A case study of cob earth based building technique in Matagalpa, Nicaragua – LCA perspective and rate of adoption

Mariana Estrada

Master´s Thesis 2013

International Master's Programme in Ecotechnology and Sustainable Development
Mid Sweden University

MID SWEDEN UNIVERSITY

Department: Ecotechnology and Sustainable Building Engineering
Examiner: Anders Jonsson, anders.jonsson@miun.se
Supervisor: Morgan Fröling, morgan.froling@miun.se
Assistant Supervisor: Henrik Haller, henrik.haller@miun.se
Author: Mariana Estrada, marianaestrada2@gmail.com
Degree programme: International Master´s Programme in Ecotechnology and Sustainable Development, 120 credits
Main field of study: Environmental Science
Semester, year: 01, 2013

Abstract

Cob is an earth based building technique that may be an alternative for the construction of new homes in developing countries. Earth based constructions techniques commonly used in the past, like adobe and wattle-and-daub, have increasingly been replaced by buildings using more processed materials commercially available such as bricks or concrete blocks. The cost of such commercial materials is often unreachable for a large part of the population in developing countries. Cob buildings could be an appropriate option in rural areas, where human labor is a less restricted resource compared to monetary capital, and most of the materials needed are locally available. The cob technique is based on a mixture of clay, sand, straw and water that enables the builder to combine different materials and to create a variety of shapes. A recently constructed cob building in Matagalpa, Nicaragua, was studied using screening LCA methodology applied to the construction phase, as well as by applying a diffusion of innovation framework (specifically the five perceived attributes of an innovation). Results regarding fossil CO_2 emissions due to material production and material transportation were contrasted to an equivalent concrete block building. The highest contribution to CO_2 emissions from the cob building was generated by paints and solvents, and bricks and tiles (cooked earth); whereas in the concrete building it was due to the concrete bricks and iron. According to this case study, cob building technique seems to have the potential to be an affordable option for rural housing in Nicaragua, and at the same time accountable for rather limited emissions of fossil CO_2 emissions in its construction phase. At present, some obstacles to the use of cob technique are lack of examples for people to see and experience, and a general limited knowledge on how to work with cob technique.

Key words: cob, house, LCA, rate of adoption, Nicaragua.

Resumen

Cob es una técnica de construcción en tierra que puede ser una alternativa para la construcción de nuevas viviendas en los países en vía de desarrollo. Algunas de las técnicas de construcciones en tierra como el adobe y el bahareque fueron comunes en el pasado, sin embargo han sido sustituidas por construcciones con materiales procesados como ladrillos o bloques de concreto. El costo de estos materiales suele ser alto volviéndose inasequibles para una gran parte de la población. Las construcciones en cob podrían ser una opción adecuada en las zonas rurales, donde la mano de obra es un recurso abundante a bajo costo, y la mayoría de los materiales necesarios están disponibles a nivel local. La técnica del cob se basa en una mezcla de arcilla, arena, paja y agua que puede ser combinada con otros materiales para crear una gran variedad de formas. La fase de construcción de una casa en cob en Matagalpa, Nicaragua; fue estudiada por medio de un LCA preliminar. Igualmente se utilizó el marco de difusión de la innovación propuesto por Rogers para evaluar los cinco atributos que hacen que esta técnica pueda o no ser difundida en Matagalpa. Los resultados en relación con las emisiones de CO_2 por la producción de material y del transporte de material se contrastaron con una casa de dimensiones similares construida en bloque de concreto. La mayor contribución a las emisiones de CO_2 de la casa de cob fue generada por las pinturas y solventes, y ladrillos y tejas (tierra cocida), mientras que en la casa de bloque de concreto las emisiones se debieron a los bloques de concreto y al hierro. De acuerdo con este caso de estudio, la técnica de construcción cob parece tener el potencial de ser una opción asequible para la vivienda rural en Nicaragua, generando emisiones de CO_2 más bajas que las construcciones de bloque de concreto durante la fase de construcción. En la actualidad, algunos de los obstáculos para la difusión de la técnica del cob son la falta de ejemplos para que las personas puedan ver y experimentar, y un escaso conocimiento general sobre cómo trabajar con esta técnica.

Palabras clave: cob, vivienda, LCA, difusión de la innovación, Nicaragua

Abstrakt

Cob är en byggteknik med jord som främsta material som kan vara ett alternativ vid byggande av nya bostäder i utvecklingsländer. Några jordkonstruktionstekniker, som adobe och ”bajareque”, var vanligare förr, men har ersatts av byggande med förädlade material som tegel eller betongblock. Kostnaden för dessa material är oftast hög och blir oöverkomlig för en stor del av befolkningen. Cob hus skulle kunna vara ett alternativ på landsbygden, där arbetskraft är en mer tillgänglig resurs än kapital, och de flesta av de material som behövs finns lokalt. Cob tekniken är en blandning av lera, sand, halm och vatten som även kan kombineras med andra material för att skapa olika former. Byggnationsfasen för ett nyligen konstruerat cob hus i Matagalpa, Nicaragua, studerades med en screenande LCA. Valda delar av Rogers teori ”diffusion of innovation” användes (främst de fem attributen för innovationsspridning). Resultaten avseende CO_2-utsläpp från produktion och transport av material jämfördes med ett hus i liknande storlek, byggt i betongblock. Det största bidraget till utsläpp av CO_2 från cob huset genererades av färger och lösningsmedel, tegel och kakel (bränd jord), medan det i betongblockshuset berodde på betongblock och järn. Enligt denna fallstudie verkar cob byggteknik att ha potential att vara ett prisvärt alternativ för bostäder på landsbygden i Nicaragua, och resulterar i relativt små CO_2-utsläpp under byggskedet. Några av de hinder för spridningen av cob tekniken som föreligger för närvarande är brist på exempel för människor att se och uppleva, samt dålig allmän kunskap om hur man arbetar med denna teknik.

