and durability and should be carefully executed. A sample of the blocks should be pressure tested before being used to ensure that they meet the criteria regarding their strength. [5, 21]

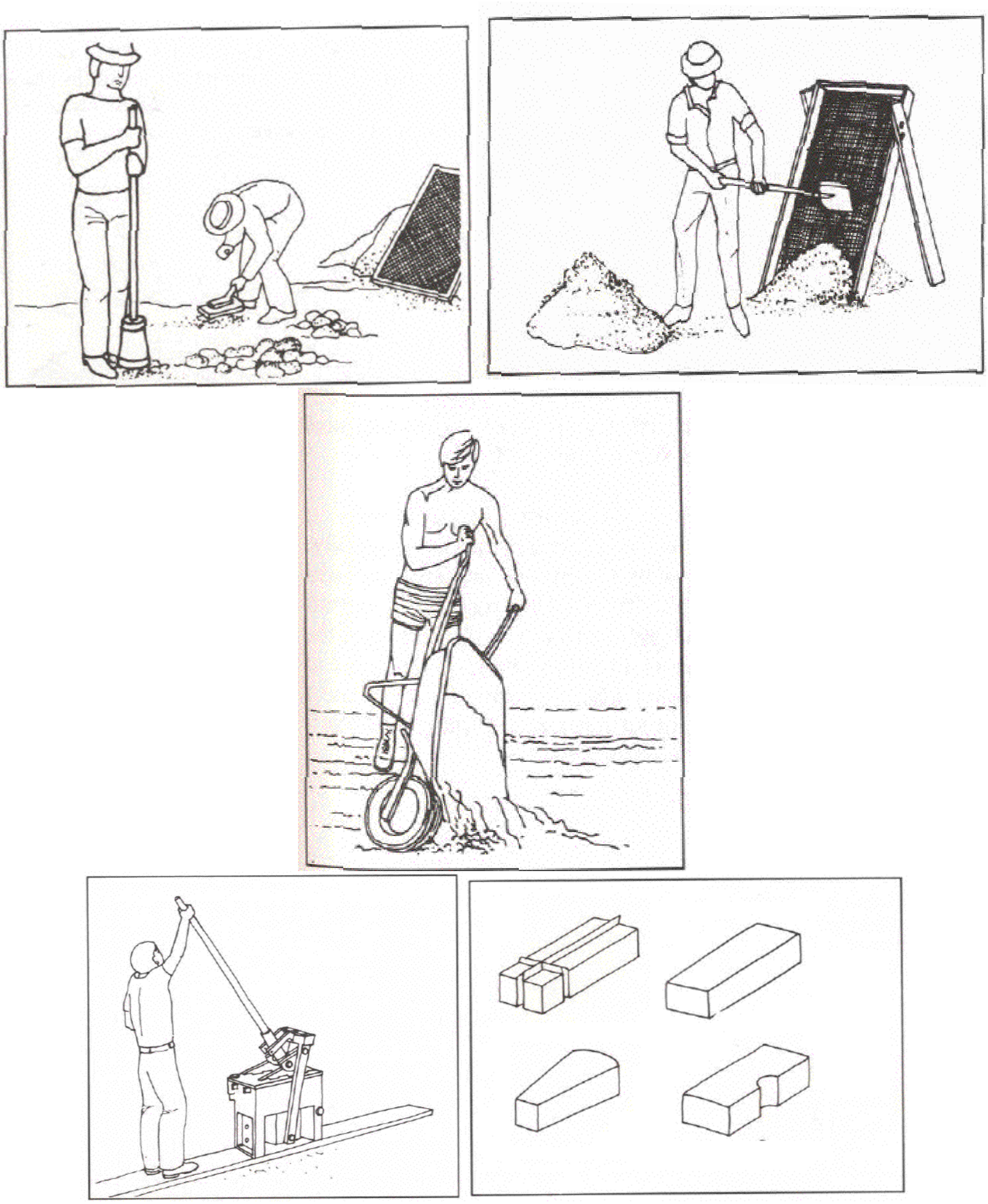


Figure 2. *The production process of CSSB; Grinding and Pulverisation, Screening, Mixing, Pressing and Curing.* [20]

5. Low-Cost housing projects in Ethiopia

Low-cost housing projects are a fundamental part of developing sustainable homes for the population in third world countries. The needs for sustainable solutions are growing rapidly in Ethiopia and solutions must be offered to the population and hopefully spread throughout the country. By constructing demonstration houses, the unfamiliar technologies will be spread to the society, showing the population the advantages they hold compared to traditional ways of building. The Low-Cost housing projects that have been studied in this project will be further described in this chapter.

5.1 Previous Studies at Halmstad University

There have been a numerous of low-cost housing projects that have been carried out in Ethiopia by different organisations from around the world. The main research project at Halmstad University was initiated in 2002 in an attempt to introduce low-cost housing technologies for the Kambaata Region in Ethiopia. The programme was initially formulated with five sub-projects; an initial survey, the development and testing of new house-building technologies, the demonstration projects, attitudes towards new house building technologies and guidelines and recommendations for implementation programme. The aim of this project has been to develop and test new, sustainable, low-cost building technologies intended for the population, with regard to local traditions, needs and affordability.

There have also been three previous field studies that have been carried out by students at the Construction Engineering programme at Halmstad University, all connected to the main research project. The first one was completed in 2002 and focused mainly on different low-cost housing materials that could replace the traditional ways of building. The second one included a study of two different block technologies and the design of an elementary school constructed with these technologies.

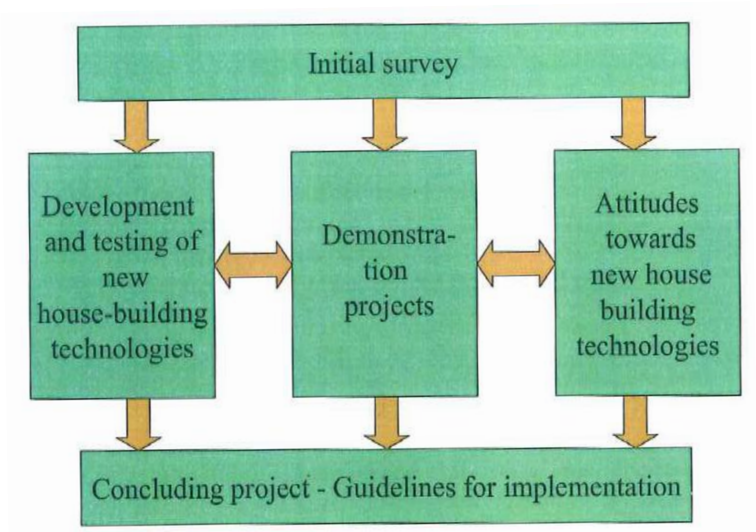


Figure 3. *Initial project programme at Halmstad University.* [4]

In the third and previous study *Low-Cost Housing for the Kambaata region, Ethiopia* performed by Johansson and Wartanian in 2008, numerous sites and low-cost housing projects were observed. The project resulted in a set of drawings and a cost calculation for two houses intended to function as demonstration houses in the Kambataa region. The results of these field studies have demonstrated that the research about the technology is relevant, essential and financially feasible.

Since the initiation of the project, the initial survey has been completed while the development and testing of new house-building technologies and the mapping of attitudes towards new house building technologies have been partly executed. Due to lack of sufficient funding the progress of the original plan has been slow. A minor research application has however been approved and the sub-projects currently consist of;

1. Demonstration project – erection of two dwelling houses
2. Studies regarding attitudes towards new house building technologies
3. Technical follow-up studies

This degree project mainly belongs in subgroup one, with a primarily focus on one of the methods of block technology; CSSB-technology. During the 7 week field-study that was carried out in April-May of 2010 in Ethiopia, mainly two low-cost housing projects were in focus; The demonstration project in Durame and The SUDU-project at Addis Abeba University. These two projects will be further described in following chapters along with two other projects. [3, 4, 26]

5.2 The demonstration project in Durame

5.2.1 General description

The demonstration project in Durame is a sub-project to the previous studies performed at Halmstad University with the aim of developing and testing new, sustainable and low-cost house building technologies intended for the population in the Kambaata region in Ethiopia. The objective is to erect two small, low-cost dwelling houses in Durame, one constructed with Adobe blocks and one with CSSB. It is the intention that the local organisation *Kembata Temro Malemat Mahber* (Kembata Learning and Developing Association) will be the owner of the buildings, using the facilities to demonstrate the usefulness of the new technology to the society.

The Kambaata region is approximately 300 km south of Addis Abeba. The site area where the buildings will be erected is 4384 m² and is located in the east outskirts of Durame. The site has an evenly inclination and previous surveying at the site have determined the difference between the highest and lowest point to 9.7 m. The vegetation on the site consists mostly of coffee and banana plants. The sitemap in Appendix A illustrates the site and the height differences. [3, 4, 5, 26]

5.2.2 The Buildings

The buildings that are intended as demonstration houses were designed in previous field study; *Low-Cost Housing for the Kambaata region, Ethiopia* conducted by Johansson and Wartanian in 2008. The major construction elements can be described according to the following:

Construction element	Description
Foundation	Stone Masonry
Flooring	Stone paving with cement-mortar screeding
Walls	Adobe Blocks and CSSB
Windows	Timber, locally produced
Doors	Timber, locally produced
Roofing	Corrugated iron sheets on eucalyptus purlins and trusses

The intention is to construct four buildings on the site consisting of:

Building	Size	Remark
Dwelling house	5.7 x 5.5 m^2	Walls of Adobe blocks
Dwelling house	5.7 x 5.5 m^2	Walls of CSSB
Kitchen building	3.4 x 3.4 m^2	Walls of Adobe blocks
Toilet building	2.5 x 5.5 m^2	Walls of Adobe blocks

Excavation of the site started in the end of February 2010 and the foundation work consisting of stone masonry were completed in the end of April. The following pictures were taken during my field study; one being taken the 9th of April and the second one 14th of May 2010. During this period there had been a delay in the construction work due to heavy rain and rising cement costs (the costs for 100 kg Portland cement rose from 225 ETB to 420 ETB during April-May 2010). The builders had also been experiencing communication problems regarding financing. This specific problem was however solved during our last trip to the site in May 2010.


Picture 5 (Left). *Excavation of the site in Durame, taken 9th of April, 2010.* [5]
Picture 6 (Right). *Foundation works on the site, taken 14th of May, 2010.* [5]

Additional information regarding the buildings and important details can be found in the previous field study; *Low-Cost Housing for the Kambaata region*, *Ethiopia* conducted by Johansson and Wartanian in 2008. The building drawings are provided in Appendix A, completed with details and information. [3, 4, 5]

5.2.3 Project execution and Cost estimation

The project is intended to be implemented in three phases. The content of the phases and the related costs are presented in Table 1. The cost estimations are from January 2010 and are based on the currency rate 1 US $ = 12.70 ETB (Januay 12, 2010).

Phase	Main Content	Estimated cost, ETB	Estimated cost, US$
1	Site preparation Construction of foundation Construction on roofing on temporary structure	35964	2832
2	Preparation of blocks	15396	1212
3	Erection of walls Mounting of doors and windows Construction of flooring	30541	2405
Total		81901	6449

Table 1. *Project execution phases and costs*. [4]

Table 2 shows the estimated costs for the demonstration buildings.

	ETB			US$
Item	Material	Labour	Total	Total
Dwelling house, Adobe block	13437	6010	19447	1530
Dwelling house, CSSB-block	22177	5319	27496	2164
Kitchen building, Adobe blocks	4593	2439	7032	553
Toilet building, Adobe blocks	2150	1620	3770	297
SUBTOTAL 1			57745	4545
General costs on site			5000	394
Transportation			2000	157
SUBTOTAL 2			64745	5095
Contingency, 15 %			9712	764
SUBTOTAL 3			74457	5860
Administration costs 10 %			7446	586
GRAND TOTAL			81902	6446

Table 2. *Estimated costs for the demonstration buildings in Durame*. [4]

5.3 Sustainable Urban Dwelling Unit (SUDU) - project at Addis Abeba University

The SUDU-project is part of a research project titled *Appropriate: Ethiopia* initiated by The Swiss Federal Institute of Technology (ETH) in cooperation with Ethiopian institute of Architecture, Building construction and City development (EiABC).

During my field study in Ethiopia I had the opportunity to be involved and integrate my research with the SUDU-project which was held on campus at Addis Abeba University. I got the chance to follow the erection of the SUDU-building during two months in April-May and I was mainly involved in the testing of CSSB [22, 25]

5.3.1 Background objectives and goals

The objective of the project is to promote and implement future-orientated strategies in building technology and urban design that advance new attitudes regarding sustainable development in Ethiopia. The social and economic concerns are addressed; the erection of the SUDU and the technologies used will hopefully be followed and implemented by local inhabitants. The aim of the project is to inspire the community by creating a structure with which the locals can identify. Creating local jobs and raising traditional building techniques embedded in the culture, such as the usage of clay tiles and the vaulting technique will hopefully encourage the population to rethink current tendencies which may not be sustainable for the future.