Nyckelord: cob, bostäder, LCA, spridning av innovation, Nicaragua

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1. Introduction

"… participating in the creation of your own home with your friends, neighbours and community, no matter at what level, whether you are cooking sumptuous feasts to sustain the workforce or stomping cob, is incredibly empowering. To have handled and known every piece of a building, and to understand how all these pieces fit together, is about getting back in touch with our ability to provide for our families and ourselves. In this way, cob and natural building can begin to subtly and powerfully enhance ourselves, society and hence the world"
(Weismann and Bryce 2011)

The use of green materials in constructions is currently a hot topic since it seems to help reduce the environmental impact during their construction and use phases. Different techniques have been developed or improved in order to build houses that meet their inhabitant's needs, but a lot of these new tendencies have a high economic cost with a reduced number of users. Around the world there are also low income families, often living in rural areas, who find in artisanal techniques ways to build houses that meets their basic needs. Many people in developing countries use building techniques that have evolved for years taking into consideration their specific environmental surroundings, in order to build functional houses. These techniques are usually based on cheap building materials, easily found in the area and frequently long lasting.

Nicaragua is the second poorest country in Latin America, with an agricultural based economy; 41,7 % of the population live in rural areas in artisanal built houses. Although techniques such as adobe[*] and wattle-and-daub (bajareque[†] in Latin American countries) are appropriate in this environment these technologies present many drawbacks, such as the impossibility to create curves and shapes that may help increase building's strength and the impossibility to build furniture using the same technique (LILI 2012), when compared to cob[‡].

Construction is known to promote economic growth and social development, but special attention needs to be paid to residential buildings in order to reduce global

[*] Mix of clay-rich soil, sand, straw and water poured into block forms and dried in the sun, that are then mortared with adobe mud (Chiras 2002).
[†] Timber or/and guadua frames filled with straw and soil. The walls are then cleaned and covered with a mixture of clay, sand and straw, and a final limewash finish is done for extra protection (Carazas Aedo and Olmos 2002).
[‡] Cob is an old English word that means lump or rounded mass, it is not related with the cob of the corn (Chiras 2002).

carbon emissions. The phases of material preparation, building construction, building operation, building demolition, and disposal of construction and demolition wastes might result in high carbon emissions into the atmosphere (Li et al. 2013). On the market there are various mechanisms to reduce carbon emissions; they range from energy conservation measures to the use of different materials. Simultaneously this minimizes carbon emissions due to fossil fuel burning, and in many cases these buildings can be constructed with reclaimed materials.

A screening Life Cycle Assessment (LCA) for the construction phase of a cob house and a concrete block house in Matagalpa, Nicaragua was carried out. Additionally the cob technique was evaluated according to the five perceived attributes (Relative Advantage, Compatibility, Complexity, Trialability, Observability) described by Rogers (2003) in order to assess its potential rate of adoption among the Nicaraguans.

1.1 Purpose and objectives

Many of the current building techniques used in developing countries focus on one aim: provide shelter. However, in many cases they are neither the best option for the environment and in many cases nor the best option for its inhabitants. Some have a high indoor temperature during the day and low temperatures during the night as in the case of zinc constructions, some like brick and concrete buildings can be expensive, and some others have a low environmental performance. Cob may constitute an intermediate technology and offer an alternative to both modern and traditional technologies, since it uses natural materials that are readily available, it is durable, gives good and healthy indoor characteristics improving the comfort of its inhabitants; but it is also quite similar to what Nicaraguans are used to, making it a technique that can possibly be easily transmitted and used by local people. Additionally cob houses are not only safe (Fordice 2000) but according to Chiras (2002) they are also affordable, comfortable, sustainable, enduring and non-toxic.

The environmental impact of the cob technique and how it compare with other commonly used building techniques in Nicaragua should be assessed in order to see if the new proposed technique is a better alternative from an environmental point of view. In this paper the cob technique was assessed and contrasted to the concrete block building technique in the construction phase. This evaluation will help different entities (government, NGO, etc.) to identify the best affordable and realistic construction technique that will improve the inhabitants' life with the lowest

environmental impact in the long run. Additionally it will pinpoint the critical attributes that slows down the diffusion of this innovation by understanding which are the perceived attributes that will result in a higher rate of adoption in the area.

The purpose of this thesis was to find a building technique adequate for the inhabitants of Matagalpa, that fulfil their needs, is cheap and had a low environmental impact. The main objectives were to assess the cob building technique and compare it with the concrete block technique in order to determine the ecological performance using the LCA analysis, and to evaluate the appropriateness of the cob technique in Matagalapa through the five perceived attributes that describe the rate of adoption of a technology.

1.2 Research questions

- What is the difference in the environmental impact during the construction phase of a house built using the cob technique compared to the technique used in a concrete block house?
- Which are some of the obstacles and advantages that this technique faces during its rate of adoption based on the five perceived attributes (Relative Advantage, Compatibility, Complexity, Trialability, Observability) described by Rogers (2003)?

2 Method

2.1 LCA – Life Cycle Assessment

The LCA is a method that can be used to analyse the environmental impact of a product taking into account the different activities involved during its life cycle. The LCA consists of a goal and scope definition, an inventory analysis and an impact assessment that work together and result in an interpretation, as shown in Figure 1, throughout the whole process in order to draw conclusions and make recommendations (Bauman and Tillman 2004).

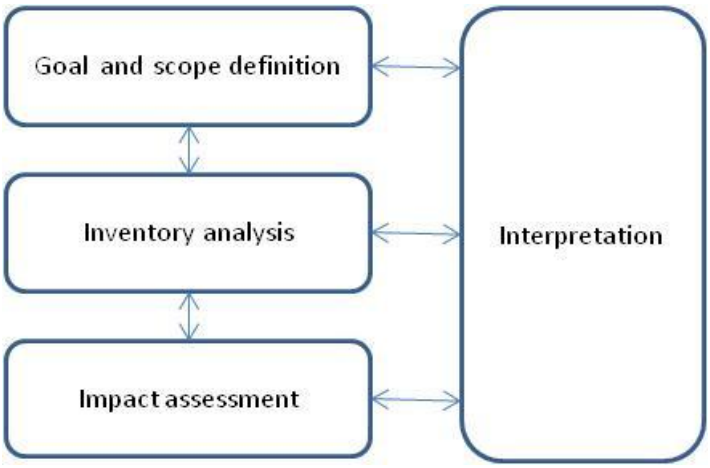

Figure 1. Life cycle assessment framework following ISO 14014 1998 standards. (Bauman and Tillman 2004)

First the *goal and scope* are defined according to the product that will be studied and the purpose is determined based on the intended application of the study and the people who will read it, and the boundaries of the study are set in order to include processes that are relevant and exclude those that are not. Then comes the *inventory phase* where the data collection and calculations are completed based on the boundaries set out during the goal and scope definition and a flow model or flowchart that shows the activities and flows included in the study. Finally the environmental impact is calculated during the *impact assessment* in order to aggregate the information so it is easy to communicate and make a comparison between products (Bauman and Tillman 2004). In this thesis the result of the LCA screening was reported as CO_2 emissions and emissions for the materials and for their transport to the construction site were calculated for both a concrete block house and a cob house.

2.2 Rate of adoption

The diffusion of innovation theory proposed by Rogers in 1962 describes the diffusion of a technology as the process whereby an innovation is communicated among members of a social system. The rate of adoption of new techniques, on the other hand, measures the speed at which people adopt new innovations into their daily life and, in many cases, can be explained by its perceived attributes, the type of innovation-decision, the communication channels, the nature of the social system and the extent of change agent´s promotion efforts. The five perceived attributes is the variable that has been studied in a greater depth in this thesis. The five attibutes looks at the relative advantage which is the "degree to which an innovation is perceived as being better than the idea it supersedes"; the compatibility which is the "degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters", the complexity which is the "degree to which an innovation is perceived as difficult to understand and use"; the trialability which is the "degree to which an innovation may be experimented with on a limited basis" and the observability which is the "degree to which the results of an innovation are visible to others" (Rogers 2003). The five perceived attributes of innovations are shown in the context of Rogers´ variables determining the rate of adoption of innovations in Figure 2

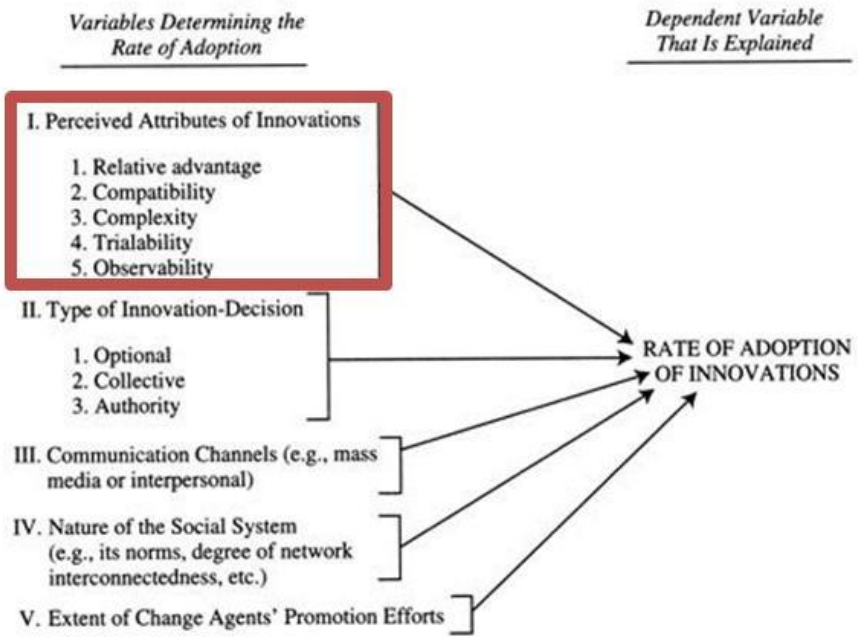

Figure 2. Variables determining the Rate of Adoption. In the red box the five perceived attributes of innovation assessed in this thesis are presented. They are the most extensively investigated variables of the Rate of Adoption theory (Rogers 2003).