One of the projects long-term goals is to educate the Ethiopian population about the country's concerns such as the urbanisation, deforestation and housing shortages. Currently there is a high demand of educated architects, planners and construction managers in Ethiopia possessing knowledge regarding sustainable low-cost housing technologies. By constructing a 1:1 scale of a sustainable low-cost building involving students at EiABC as well as ETH in seminars, workshops and summer school, the project will help to build a new ideology in the education of future planners, designers and builders. It is intended that the structure will be used for exhibitions and a small publication will show the implementation of the SUDU for the future urban development of Addis Abeba, Ethiopia. [22, 25]

5.3.2 The building

The SUDU-project consists of building a 2-storey residence house intended to work as a demonstration building for the population in Ethiopia. The structure is built on the grounds of Addis Abeba University and was designed in cooperation of ETH and EiABC. The intention is to include new, sustainable construction technology in the project such as the methods of rammed earth, CSSB and biogas systems as well as constructing an easy to operate and maintainable building.

The major constructions elements of the SUDU-building are the following:

Construction element	Description
Foundation	Reinforced concrete slab
Flooring	Screedwood
Walls	Rammed earth and Interlocking soil blocks
Windows	Timber
Doors	Timber
Roofing	Ring beam, vault constructed with 8 % cement clay tiles

Surveying and excavation work of the site started in the middle of Mars 2010. I had the chance to follow the progress during 7 weeks, starting in the beginning of April with the foundation work and testing of materials such as the CSSB. There were many students from EiABC involved in the project, working on research sub-projects or on site as building managers. The workers were hired locally and were all Ethiopian, some having received training from Selam Technical and Vocational Center in Addis Abeba.

The walls of the first floor of the building were built with rammed earth technology. This method is a fairly straightforward affair: earth and soil is tipped over into a formwork, and compacted, “rammed”. This is an ancient building method found on every continent dating back to as late as 4000 BC. The forms are usually of timber, connected by steel ties and this was the method of use at the SUDU-project. Further description of this method can be found in *Low cost housing for the kambaata region, Ethiopia, an invesitigation of new building materials* by Berglund and Andersson in 2002.

The walls of the second floor consist of interlocking soil blocks. To find suitable soil for the block-making, the block production team had to test a few soils from different sites around Addis Abeba. The tests that were performed were fraction-size tests, sedimentation- and simple consistency-tests to identify which of the soils were suitable for block production. During the test production of the blocks, we used different proportions of cement from 0 % - 10 % to determine at which proportion the blocks would meet the criteria regarding their strength and durability. The blocks with a 6-8 % cement content showed enhanced quality regarding their robustness after being pressed. Surprisingly the blocks without any cement content showed good qualities as well after being pressed. This lead to the decision that the 2nd floor should be built with interlocking soil blocks, with no cement. After the walls have been constructed, they will be rendered to prevent the walls from being decomposed when in contact with water. The drawings and schedule of the project are attached in Appendix D. Following pictures 6-8 illustrates the construction process of the SUDU-building. [5, 22, 25]

Picture 7. *The concrete foundation is completed and formwork for the rammed earth is placed in position. May 2010.* [5]

Picture 8. *The first floor wall, built with rammed earth is completed. The picture also illustrates the scaffolding and weather protection. June 2010.* [25]

Picture 9. *The construction of the 1st floor vault is under process. 3 different layers of tiles containing 8 % cement were used. The CSSB-walls of the 2nd floor are being constructed. July, 2010.* [25]

5.4 Selam Technical and Vocational Center

Selam Technical and Vocational Center (STVC) is located in Addis Abeba and was established over 20 years ago. The centre provides child care for orphans, education, vocational training and development of appropriate and sustainable technology. By providing courses in different subjects, such as construction technology the centre aims to train and educate the population and contribute to a more sustainable future. Since its establishment it has grown to a well equipped and organised training college and is currently in the forefront of CSSB-production. It also has an extensive production of other types of soil blocks such as Adobe blocks and produces different types of block making presses.

Different types of CSSB are produced at their facilities, all with different shapes. The most common produced block is the interlocking CSSB, with a cement proportion of 8 %. Another type of block has one corner made as a quarter of a circle which is ideal for corners or freestanding columns. The productivity is approximately 4 blocks per minute using the electrical press and the blocks were then placed under shade for 28 days of drying. The blocks are then sold to costumers with a price range of 3-8 ETB per block (1.50-4 SEK) depending on the type block.

I made several site visits to *STVC* during my field study and had the opportunity to produce my test blocks using their facilities. The Center has good knowledge and experience of appropriate building technology and is eager to share it to the Ethiopian population. [5]

Picture 10 (Left). *An employee at STVC holding a manually pressed CSSB.* [5]
Picture 11 (Right). *The kitchen facility at STVC, built with interlocking CSSB.* [5]

5.5 Save the children, Office building

Rädda Barnen, the Swedish save the children organisation has an office building in Mekanissa, situated on the hill to the Akaki River in Addis Abeba. The office consists of a two storey building with a concrete frame and a roof that is made out of Onduline; a corrugated asphalt impregnated cellulose sheet making the roof lightweight.

The interior and exterior walls consist of CSSB and were produced on the site with the soil from the site. The block production team was introduced to the block making methods and trained by Abako International Partners, an architecture and construction management company based in Gothenburg Sweden. The blocks in the exterior walls are 200 mm wide and have a cement content of 15 %. The blocks in the interior walls are built with 140 mm wide blocks and have a cement content of 7 %. The walls were then painted with emulsion paint.

The building was built from 1995-1997 and has a gross area of 850 m². It is of good demonstration that the CSSB can be used in office buildings and not only used in low-cost housing projects. [5, 23]

Picture 12. *The Save the children Office building in Addis Abeba.* [5]

6. Field study project; Producing and testing of CSSB

6.1 Background

As described in the previous chapter about the demonstration project in Durame; one of the houses is planned to be constructed with CSSB-technology. In previous field studies that have been carried out, different tests such as bottle test, roll-test and shrinkage-test of the site-soil has been performed to find suitable methods of constructing the houses. In the first field study titled *Low cost housing for the Kambaata region, Ethiopia, an investigation of new building materials* by Berglund and Andersson in 2002, two simple soil tests were performed; bottle test and roll test to measure the clay content. They collected soil from two different sites in Durame, one black soil and one red soil. The results of the tests showed that the clay content were high; 46 % in the black soil and 37.5 % in the red soil. The test results allowed them to recommend the red soil added with sand for CSSB-production, because of the lower content of clay.

In the second field study titled *Low cost housing for the kambaata region, Ethiopia, a demonstration project* by Carlsson and Gustavsson in 2003, two tests were completed; a bottle test and a shrinkage test. They collected samples from the site soil in Durame and wanted to find out its content, and from that decide which technology the soil is most suitable for. The result was that the soil had a very low content of sand, not suitable for CSSB-production. The shrinkage of the soil was within limits, making it suitable for block making. They drew the conclusion that the soil is suitable for producing Adobe blocks. They also produced some Adobe blocks of the soil from the site in Durame, and carried out a test of compressive strength on one of the blocks with good result; the block resisted 1.4 MPa.

There has been no attempt to produce CSSB from the site soil in Durame,. My project was to produce test blocks with different cement and sand content to find out if the CSSB-method is promising and if the blocks meet the requirements regarding strength and quality.
[1-4, 26]

6.2 Description

The task was to produce 24 CSSB with different cement and sand contents from the soil from the site in Durame. The blocks would be divided into 6 groups with 4 blocks in each. Table 3 shows the different groups and their description.

Group	Description	Quantity (Blocks)
1	0 % Cement, Soil and Water	4
2	4 % Cement, Soil and Water	4
3	8 % Cement, Soil and Water	4
4	0 % Cement + 10 % Sand, Soil and Water	4
5	4 % Cement + 10 % Sand, Soil and Water	4
6	8 % Cement + 10 % Sand, Soil and Water	4
		∑= 24

Table 3. *A description of blocks that would be produced.* [5]

The amount of cement and sand content was measured in weight percentage. Cement is an expensive component in the CSSB so the range from 0-8 % was suitable for this project.

It was decided that soil from the site in Durame would be collected, and transported to Addis Abeba. A sample of the soil would be taken and tested regarding to its grain size distribution. For the production of the blocks, *Selam Technical and Vocational Center* in Addis Abeba would be highly suitable due to their knowledge and experience in producing CSSB. The blocks would be cured and stored in their facilities and each block would be pressure tested after 28 days, using their hydraulic jack.

6.3 Collecting the soil

The collecting of soil took place during a visit from Addis Abeba to Durame between the 7th and 8th of April, 2010. The aim of the visit was to collect an amount of soil for the block-production, talk to the builders on site and to see the construction progress of the demonstration houses in Durame.

The measured amount of soil to be collected was set to 300 kg, which would be an adequate amount to produce 24 CSSB and for taking soil samples for the testing. The soil was collected in sacks, weighed on a simple weighing scale on hard surface and loaded on the back of our pickup truck. The sacks were sealed to protect the soil from leaking, strapped with ropes and covered with a plastic sheet to prevent the soil from being drenched from any rainfall during our trip back to Addis Abeba. [5, 26]


Picture 13 (Left) *Soil from the construction site in Durame was collected in sacks,...*[5]
Picture 14 (Right) *...weighed and loaded on the back of the pickup truck. 7th of April 2010.* [5]

6.4 Preparing the soil

The soil was transported to Addis Abeba and was spread evenly on a plastic sheet in the shade for drying. It was fairly damp and contained lumps and larger pieces such as stones, leaves and branches. Those pieces were removed as well as possible by hand and the lumps were crushed either by foot or by a wooden tool. The soil was mixed and turned over with a shovel once per day to quicken the drying process of the soil. The soil remained on the compound until my permission to produce the blocks at *Selam Technical and Vocational Center* in Addis Abeba was granted. [5]

Picture 15. *The soil was spread out on a plastic sheet in the shade for drying. 10th of March, 2010.* [5]

6.5 Soil tests

Soil tests were in this project performed to find out if the soil was suitable for CSSB-production. Two different tests had to be performed; Sedimentation test and Grain size distribution test.

6.5.1 Sedimentation test (Bottle test)

The sedimentation test, also known as a "bottle test" is an easy method that can be used for measuring the percentage of gravel, sand, silt, and clay in a soil sample. The method is based on the fact that large and heavy particles will settle faster in water, while small and light particles will settle more slowly. After the soil has been settled, one can hopefully distinguish the different layers of gravel, sand, silt and clay, settled on the bottom of the glass jar or bottle that has been used. Salt may be used to accelerate the sedimentation process. [18]

A sedimentation test of the soil from the site in Durame was carried out at the testing department in Addis Abeba University on the 19th of April 2010. The test is easy to carry out at home but was here accomplished with the help of the supervisor of the testing department in Addis Abeba University. Table 4 shows the components and the amounts that were used.

Component	Amount
Soil	182.8 g
Salt (table salt)	10 g
Water	1000 ml

Table 4. *The components and their amounts used in the sedimentation test*. [5]

The soil that was used in the test was crushed and sieved. The different components were poured into a graduated cylinder and properly shaken for approximately 3 minutes. The cylinder was then placed on a table for settlement. The time to identify the layers was set to 3 hours. The result of the test was however not assuring. The soil had settled after 3 hours but any layers of gravel, sand, silt and clay could not be identified and measured. The test was performed at another occasion with the same result. The explanation why no layers could be identified would later turn out to be due to the dominance of one particle fraction that was silt.

The sedimentation test is easily carried out but is not precise method of measuring different contents in soils. To measure the accurate percentage of gravel, sand, silt and clay in a soil, a grain size distribution test had to be performed. [5]

Picture 16 (Left). *The supervisor at the testing department is mixing the components.*[5]
Picture 17 (Right). *It was difficult to identify the different layers in the soil.* [5]

6.5.2 Grain size distribution test

A grain size distribution test is similar to the sedimentation test but takes longer time and is more accurate. The test was performed at the testing department of Addis Abeba University, using their Particle Size Distribution-device, which sieved the soiled according to their size over a longer period of time, in this case during 1400 minutes. Following distribution curve was received after the test was completed.

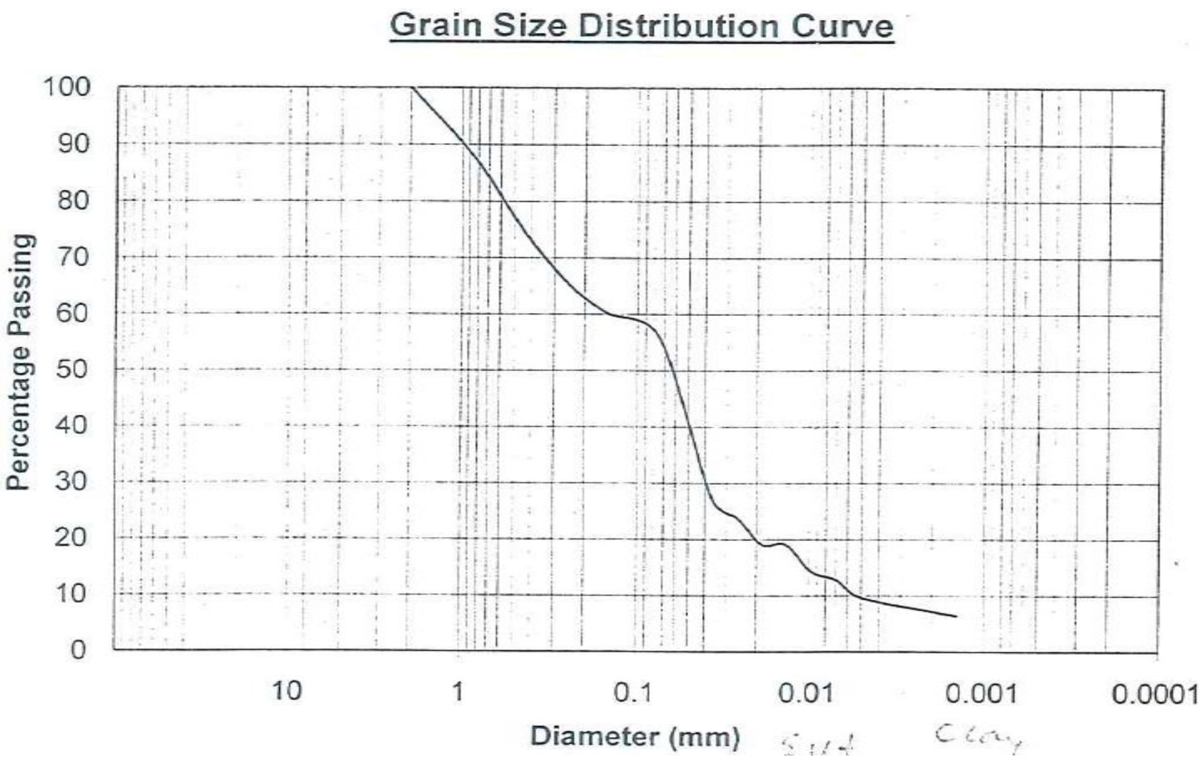


Figure 4. *The grain size distribution result of the soil from Durame.* [5]

With the help of the grain size distribution curve I was able to measure the percentages of gravel, coarse sand, fine sand, silt and clay in the soil. Table 5 shows the result of the test, with the distribution of the fractions in the soil.

Fraction	Diameter of particles	Distribution (%)	Distribution (%)	Optimal distribution (%)
Gravel	2-20 mm	0		
Coarse sand	0.2-2 mm	37	37	50-75
Fine Sand	0.02-0.2	44		
Silt	0.002-0.02	13	57	20-40
Clay	0.0-0.002	6	6	5-10
		∑= 100 %	∑= 100 %	∑= 100 %

Table 5. *Fraction size, distribution of the soil and optimal distribution for CSSB-production.* [5, 18, 19]

The ideal soil for CSSB-production contain 50-75 % of coarse sand and fine gravel, 20-40 % of silt and fine sand and 5-10 % of clay. This means that our soil needs to contain more coarse sand and fine gravel, and less fine sand and silt to be optimal for CSSB-production. The amount of clay is within the optimal limits. [19]

Figure 5 shows the grain size distribution zone which is recommended for compressed earth blocks. The dotted line in the graph represents our soil that has been tested.

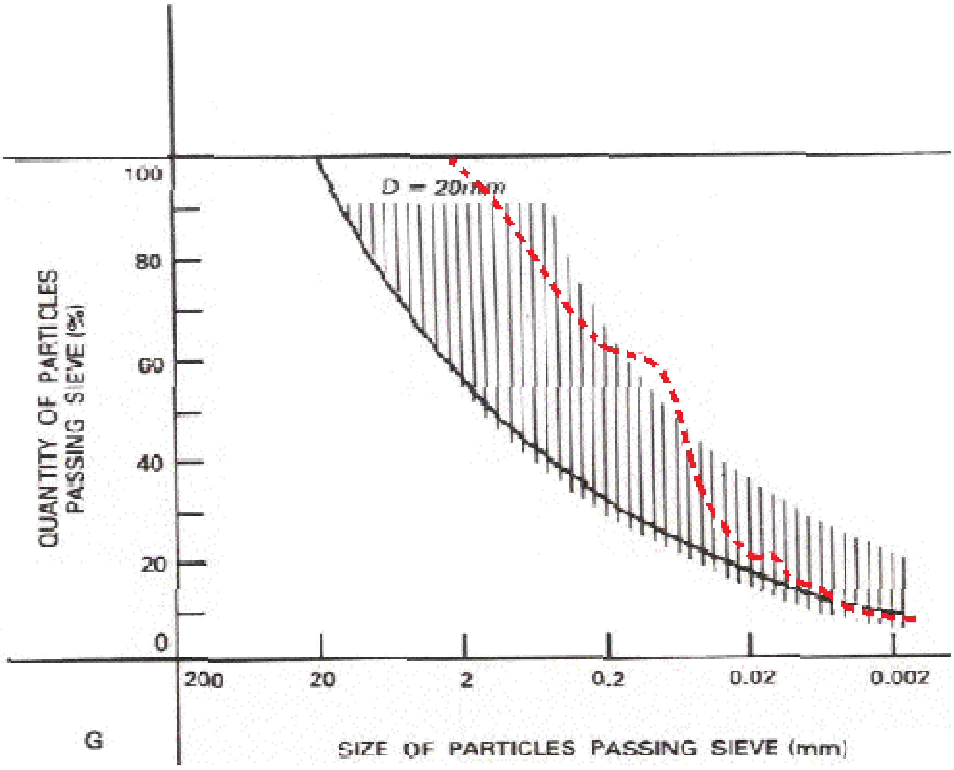


Figure 5. *Recommended grain size distribution zone for CSSB-production. The red dotted line in the graph represents the soil from Durame* [5, 18]

The limits of the zones recommended are approximate, and the permitted tolerances vary considerably. According to [18], p116:

" many soils which fail, for one reason or another, to comply with the requirements have been found satisfactory in practice; all that is claimed for the recommendation is that materials which comply with it are more likely to be satisfactory than those which are not. The zones are intended to provide guidance and are not intended to be applied as a rigid specification. "

There are many other factors to consider when producing CSSB such as the amount of organic content and sulphates in the soil and the mixing and drying period which will have a great effect on the finished product, and one shouldn't simply focus on the distribution of the fractions in the soil.

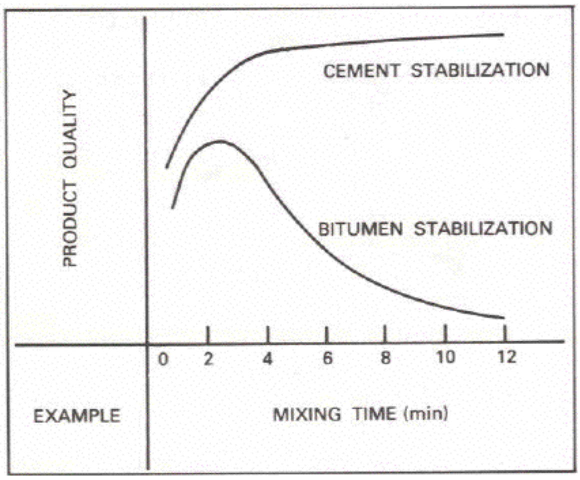
The blocks had already been pressed when I received the grain-size distribution test which disabled me to experiment by adding more coarse sand and gravel to the soil and reducing the amounts of fine sand and silts. This would have been a good experiment, to evaluate how much effect the grain size distribution of a soil has, on the strength of a block. [5, 18]

6.6 Producing the Blocks

The block-pressing took place on the 19th and 20th of April 2010, at *Selam Technical and Vocational Center* in Addis Abeba. After being granted to use their facilities and paying an amount in ETB for the inconvenience, I was able to produce the 24 blocks with the help of two of their workers at the CSSB-facility. The soil, which by then was dry, was sieved with a screen net with 1 cm x 1 cm openings. The soil was then mixed dry with the different contents of cement and sand. I was told by my assistants at the facility that I would need approximately 30 kg of soil to produce 4 blocks, and with the help of this, I could measure and mix the different contents of cement and sand. I decided that I would mix and press 4 blocks at a time, to reduce the hold-back time and prevent the cement to settle.

The mixing was properly performed using shovels on the cement floor. I had help of my two assistants, making sure that the mixture had a consistent colour and no dissimilar layers could be seen. Water was then added to the mixture, and the mixture was again mixed. I calculated the time for the dry mixing to approximately 5 minutes and 5 minutes for the wet mixing. The right amount of water that was added to the mix was approximately 7.5 kg for each group (30 kg of soil) and decided by my assistants due to their experience and sure instinct. Figure 6 illustrates the effect on the blocks depending on the mixing time. The minimum mixing time for CSSB is between three and four minutes.

We carried the mixture on wheelbarrows to the pressing machine, which was a Cinva-Ram. It was important to press the blocks without delay after water had been added to the soil and cement mixture. This is illustrated in Figure 7 and is due to the danger that the cement may set prematurely. The 4 blocks were then pressed and placed on a shelf which made it easier to carry them without causing any damage to the fresh blocks. I calculated the time between the mixing was completed and all 4 block were pressed to approximately 10 minutes.



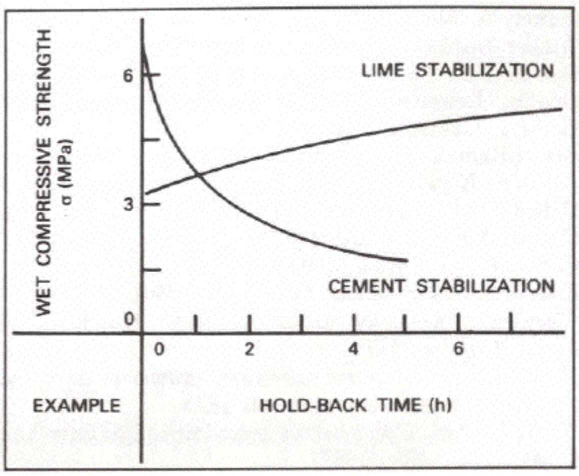


Figure 6 (left) *The effect on the quality of CSSB, depending on the mixing time.* [18]
Figure 7 (right) *The effect on the wet compressive strength depending on the hold-back time (time between mixing and pressing).* [18]

This procedure was done, until all blocks were pressed. The pressed blocks were then carried on shelves and placed inside the open facility. The blocks that were produced were of standard size; 29 x 15 x 12 cm (length, width, height). Picture 18-21 illustrate the screening, mixing and pressing of the blocks. [5, 24]


Picture 18 (left). *The soil is being screened...* [5]
Picture 19 (right). *...and then dry-mixed with the cement.* [5]


Picture 20 (left). *Water was then added and the different components were wet-mixed.* [5]
Picture 21 (right). *A fresh CSSB has just been pressed using the Cinva-Ram.* [5]

6.7 Curing of the blocks

The blocks were placed on shelves; with each group on one level and covered by a plastic sheet. The blocks were sprinkled once per day, during the first 7 days, making sure that they wouldn't crack and covered again by the plastic sheet. The plastic sheet was removed and the sprinkling was ceased after 7 days so blocks could start their dry curing during the following 21 days. The blocks would be ready for pressure testing on the 19th of May. Following pictures 22 and 23 illustrates the curing of the blocks.

Picture 22 (left). *The pressed blocks were stored on shelves, covered with a plastic sheet and sprinkled with water once per day during the wet-curing.* [5]
Picture 23 (right). *The plastic sheet was removed after 7 days and the blocks could be dry-cured. My assistants Biyok Work (left) and Yonas Ayele (right) at STVC .* [5]

6.8 Strength test

A strength test of all blocks was performed at *STVC* with the help of their hydraulic Jack. The brand was Hydroform (Hydrojack) with a pumping mechanism, going from 0 - 10.5 MPa, with steps of 0.5 MPa. A plate with an 8 x 8.5 cm stamp was placed between the jack and the blocks. During this process, I had help from two assistants with previous experience in strength testing. Each block was initially weighed and then placed between the stamps. The hydrojack was then pumped and stopped as soon as we noticed any cracks on the block. The analogue scale would then show the pressure that the blocks were able to resist. The weight of the blocks was very similar; varying from 7.3-7.8 Kg. Table 6 shows the blocks, the pressure that they could resist and the mean value of each group.

Group	Block		Compressive Strenght (MPa)	Mean Value (MPa)
1	1	0 % Cement, Soil and Water	0,7	1,05
	2		1	
	3		1	
	4		1,5	
2	5	4 % Cement, Soil and Water	1,8	2,075
	6		2	
	7		2	
	8		2,5	
3	9	8 % Cement, Soil and Water	2,8	3,2
	10		3	
	11		3,5	
	12		3,5	
4	13	0 % Cement + 10 % Sand, Soil and Water	0,8	0,975
	14		1	
	15		1	
	16		1,1	
5	17	4 % Cement + 10 % Sand, Soil and Water	2	2,7
	18		2,5	
	19		3,1	
	20		3,2	
6	21	8 % Cement + 10 % Sand, Soil and Water	2	2,1
	22		2	
	23		2,1	
	24		2,3	

Table 6. *The produced blocks, their compressive strengths in MPa and the different groups mean value in MPa.* [5]

Figure 8 and 9 shows the results from each groups.