3 Cob building technique

Cob is an earth building technique based on a mixture of clay, sand, straw and water (LILI 2012). The mixture is kneaded with hands, feet or simple tools, subsequently lumps are made, that are then compressed together and shaped by hand forming foundations and walls (LILI 2012; Chiras 2002). At the same time as the walls are being built, the doors, windows, plumbing, electrical circuits, etc are placed and covered with the cob as the walls are constructed (Smith 2000). The walls can be covered with earthen plaster or lime plaster, or painted with lime wash and/or silica paint, to give them some extra protection and improve their appearance (Chiras 2002). The mix is highly malleable and can be used to create sculptures and to accommodate elements such as bottles to enable natural light to enter into the house, benches, shelves, niches, etc. (Snell 2012). The cob building technique is ancient; in fact there are archaeological excavations in the UK that confirm that during the 1200 AD there were cob buildings in the area (Weismann and Bryce 2011). Some cob-houses built in United Kingdom during the 1600s are still in use (Fordice 2000), especially in the South-West, Scotland, parts of East Anglia and Wales (LILI 2012). In New Zealand two earthquakes during the late 1800s and early 1900s didn't affect cob houses, which lack mortar joints, but destroyed or damaged great brick buildings (Smith 2000).

Cob has benefits but also drawbacks; some of them are described in Table 1.

Table 1. Generalities of cob, benefits and drawbacks (LILI 2012).

Cob is an ancient building technique that uses a combination of clay, sand, straw and water; to form lumps that when put together will form a wall	
What are its benefits?	**What are its drawbacks?**
• Materials are easily found and cheap (or sometimes even free) • CO_2 emissions during processing are minimum and CO_2 emissions during transport of materials can be reduced • Enables the use of reclaimed materials • May be combined with other natural elements (stone, lime, slate, etc.) and requires little timber • Allows curved shapes increasing the building´s strength and its perceived space • Can be recycled and it is not toxic • Can be easily repaired • Can be used to make the furniture of the house (benches, desks, beds, etc.) • Has a good thermal mass reducing internal temperature fluctuations during warm days and cold nights	• Site has to be picked carefully considering water and suitable clay supply if CO_2 emissions due to transport want to be reduced • Materials are heavy making transport difficult • Labour-intensive • Better to build during dry season • Needs good roof and solid and dry foundations • Bad insulation properties

Earthen building such as adobe and wattle-and-daub are also earth building techniques, and even though they use the same materials as the cob technique the way these materials are used differ. Adobe uses the same materials as cob but these materials are made into bricks and sundried. These bricks are then put together to

create walls that are straight and usually connecting with other walls at right angels (90º). In wattle-and-daub technique woven sticks are intertwined forming a net and then covered with a thin layer of a mixture of dirt, straw and water, when the walls are connected they too form right angels (Bee 1998). The earthbag technique uses burlap or polypropylene bags filled with clay-dirt or cement-stabilized dirt that are laid down on a foundation or piled up to make walls. A technique with which it is easy to create vaults or to build round structures (Chiras 2002).

Earth building techniques are labour intensive and time consuming, but mud (a mixture of earth and water) is the most available building material on the planet, and it can be used by everyone regardless their social status, potentially giving earthen buildings environmental and social value (Weisman and Bryce 2011). Cob may be considered an appropriate construction technique in developing countries where conventional building material is expensive and labour is abundant, and it doesn't need high technology (Weismann and Bryce 2011) thus reducing costs in machinery implementation and in teaching people on how to build with cob. Cob houses are thought to have a low environmental impact during the construction phase, they use local and natural materials; and during the use phase, since they have special characteristics that can help reduce the use of cooling systems (like fans) and even control humidity indoors through moisture transfer mechanisms (Foster, Medero, Morton, & Buckman 2008). Moreover walls made up of earth are strong and capable of resisting insects, earthquakes, hurricanes, tornados and even fire (Chiras 2002).

3.1 Description of studied building

The cob house in this case study is a 60m^2 house built in Matagalpa, Nicaragua in 2012. The house was built and it's owned by a Spanish couple who learned the technique and wanted to try it out themselves.