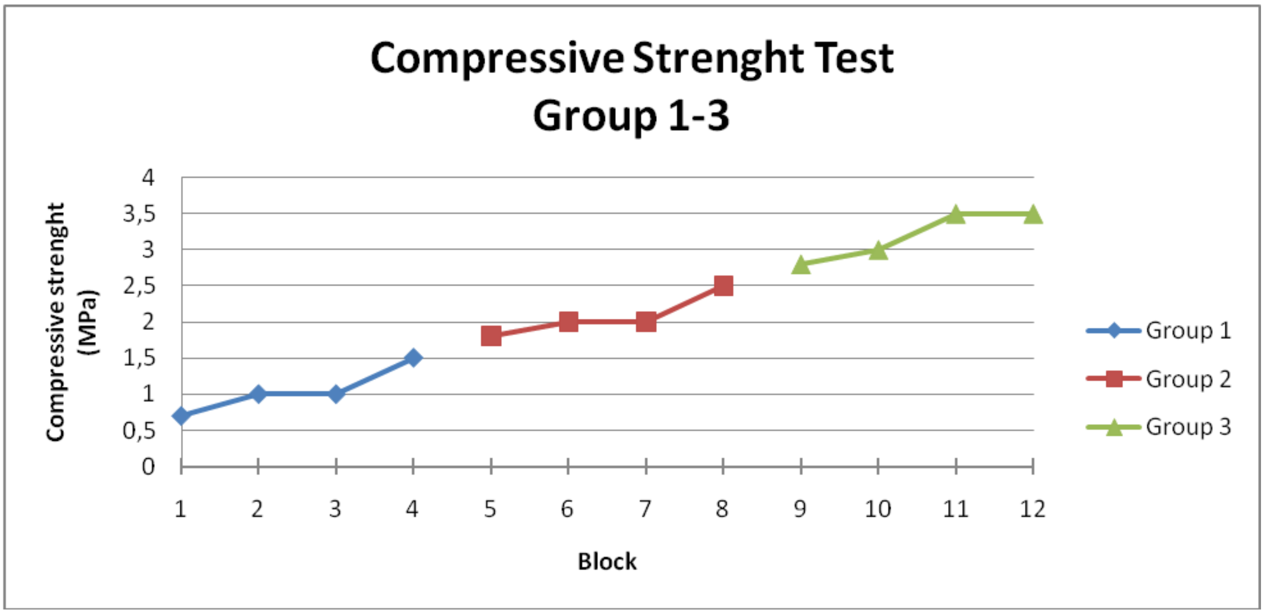


Figure 8. *A graph showing the Compressive strengths of the blocks in Group 1-3.* [5]

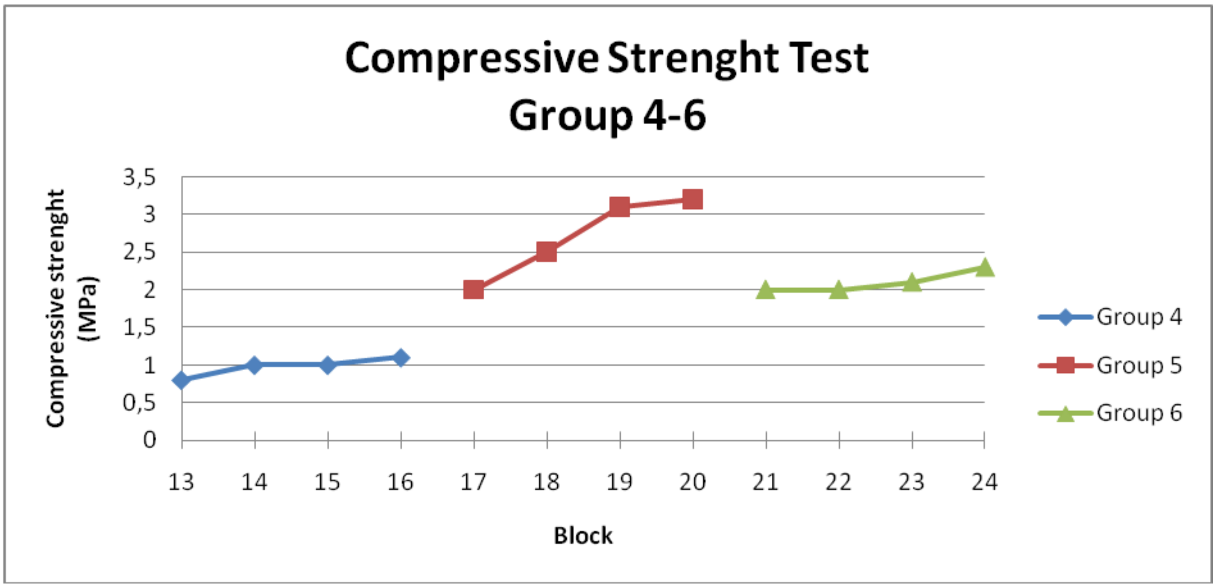


Figure 9. *A graph showing the Compressive strengths of the blocks in Group 4-6.* [5]

After the strength test was completed I had the opportunity to see how the different blocks would resist to water. The test was simple; I poured water from a sprinkler on one block from each group and let the blocks dry. After five minutes I observed the blocks to see if the water had done any damage. The result was that the blocks containing 0 % cement had much more damage to the outer structures than the blocks containing cement. This supported the statement that cement prevents the blocks from being decomposed when in contact with water. Pictures 24-28 illustrate the strength testing and water test.


Picture 24 (left). *The pressed blocks were weighed...* [5]
Picture 25 (right). *...before being placed between the stamps of the Compressive strength testing machine* [5]

Picture 26. *Water was poured on 3 blocks from group 1-3 (0 %, 4 % and 8 %-cement). The water had done much more damage to the 0% cement block than to the 4 % and 8% cement blocks.* [5]

Picture 27 . *Organic crops had been growing in some of the blocks, here a 0% cement block.* [5]

Picture 28. *Myself in the middle and my assistant Biyok Work on the right.* [5]

6.9 Results and Recommendations

The field project was completed in approximately 6 weeks from the initiation of collecting soil in Durame to the strength test of the blocks in Addis Abeba. It provided me with much knowledge and information about CSSB-technology. The production wasn't as easy as I thought and it is a lot of factors to consider when producing CSSB.

During the strength testing I noticed that many blocks had small organic crops growing in them. A great percentage of the soil that we had collected in Durame had most definitely contained topsoil with humus and biological material. It has bad effects on the quality of the block, making it slower for the cement to settle and lowers the strengths. This was a mistake that had occurred due to the fact that I by then didn't know that topsoils (30-40 cm) should be avoided when collecting soils for CSSB-production. Topsoils may also be contaminated so my recommendation for the Durame project is to dig deeper to find more suitable soil, preferably using the soil which has been dug out from what is going to be the latrine pit on the site. The soil that I tested needed to contain more coarse sand and fine gravel, and less fine sand and silt to be optimal for CSSB-production. Adding larger fractions between 1-10 mm in diameter should improve the quality of the blocks. I would also recommend doing a chemical analysis on the pH level and salt percentages of the soil. [5, 23]

During the processes of screening, mixing, pressing and curing, I become aware that knowledge and training is of key essence when producing blocks. I had the opportunity to have assistance and guidance from the block-making workshop during these processes. From the experience that I received during my field study, observing the SUDU-project and performing my own, I really have to emphasise the fine meaning of having a knowledgeable and trained team. During my time at the workshop I talked to a couple of "trainees" that had bought pressing machines such as the Cinva-Ram and undertook 1-2 weeks of training at the workshop. My recommendation for the Durame demonstration project is that at least one individual should receive a 1-2 week training at *STVC*, block production workshop. This trained individual can act as a block-production leader on site and further train the other workers in producing high-quality blocks. I also recommend the Hydroform-guide on producing blocks which was handed to me at *STVC* and which is attached in Appendix G. [5]

The results of the strength test were satisfying and fairly expected. The Ethiopian standards for compressed earth blocks do not state any criteria regarding the compressive strength of the blocks but there are however other reliable sources that provide guidelines. CRATerre, the International Centre for Earth Construction in France, recommends a sufficient dry compressive strength of 2-2.4 MPa for blocks used in one or two-storey buildings. Their calculation is as follows:

1.	**Resistance required by downward load**	
	- Single or two storey buildings	0.1 MPa
2.	**Safety factor**	x 3
	-variation in production quality	
	-variation in execution quality	
	-unintentional increase in overloads	
3.	**Reduction coefficient**	x 4
	-Nature of material	
	-Resistance of mortar	
	-Thickness of wall	
	-Loading method.	

4. **Saturation coefficient** x 2
-Dry / wet resistance ratio.

This gives a compressive dry resistance of 2.4 MPa. The blocks that didn't contain any cement had low resistance values around 1 MPa. The blocks containing 4 % cement showed much higher value with around 2.1 and 2.7 MPa in average. The same results were obtained with the blocks containing 8 % cement; 3.2 and 2.1 MPa. This means that the blocks with 4-8 % of cement meet the requirements regarding their compressive strengths, according to CRATerre.

The blocks containing 8 % cement and 10 % sand obtained lower compressive strength values in comparison to the blocks containing 4 % cement and 10 % cement. This could have been depending on a coincidence in this case, or could depend on other factors such as the combination of high cement content with sand content. Further experiments needs to be done to reach a conclusion regarding this occurrence.

The water test supported the fact that cement prevents the blocks from being decomposed when in contact with water. The blocks containing cement appeared to have a much better resistance to water than the blocks not containing any cement. The demonstration building that is being constructed with CSSB in Durame will be externally plastered with cement and cement-mortar which further protects the walls from wind and weather. [5, 23]

7. Conclusion & Recommendations

Ethiopia is experiencing problems such as a rapid population growth rate, uncontrolled urbanisation and housing shortages which directly affect the population's wellbeing. These problems are severe and the needs for sustainable solutions are growing. There is a big need for sustainable low-cost housing in the country and one of the solutions is the Cement Stabilised Soil Block-technique. The blocks are made from soil, water and cement; working as a stabiliser, mixed and compressed in a pressing machine. The blocks are very suitable for the population with a low income if they are manually produced and the production process is relatively easy to learn. There are however essential processes in the production which highly affect the quality of the blocks and require consideration. I recommend the method of constructing houses with CSSB-technology due to the fact that the blocks are durable if produced right, have a low negative impact on the environment and eco-system and may cut down building costs significantly.

The field study project that I carried out enabled me consider key processes in the production process of CSSB. Although the test production only was at a small scale, it gave me a good view in what to consider when producing the blocks. Choosing the right soil for the production is important and can save a lot of time and money in the practice. Having preexisting knowledge and training is also of key essence. Achieving a good result with durable and high quality blocks relies a lot on the production team and their knowledge and routines during the production process. For the project in Durame, I recommend that the production is lead by a supervisor who has received sufficient block production training.

Demonstration projects are a good way of introducing unfamiliar low-cost housing techniques to the population in the different regions of Ethiopia. Projects such as the demonstration houses in Durame and the SUDU-project at Addis Abeba University will hopefully show the population the advantages that the buildings hold and be spread to the society. It is important that the techniques which are introduced also are developed so that they are easily implemented with the available recourses in the different regions of Ethiopia.

The field study that I carried out in Ethiopia gave me a lot of knowledge and experience, which is often missed out when only reading books and other litterateur. Although I only got to experience a small portion of the problems that the population is experiencing, it gave me a good insight which enabled me to think differently about existing problems and solutions. I am glad that I had the opportunity to carry out this project.

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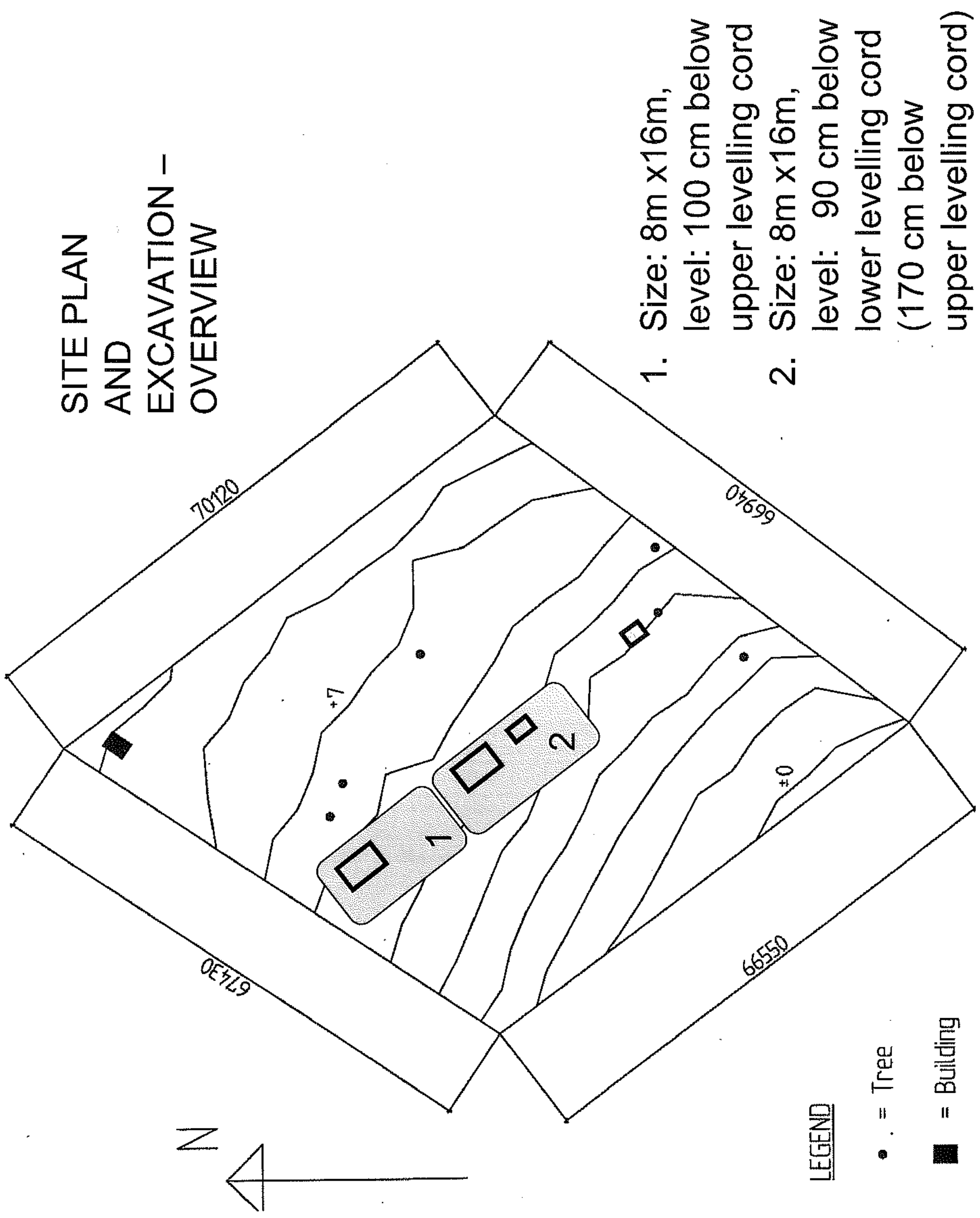
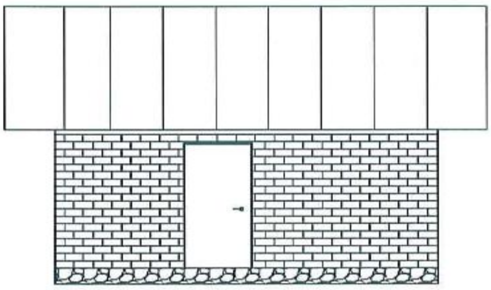
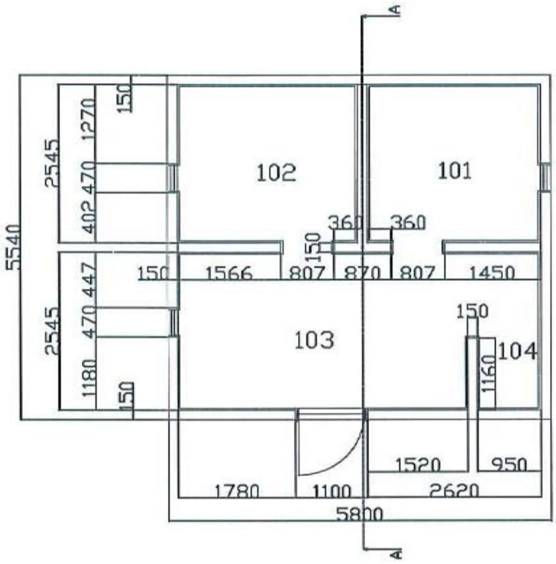
Appendix A

Drawings for the Demonstration houses in Durame, Ethiopia


SITE PLAN AND EXCAVATION – OVERVIEW
1. Size: 8m x16m, level: 100 cm below upper levelling cord
2. Size: 8m x16m, level: 90 cm below lower levelling cord (170 cm below upper levelling cord)
70120
66940
67430
66550
+7
±0
1
2
N
LEGEND
• = Tree
■ = Building

Cement stabilized soil block house





Legend

No.	Room Description	Area [m2]
101	Children's chamber	6,7
102	Parent's chamber	7,0
103	Living room	11,2
104	Storage	1,1

Legend of materials

☐ Load bearing walls, cement stabilized soil blocks dim. 290x150x120 mm

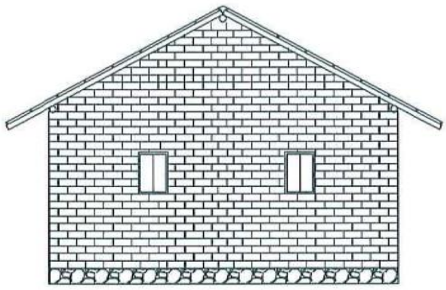
Notes:

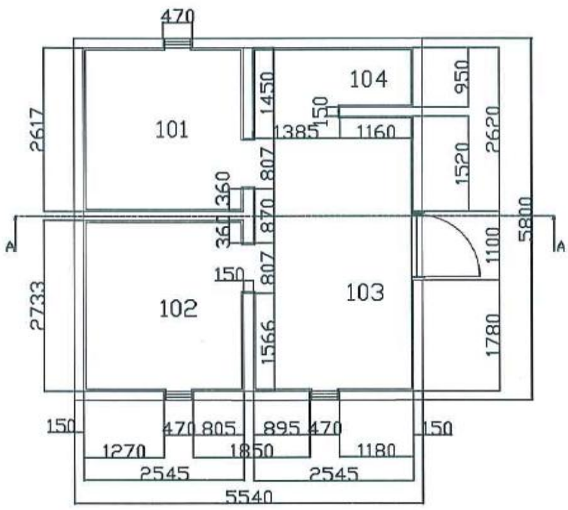
Indoor walls are covered with cement plaster by a thickness of approximatly 10mm

Chamber rooms have the option for door installement if so needed by the dweller

Demo. project: CSSB and Adobe soil block dwelling house			
Facade North side and Typical floor	By: Raffi Wartanian, Ann-Charlotte Johansson	For: Högskolan i Halmstad	Scale: M1:100
	Drawing nr: 001	Year: S 2008	

Cement stabilized soil block house





Legend

No.	Room Description	Area [m2]
101	Children's chamber	6,7
102	Parent's chamber	7,0
103	Living room	11,2
104	Storage	1,1

Legend of materials

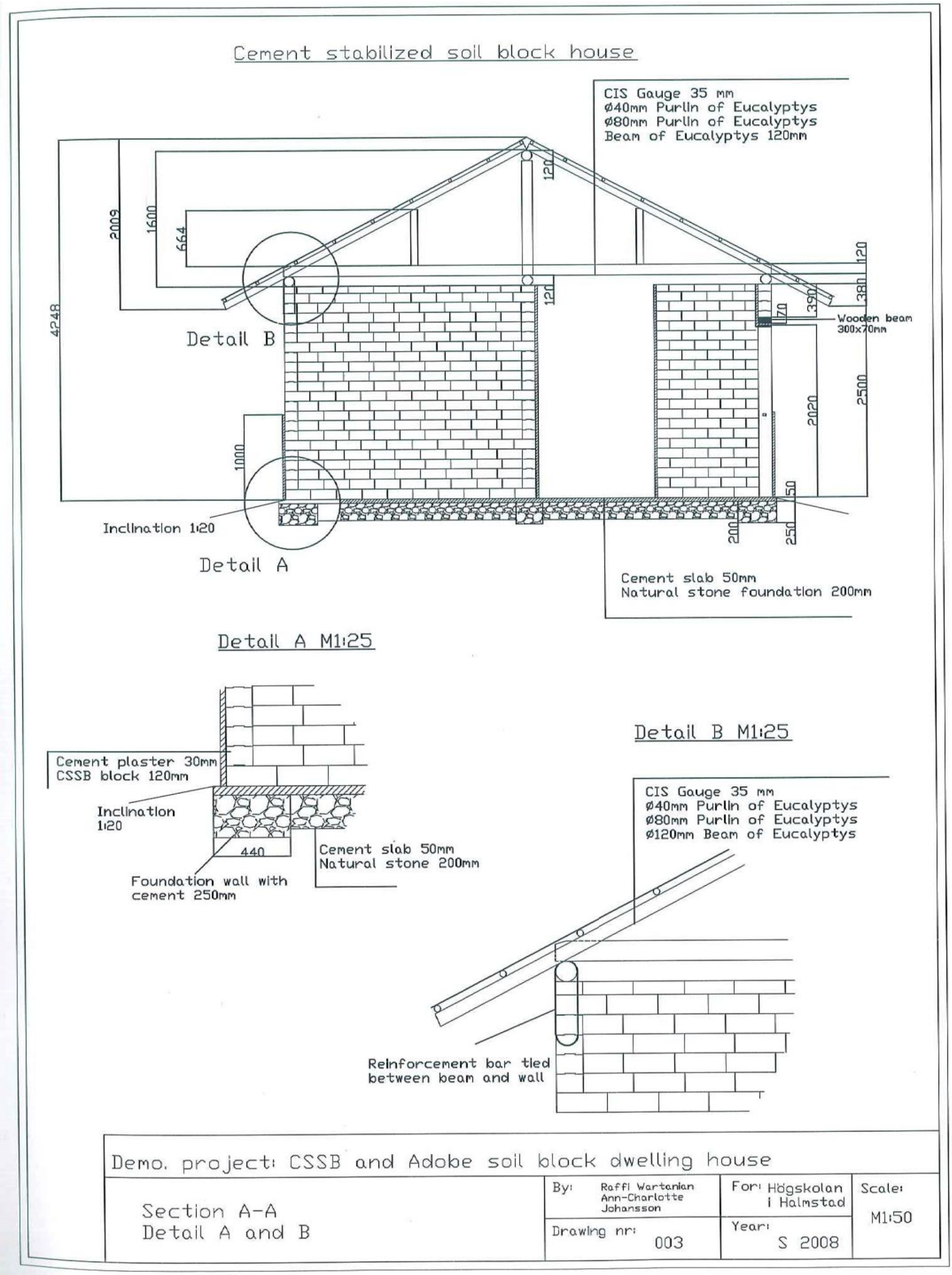
☐ Load bearing walls, cement stabilized soil blocks dim. 290x150x120 mm

Notes:

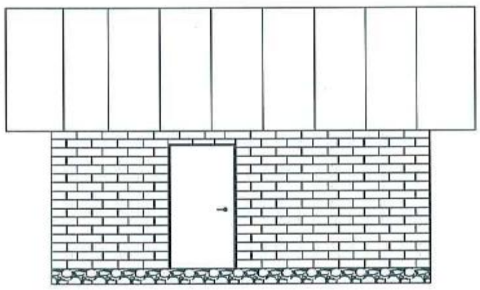
Indoor walls are covered with cement plaster by a thickness of approximatly 10mm

Chamber rooms have the option for door installement if so needed by the dweller

Demo. project: CSSB and Adobe soil block dwelling house			
Facade West side and Typical floor	By: Raffi Wartanian Ann-Charlotte Johansson	For: Högskolan i Halmstad	Scale: M1:100
	Drawing nr: 002	Year: S 2008	

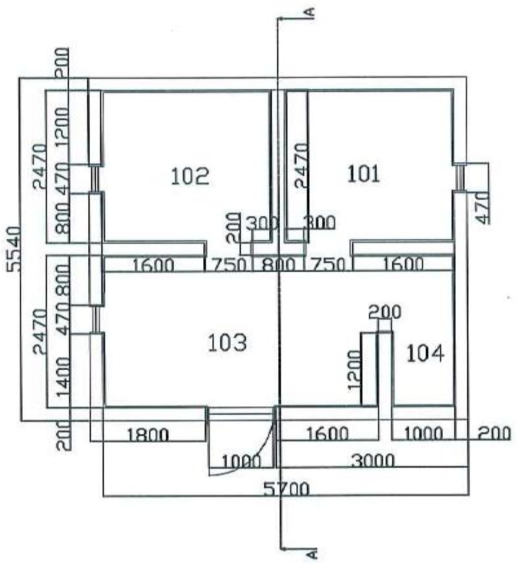

Cement stabilized soil block house
CIS Gauge 35 mm
Ø40mm Purlin of Eucalyptys
Ø80mm Purlin of Eucalyptys
Beam of Eucalyptys 120mm
4248
2009
1600
664
120
120
120
380
390
170
Wooden beam 300x70mm
2500
2020
1000
50
200
250
Detail B
Inclination 1:20
Detail A
Cement slab 50mm
Natural stone foundation 200mm
Detail A M1:25
Cement plaster 30mm
CSSB block 120mm
Inclination 1:20
440
Cement slab 50mm
Natural stone 200mm
Foundation wall with cement 250mm
Detail B M1:25
CIS Gauge 35 mm
Ø40mm Purlin of Eucalyptys
Ø80mm Purlin of Eucalyptys
Ø120mm Beam of Eucalyptys
Reinforcement bar tied between beam and wall
Demo. project: CSSB and Adobe soil block dwelling house
Section A-A
Detail A and B
By: Raffi Wartanian Ann-Charlotte Johansson
For: Högskolan i Halmstad
Scale: M1:50
Drawing nr: 003
Year: S 2008