The house is approximately 4m high at its highest point, it is on one level and it has an attic. The main floor has a bathroom, a study, a living room, a kitchen and a small area for a dining table. The attic serves as a bedroom. The floor is made of compacted earth and they only used tiles in the kitchen. The house has furniture made with cob and wood and there are niches and bookshelves carved into the walls, which are 50cm thick. The house has a 70cm deep ditch around its perimeter ensuring stability in the event of an earthquake and it has a 50cm high rock chain which is visible from the outside, and it also works as a drainage system. Therefore

during the rainy season, the water can flow without added restrictions under the ground avoiding accumulation of water under the house. The roof is made with clay tiles and a plastic sheet was added to avoid of leaks. The wooden beams supporting the ceiling have nails on the edges to increase the area and they were incorporated into the surrounding cob walls. The inner walls have a fine layer of plaster made of sand and clay to make them smooth and nicer. See Figure 3.

Figure 3. Cob house studied. The figure shows some pictures of the building elements in the studied cob house build in 2012 in Matagalpa, Nicaragua. Photos by the author.

According to Ruben Meiro and Martha Solvany (2013), the owners and builders of the cob house, all the wood used in the house is either reclaimed from old demolished houses or bought at legal wood plantations. This wood was used for doors, stairs, pillars and window frames. The glass used for the windows was bought in Managua (Nicaragua's capital) and the bottles used in the walls for the sun light to shine inside the house were donated by a local restaurant. The chemicals

needed in the house mainly for wood treatment (anti-termite, sealer, solvent and paint), were bought from a Costa Rican company called Grupo Sur that according to its webpage has an integrated management system covering the environmental area that aims to achieve environmental improvements to reduce the impact during manufacturing, operations and marketing (Grupo Sur 2009).

3.2 Description of the concrete block house used for assessment purposes

To be able to better understand the environmental impacts of the cob house another building technique is used for contrasting. According to Athens, J (2004) around 31.9% of the housing in Nicaragua has cement or concrete walls and around 67.7% have zinc roofs. Taking this into account and for the purpose of this study a concrete block house was used. A model of a generic house of around 60m^2 with 2 rooms, a kitchen, and a bathroom was studied. The walls are made of concrete blocks put together with concrete and iron rebars, the floor is made of concrete and the roof is of galvanized steel sheets supported by iron beams.

4 LCA

4.1 LCA goal and scope

In this study the environmental impact, measured in fossil CO_2 emissions, during the construction phase of houses built with cob and concrete blocks, respectively, was investigated using screening LCA assessment methodology. The goal is to find a building technique with the lowest fossil CO_2 emissions, that is adequate for the inhabitants of Matagalpa, that fulfil their needs, is cheap and has a low environmental impact. The functional unit used was a cob house of 60m^2 built in Matagalpa, Nicaragua in 2012. For comparison purposes a model of a generic concrete block house of around 60m^2 with 2 rooms, a kitchen, and a bathroom was studied. For more information on the cob house studied refer to Chapter 3.1 and for more information on the generic concrete block house refer to Chapter 3.2.

The LCA methodology comprises all sorts of processes and activities, in different areas and timeframes of a product; therefor it is necessary to clarify which aspects are taken into account in this specific LCA assessment. For this LCA assessment the system boundaries were defined as follows:

- Technical system boundaries: extraction of raw materials, reclaiming of reused materials, processing of new materials, and transport to the construction site. See Figure 4 for a simple flowchart of the processes included for the cob house assessment and Figure 5 for a simple flowchart of the processes included for the generic concrete block house assessment.
- Spatial and geographical system boundaries: Nicaragua and Costa Rica in Central America.
- Time horizon system boundaries: 2 years around year 2010. That was the time needed for the construction of the cob house.

The LCA assessment methodology had a cradle-to-gate approach using primary data, provided by the cob house builders and owners Rubén Meiro and Martha Solvany (2013); and secondary data gathered from the internet and fact sheets. The fossil CO_2 emission was the parameter used to describe the environmental impact. For natural materials (wood, river sand, clay, etc.) it was assumed that no CO_2 emissions during its extraction was generated. For materials "bought new" (See Figure 4 and Figure 5) such as paints, solvents, glass, and iron/steel/zinc generic CO_2 emission during its manufacturing found in the literature were taken into consideration. When materials were reclaimed and used in the house, the fossil CO_2

emissions due to their production were not included since materials have already been used elsewhere and its impacts were fully allocated to the first user.

To calculate fossil CO_2 emission due to transport, emissions from the extraction site of the natural materials and emissions from the store where other materials where bought or reclaimed where estimated taken into consideration the distance travelled to the construction site and an average fossil CO_2 emissions of 78.6g CO_2 per tonne per kilometre using the information reported in The Hitch Hiker´s Guide to LCA (Bauman & Tillman 2004, pg 297) for trucks and taking into account long distance routes. The study was carried out in Matagalpa, Nicaragua and most of the materials came from nearby (from Matagalpa itself or from Managua, San Isidro, Labranza, La Paz Centro, or Ciudad Dario). In some cases materials were transported from San Juan, Costa Rica; in this case transport from the purchase place to the construction place was included.