Adobe soil block house



Legend

No.	Room Description	Area [m2]
101	Children's chamber	6,5
102	Parent's chamber	6,6
103	Living room	12,0
104	Storage	1,2



Legend of materials

Load bearing walls, adobe blocks dim. 4000x200x140 mm

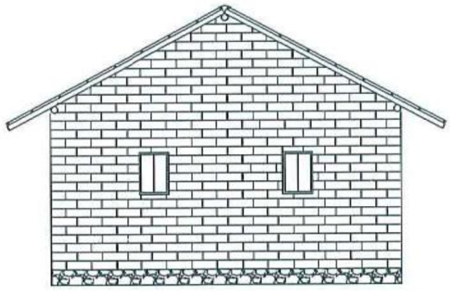
Notes:

Indoor walls are covered with mud plaster by a thickness of approximatly 30mm

Chamber rooms have the option for door installement if so needed by the dweller

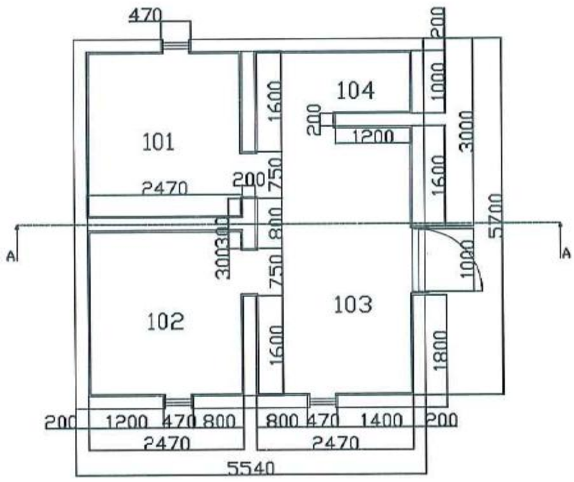
Demo. project: CSSB and Adobe soil block dwelling house			
Facade North side and Typical floor	By: Raffi Wartanian, Ann-Charlotte Johansson	For: Högskolan i Halmstad	Scale: M1:100
	Drawing nr: 004	Year: S 2008	

Adobe soil block house



Legend

No.	Room Description	Area [m2]
101	Children's chamber	6,5
102	Parent's chamber	6,6
103	Living room	12,0
104	Storage	1,2



Legend of materials

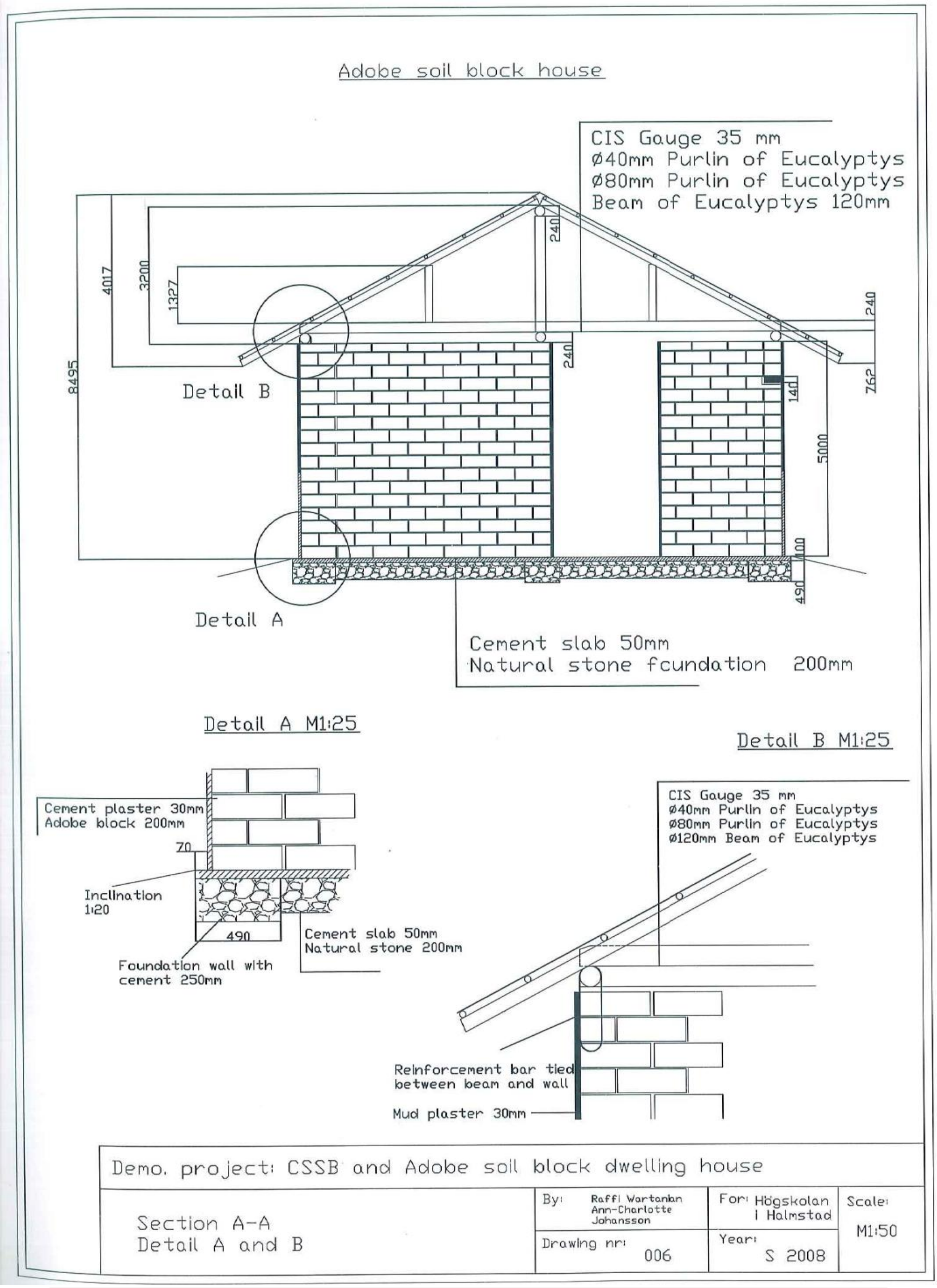
☐ Load bearing walls, adobe blocks dim. 400x200x140 mm

Notes:

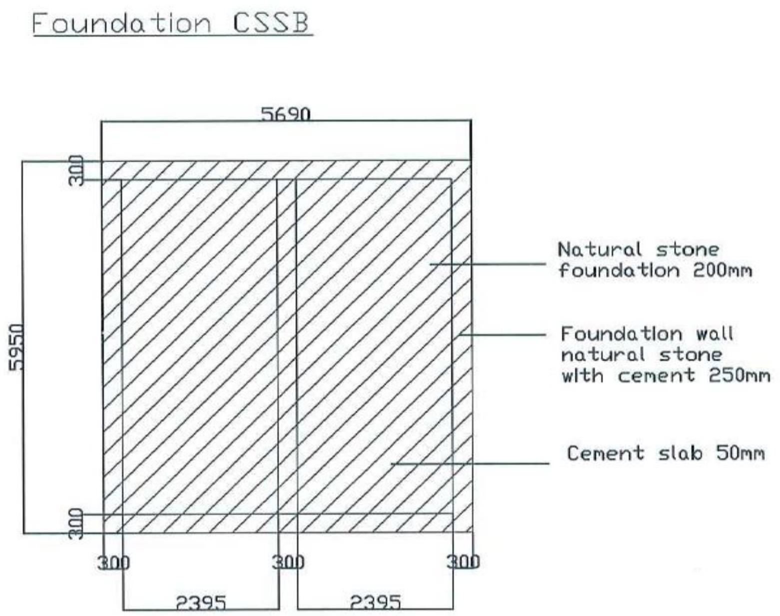
Indoor walls are covered with mud plaster by a thickness of approximatly 30mm

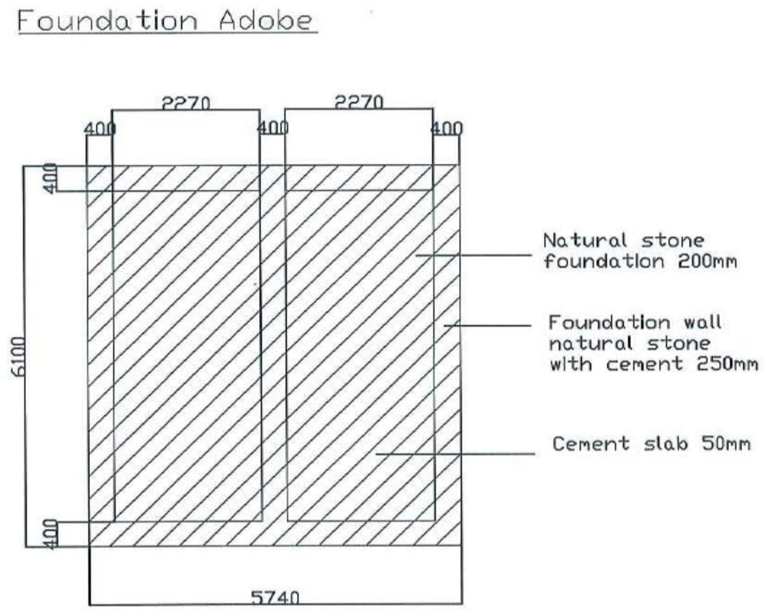
Chamber rooms have the option for door installement if so needed by the dweller

Demo. project: CSSB and Adobe soil block dwelling house			
Facade West side and Typical floor	By: Raffi Wartanian Ann-Charlotte Johansson	For: Högskolan i Halmstad	Scale: M1:100
	Drawing nr: 005	Year: S 2008	

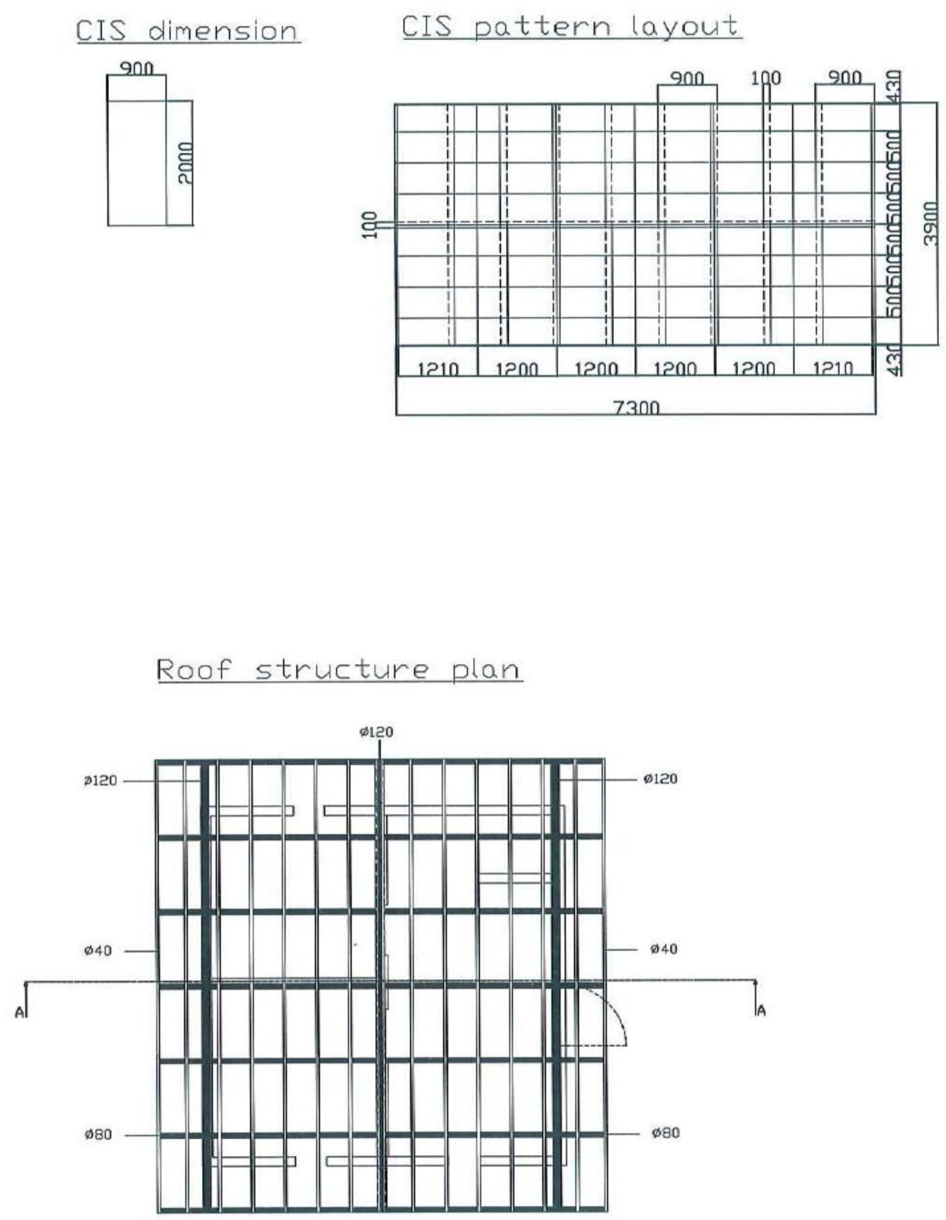


Adobe soil block house
CIS Gauge 35 mm
Ø40mm Purlin of Eucalyptys
Ø80mm Purlin of Eucalyptys
Beam of Eucalyptys 120mm
240
4017
3200
1327
8495
240
240
762
140
5000
100
490
Detail B
Detail A
Cement slab 50mm
Natural stone fcundation 200mm
Detail A M1:25
Cement plaster 30mm
Adobe block 200mm
70
Inclination 1:20
490
Cement slab 50mm
Natural stone 200mm
Foundation wall with cement 250mm
Detail B M1:25
CIS Gauge 35 mm
Ø40mm Purlin of Eucalyptys
Ø80mm Purlin of Eucalyptys
Ø120mm Beam of Eucalyptys
Reinforcement bar tied between beam and wall
Mud plaster 30mm
Demo. project: CSSB and Adobe soil block dwelling house
Section A-A
Detail A and B
By: Raffi Wartanian Ann-Charlotte Johansson
For: Högskolan i Halmstad
Scale: M1:50
Drawing nr: 006
Year: S 2008