4.2 Technical system overview

The main materials used during the construction of the cob house were grouped in raw materials i.e., materials used in the same form as they were extracted from nature. These materials are wood from wood plantations (mainly pine and bamboo), and mineral materials extracted for the cob mixture such as clay, river sand, and rocks. CO_2 emissions resulting from raw material extraction were considered to be zero since wood comes from sustainable managed plantations and assumed to be cut with minimal environmental impacts, and the extraction of mineral materials was typically done by hand (human labour) using simple tools such as shovels (with no CO_2 emissions).

The other group of materials corresponds to processed materials. These materials have been transformed during industrial processes and include materials bought new like chemicals used for wood treatment, paints, cooked earth such as clay tiles, plastics, cement, hardware, skylight sheet, aluminium and glass. It also includes reclaimed materials like quarry stone, plastic, zinc sheet, and glass bottles (wine bottles). For purchased materials, CO_2 emissions due to material production was looked up in bibliography and CO_2 emissions due to material transport were included. For reclaimed (reused) materials CO_2 emissions due to material production were considered to be zero and CO_2 emissions due to material transport were included.

Figure 4 illustrates a simple flowchart for the process of building the cob house that was analysed in this study.

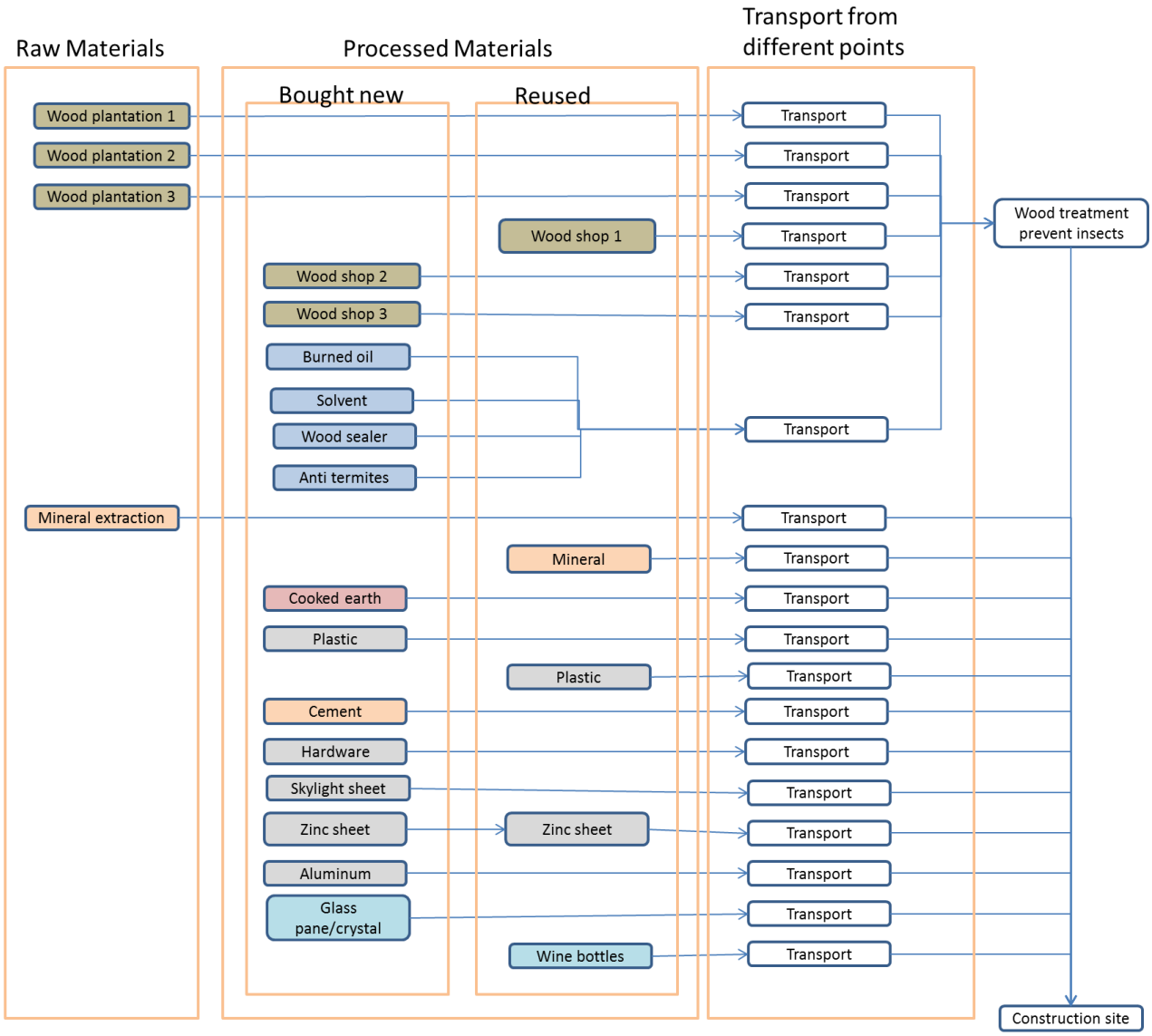

Figure 4. Simple flowchart for the process of building a cob house in Matagalpa, Nicaragua. Colours represent the group to which each material is grouped into in the inventory, see **Table 2**.

Figure 5 illustrates a simple flowchart for the process of building the generic concrete block house that was analysed in this study.