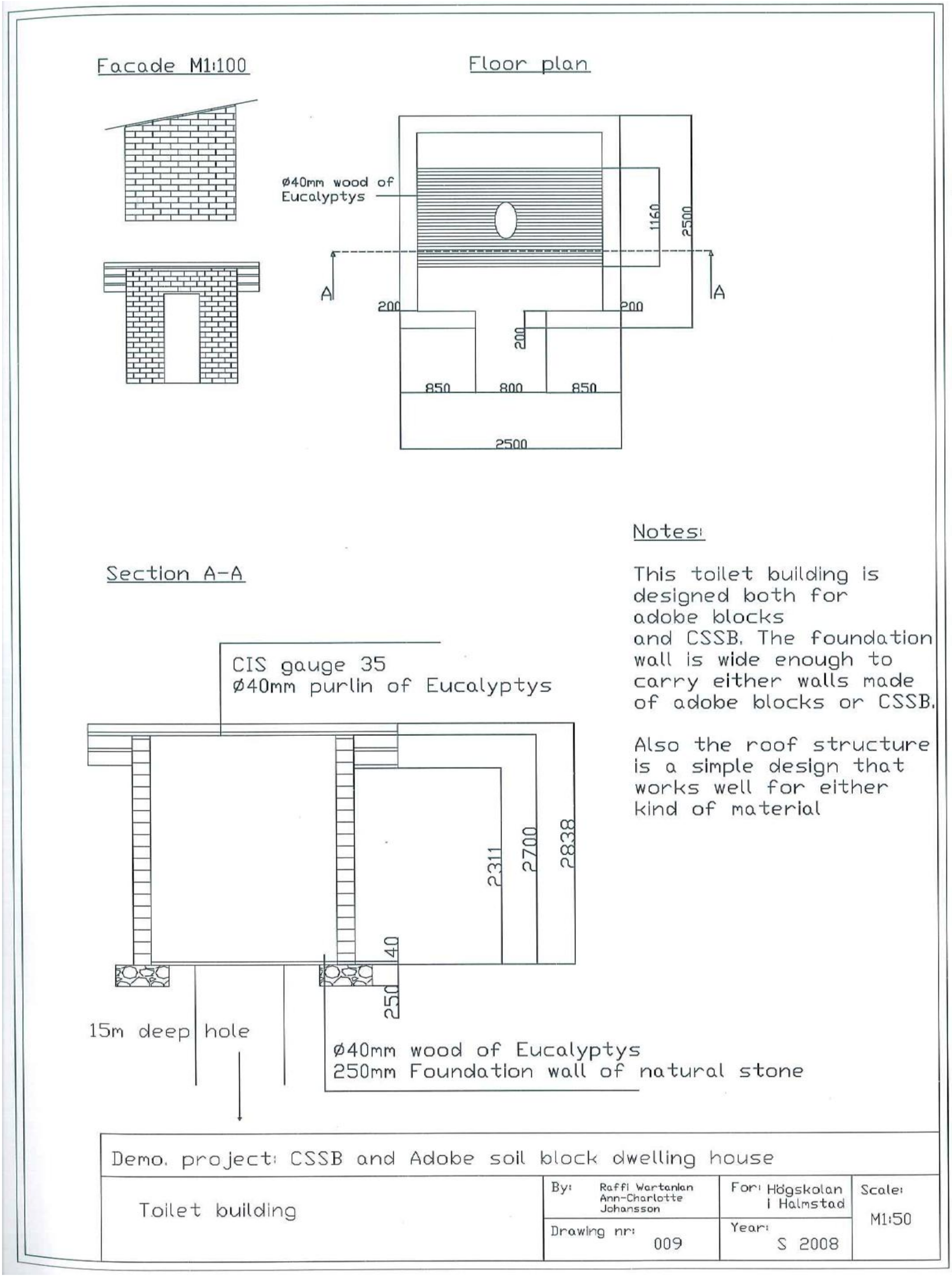


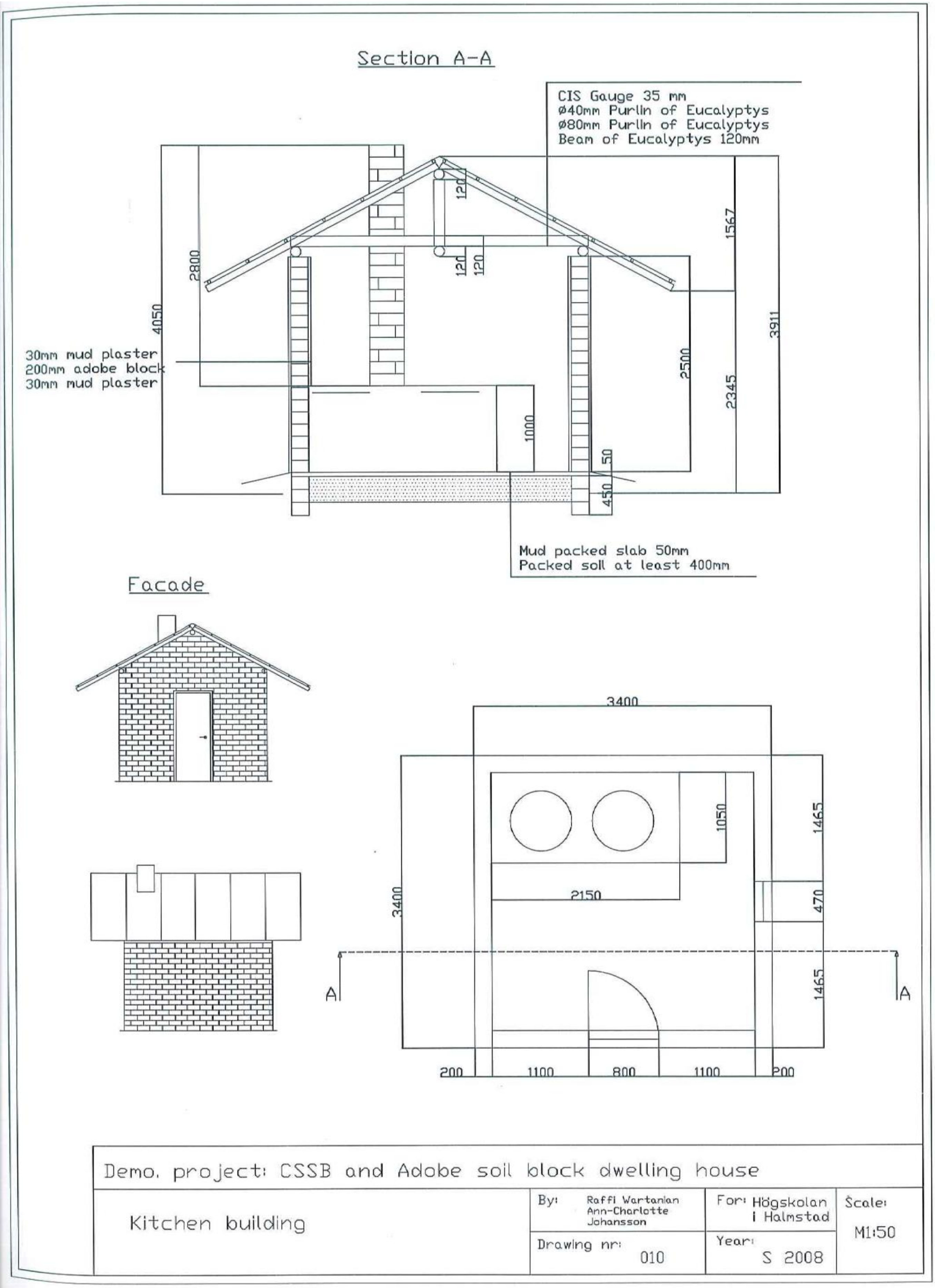
Demo. project: CSSB and Adobe soil block dwelling house			
Foundation plan	By: Raffi Wartanian, Ann-Charlotte Johansson	For: Högskolan i Halmstad	Scale: M1:100
	Drawing nr: 007	Year: S 2008	



Demo. project: CSSB and Adobe soil block dwelling house

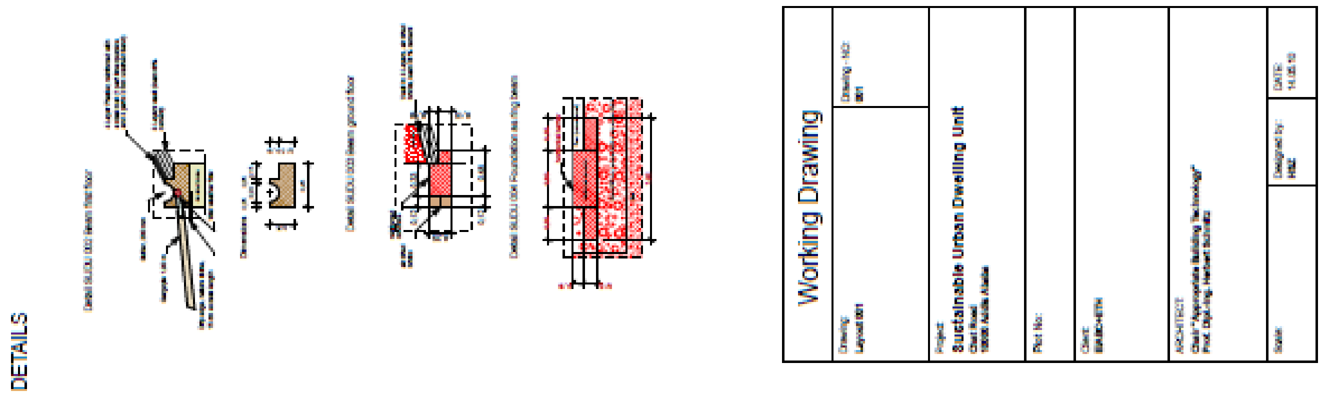
Roof and CIS structure for CSSB house and Adobe House	By: Raffi Wartanian, Ann-Charlotte Johansson	For: Högskolan i Halmstad	Scale: M1:100
	Drawing nr: 008	Year: S 2008	

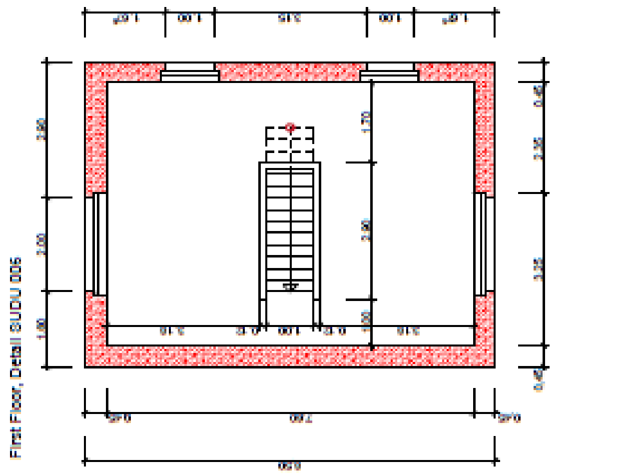

Facade M1:100
Floor plan
Ø40mm wood of Eucalyptys
1160
2500
A
A
200
200
200
850
800
850
2500
Section A-A
CIS gauge 35
Ø40mm purlin of Eucalyptys
2311
2700
2838
40
250
15m deep hole
Ø40mm wood of Eucalyptys
250mm Foundation wall of natural stone
Notes:
This toilet building is designed both for adobe blocks and CSSB. The foundation wall is wide enough to carry either walls made of adobe blocks or CSSB.
Also the roof structure is a simple design that works well for either kind of material
Demo. project: CSSB and Adobe soil block dwelling house
Toilet building
By: Raffi Wartanian Ann-Charlotte Johansson
For: Högskolan i Halmstad
Scale: M1:50
Drawing nr: 009
Year: S 2008