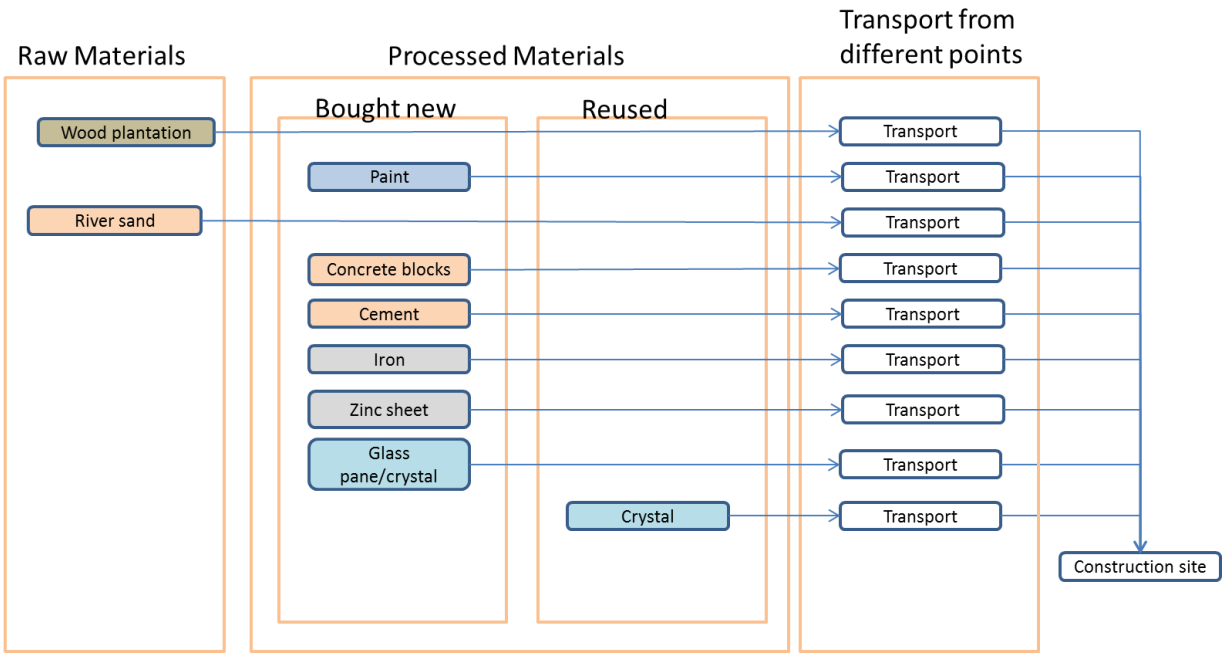

Figure 5. Simple flowchart for the process of building the generic concrete block house in Matagalpa, Nicaragua. Colours represent the group to which each material is grouped into in the inventory, see **Table 2**.

4.3 Inventory

The primary data for the cob house inventory was provided from the builders and owners of the cob house Ruben Meiro and Martha Solvany (2013). The data for the dimensions of concrete block house was provided by the owner of the house next door where I lived in Matagalpa, Nicaragua and the calculations for the amounts needed for that house were given by Raul Pérez a family friend who has building experience. For the inventory process, materials were grouped according to their nature and assigned a colour to facilitate easy overview as shown in Table 2. Transport distances are listed at the end of this table. Quantifications, weights, distance travelled for each material and fossil CO_2 emission calculations due to production and transportation are described in Appendix 1 for the cob house and in Appendix 2 for the concrete block house. ,

Table 2. Overview of materials used to build the cob-house and the concrete block house, grouped according to types, and with some generic information on environmental issues for each group. The amounts used are given in Table 4.

Solvents/adhesives paints from Grupo Sur Company	
Materials included: • Used oil • Anti-termite • Sealer (coat) • Solvent • Paint	Use: The used oil and the anti-termite where used in the cob house to treat the wood in order to eliminate any animal, bacteria or fungus that was present; and the sealer and solvent where added to the wood afterward to avoid future animal, bacteria or fungus that could damage it. The paint was used in the concrete block house to paint the cement floor. Environmental impact: These products are known to be toxic to the environment and to humans, and although eco-friendly products were bought they still have a negative impact during the production and use phases. CO_2 emissions per kilogram: Due to information and time shortage the same value was used for all of these materials. 35kgCO_2 per kg of material (Ecofx.org 2009)
Wood	
Materials included: • Bamboo • Beams and cross beams • Wooden posts • Castilla canes • Pochote wood	Use: The wood was used throughout the whole construction process. Some of it was used for temporal support and for the scaffolding, but most is used for supporting the roof and the clay tiles. Environmental impact: Nicaragua has high rates of deforestation causing diverse environmental impacts including deforestation and soil degradation. For this, it was very important for the builders and owners of the cob house to make sure that the wood was bought from legal plantation sites or reused if it was going to be dumped. CO_2 emissions per kilogram: Fossil CO_2 emissions were considered to be zero, since it was assumed that the plantations are legal and sustainable (well managed) and are nearly CO_2 neutral. For reused wood, the CO_2 emissions are allocated to the first user.