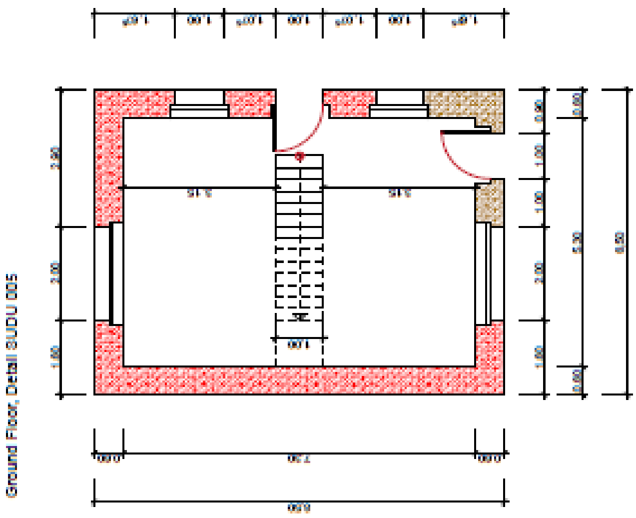

Section A-A
CIS Gauge 35 mm
Ø40mm Purlin of Eucalyptys
Ø80mm Purlin of Eucalyptys
Beam of Eucalyptys 120mm
30mm mud plaster
200mm adobe block
30mm mud plaster
Mud packed slab 50mm
Packed soil at least 400mm
Facade
A
A
Demo. project: CSSB and Adobe soil block dwelling house
Kitchen building
By: Raffi Wartanian Ann-Charlotte Johansson
For: Högskolan i Halmstad
Scale: M1:50
Drawing nr: 010
Year: S 2008

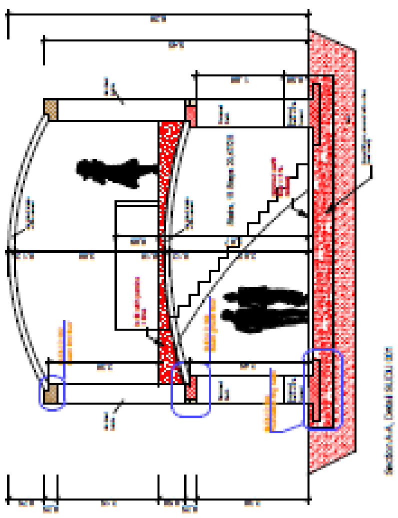
Appendix B

Drawings for the SUDU-project


DETAILS
Working Drawing
Sustainable Urban Dwelling Unit

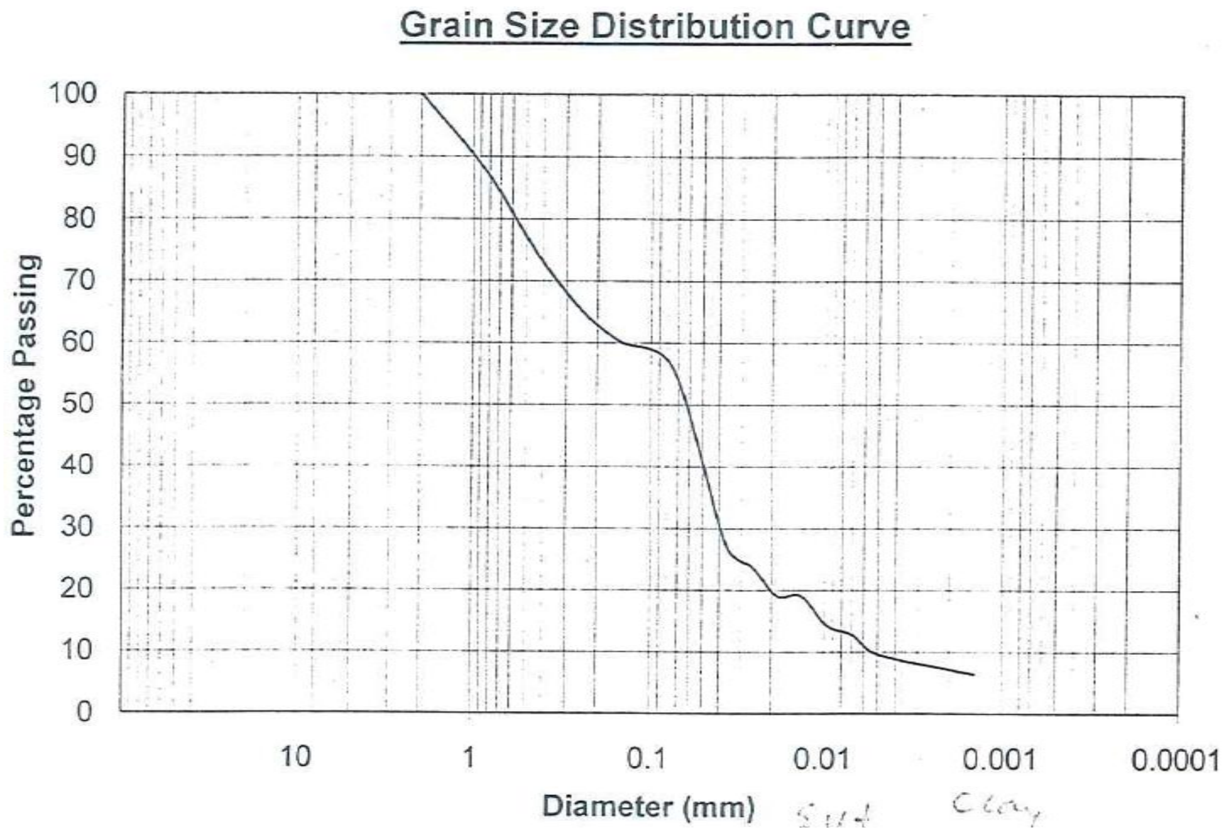

First Floor, Detail SUDU 005


Ground Floor, Detail SUDU 005



Appendix C

Grain size distribution test of site soil from Durame



Client	staff				Wt. Rt.	% Rt.	Dia.	%Pass.
Location					0	0	2	100
S. number					6.1	12.2	0.85	87.8
Test pit			S.depth		13	26	0.425	74
K value	0.01414				17.3	34.6	0.25	65.4
Hydro. Cor	1.003		corrected		19.9	39.8	0.15	60.2
Time (min.	Actual hydro. Rding		hydo. Rdin	Temp. (°c)	22	44	0.075	56
2	11.5	1.0115	0.0085	17	0.01414	13.25802	0.036406	27.03
4	10.5	1.0105	0.0075			13.52254	0.025999	23.85
8	9	1.009	0.006			13.91932	0.018651	19.08
15	9	1.009	0.006			13.91932	0.013621	19.08
30	7.5	1.0075	0.0045			14.3161	0.009768	14.31
60	7	1.007	0.004			14.44836	0.006939	12.72
120	6	1.006	0.003			14.71288	0.004951	9.54
1440	5	1.005	0.002	17	0.01414	14.9774	0.001442	6.36

Appendix D

Interview with Prof. Herbert Schmitz, Chair holder "Appropriate Building Technology", EiABC

Interview with Prof. Herbert Schmitz

The following interview was planned to take place in Addis Abeba University on Tuesday the 18 of May 2010 but had to be postponed due to illness. The interview was therefore accomplished during E-mail contact on the 22 July 2010.

1. What is your experience of building with low-cost materials (a) In the world, (b) In Ethiopia?

1a) When I look back in the last 30 years of my experience in constructing with natural building materials, I have mostly used loam as main material. I have never been disappointed using this natural material and the constructions that I have worked with still exist without any problems.
b) For the last 3 years I have worked here in Ethiopia, but I have a broad experience from around the world. Ethiopia has big potential; the laborers are cheap, the materials are available everywhere but energy is very expensive. Educating and training people will provide new ways of building constructions.

2. What do you consider are the advantages & disadvantages of building with low-cost materials in Ethiopia?

The advantages are: Short training time for laborers, material is available everywhere, low transportation costs, no garbage or waste and good climate.
The disadvantages are: Lack of knowledge about construction technology, lack of weather protection and a low acceptance in the society regarding new low-cost materials.

3. What obstacles and difficulties have you encountered building with low-cost materials in Ethiopia?

The obstacles have mainly been the lack of acceptance in the society and the lack of knowledge amongst the people about new technology. There have also been cultural difficulties and problems regarding information flow.

4. In the SUDU-project; what details have required and will require careful consideration to obtain durability?

It has been necessary to do research of certain materials and to develop all details for the Ethiopian context. It has also been of significant matter to widen the knowledge about maintenance of the building.

5. Which method do you prefer for dwelling houses in Ethiopia from an overall point of view: (A) Adobe block usage or (B) Cement Stabilized Soil Block usage?

From a starting point of view I prefer the cement stabilized soil block system. However after a few years of experience it should be possible to start constructing buildings of pure loam blocks such as the Adobe blocks.

6. Based on your experience, what are the Ethiopian people's attitudes towards these alternative low-cost building technologies?

Most of the people I have encountered during my stay here in Ethiopia have shown little acceptance of this new technology. In the moment I am very skeptical, but due to the energy shortage problem and recession I think the interest will increase to a point that there will be no other choice in the future.

7. What alternatives do you recommend as stabilisers for soil-blocks?

Maybe sodium silicate or cactus liquid (pieces of the opunzie cactus with 3 parts of water for 5 days in a drum), but we have to test these methods.

8. If you would do a prediction: How do you see the development of building with these low-cost materials in Ethiopia?

It will take a lot of time for acceptance and education to give this technology a real chance in Ethiopia. The cement lobby is very strong. In the moment the Ethiopian government planned 22 new cement factories for the next 2 years!

Appendix E

Hydroform – The ideal production method for producing + / - 1500 blocks per day

THE IDEAL BLOCK PRODUCTION METHOD
FOR PRODUCING +/- 1 500 BLOCKS PER DAY

A seven-person team can produce 1 500 blocks per day, if the following procedure is followed:

1. The soil must be sieved with a minimum of two days' lead time, i.e., $1m^3$ per 100 blocks or $30m^3$ sieved soil for two days' production of 1 500 blocks / day.

2. The water must be available close to the operation, preferably by hosepipe, from either a gravity-fed tank or by municipal pipeline.

3. Cement must be stacked next to the mixing area. The full day's supply must be stacked before any production begins:

   - 5% cement = 23 bags for 1 500 blocks
   - 10% cement = 45 bags for 1 500 blocks

4. The labor force employed should be composed of neither elderly people, nor young girls. Instead, they should be healthy, strong individuals who are able to work hard. To run one machine, seven people are required; this excludes the carrying of the cement to the production area, curing of the blocks, stockpiling and sieving of the soil. All activities, other than running the machine, must be done by separate personnel.

   The block production team, and functions of each of the seven, are as follows:

   - One machine operator
   - One person loading soil by bucket into the machine
   - Carrying blocks up to 15m from the machine: 1 person; if the distance exceeds an average of 15m from machine to final stacking point: 2 persons
   - Two people mixing the first mix
   - Two people mixing the second mix

   The second mix is the most crucial mix. If it is not always 100% ready, the machine will have to stop and wait for the mixing to be completed. If the machine stops, production will fall by four blocks per minute.

To illustrate, if the machine stops between each and every mix for only seven minutes, production will fall by almost 30 blocks per mix. To produce 1 500 blocks per day, 15-20 mixes are typically, which means that the production would drop by almost 600 blocks per day – as a result of a mere seven-minute delay per mix.

5. Production pay is normally the most effective pay method. The team is paid a fixed amount per good quality finished block. The incentive will ensure that production is maximised while giving the team a goal to increase their daily pay. Example: 7 individuals x daily rates/1 500 blocks = value for 1 block.

6. Curing is extremely important and should be done by a responsible person who is separate from the seven-man team. This person should be also used to carry the cement bags before production begins and to prepare the ground for the newly staked blocks.

7. Tools should be of good quality and there should be no shortage of tools, forcing people to share.

Tools required are as follows:

1. Spades (shovels)
   4 spades for mixing and loading the bucket
   2 spades for sieving of soil
   1 spade for levelling the ground

2. Wheelbarrows
   2 wheelbarrows for moving soil to the mix and for measuring out the mix
   2 wheelbarrows for sieving
   1 wheelbarrow for moving the cement
   1 wheelbarrow for the person moving the fully cured blocks

3. Sieve (8-10mm)
   A good quality sieve, undamaged and supported by a frame at approximately 45°.

4. Ten-litre buckets
   2 ten-litre buckets, to be used for filling the machine; while one is being lifted the other can be filled on the ground

5. Block brush
   For keeping the machine clean and keeping the bottom ram free from soil build-up

6. Shade cloth
   Not essential but will help to reduce operator fatigue on a hot day

8. Lunchtime – Before the team goes on lunch, they should prepare the mix for after lunch. The cement bags should be placed on top of the soil, ready to be opened, and spread out over the soil. No mix must be left unused before lunch and if the cement has been mixed into the soil, it must be used before lunch. Lunchtime must be strictly monitored. After lunch, the full team should help to get the first mix ready.

9. End of the day – Before packing up, the soil must be measured out for the following day's first two mixes (without adding cement). The machine must be filled with diesel and cleaned. The next morning, the machine should be ready to run 10 minutes after work begins.

10. The blockyard should be set out properly with sufficient space to move freely. The blocks should be set out neatly so as not waste space. The total of 1 500 blocks should take up approximately 2,2mx12m.