<table>
<tr><th colspan="2">Cooked earth</th></tr>
<tr><td><u>Materials included:</u>
• Bricks
• Clay tiles</td><td><u>Use:</u>
Bricks were used for levelling up and creating the base for the cob house and the clay tiles where used for the roofing of the cob house.
<u>Environmental impact:</u>
Although these are natural materials, its production generates high fossil CO_2 emissions. In Nicaragua bricks and clay tiles are cooked in ovens fuelled with wood. Since they need high temperatures for long periods of time to be properly cooked, a lot of burning wood is required generating fossil CO_2 emissions.
<u>CO_2 emissions per kilogram:</u>
• Bricks: 0,176kgCO_2 per kg (Diaz 2011pg 105)
• Clay tiles: 0,223kgCO_2 per kg (Diaz 2011 pg 113)</td></tr>
<tr><th colspan="2">Steel – Aluminium – Zinc - Iron</th></tr>
<tr><td><u>Materials included:</u>
• Nails
• Fastening wire
• Galvanized wire
• Flat zinc sheet
• Aluminium
• Iron (only used in concrete block house)</td><td><u>Use:</u>
Nails and wires where used to secure the different materials of the house. Aluminium and zinc where mainly used for division or roofing purposes and the iron (only used in the concrete block house) was used to add support to the walls.
<u>Environmental impact:</u>
Products in this group are known to have a high environmental impact during the extraction and processing stages.
<u>CO_2 emissions per kilogram:</u>
• Steel (nails, fastening wire, galvanized wire): 4,0kgCO_2 per kg (The.CO2List.org 2013)
• Zinc: 19,2kgCO_2 per kg (Zinc for life 2009)
• Aluminium: 0,86 kgCO2 per kg (The.CO2List.org 2013)
• Iron: 4,0kgCO_2 per kg (The.CO2List.org 2013)</td></tr>
</table>

Glass	
Materials included: • Crystal • Wine bottles	Use: Crystal and wine bottles were used to allow light to enter the house and for decoration. Environmental impact: Materials used to create crystal may cause air pollution due to their small size that makes them easily transferable by air. Crystal making needs high temperatures that are generated by fossil fuelled ovens and large water is then needed to cool the crystal. CO_2 emissions per kilogram: • Crystal: 0,6kgCO_2 per kg (The.CO2List.org 2013) • Wine bottles: Fossil CO_2 emissions were considered to be zero since the bottles were reclaimed and CO_2 emissions are allocated to the first user.
Other building materials	
Materials included: • Quarry stone • Cobble stone • Fine stone • Selected material§ • River sand • Beach sand • Straw • Clay • Cement • Concrete blocks**	Use: These materials are used for support purposes and to build walls and floors. Most of them are mixed up to create construction materials that will then work to "glue" all the materials throughout the house. In the cob house the materials used were quarry stone, cobble stone, fine stone, selected material, river sand, beach sand, straw, clay and cement. In the concrete block house river sand, cement and concrete blocks were used. Environmental impact: The extraction of most of these materials require heavy machinery due to their weight. CO_2 emissions per kilogram: • Cement: 0,9kgCO_2 per kg (Global Greenhouse Warming 2013) • Concrete block: 0,203kgCO_2 per kg (Hacker et al. 2008) The rest of the building materials listed here were donated, resulted as byproducts or extracted by hand so its fossil CO_2 emissions were considered to be zero.

§ Material of various sizes ranging from fine to large, with some plasticity, making it easily compactable. It can also be called natural gravel and is generally used for construction of roads and refills (Navarro 2008).
** Only for the concrete block house.

Transport	
CO_2 emissions were assumed to be 78.6gCO_2 per tonne per km (Bauman & Tillman 2004, pg 297)..	<u>Distance travelled:</u> • Used oil, anti-termite, sealer (coat), solvent and paint: From San José de Costa Rica that is 566 km from Matagalpa (INIFOM 2013). • Bamboo: 20km from Matagalpa (Meiro & Salvany 2013). • Beams and cross beams: 20km from Matagalpa (Meiro & Salvany 2013). • Wooden posts: 5km from Matagalpa (Meiro & Salvany 2013). • Castilla canes: 25km from Matagalpa (Meiro & Salvany 2013). • Pochote wood: 5km from Matagalpa (Meiro & Salvany 2013). • Bricks: Ciudad Dario to Matagalpa 40km (INIFOM 2013) • Clay tiles: La Paz Centro to Matagalpa 146km (INIFOM 2013) • Nails: 5km from Matagalpa (Meiro & Salvany 2013). • Fastening wire: 5km from Matagalpa (Meiro & Salvany 2013). • Galvanized wire: 5km from Matagalpa (Meiro & Salvany 2013). • Flat zinc sheet: Managua to Matagalpa 140km (Vianica.com 2013) • Aluminium: 5km from Matagalpa (Meiro & Salvany 2013). • Iron: From 5km from Matagalpa (Meiro & Salvany 2013). • Crystal: Managua to Matagalpa 140km (Vianica.com 2013) • Wine bottles: it was considered to be zero since the builders transported them to the construction site themselves when they were going to work. • Quarry stone: 20km from Matagalpa (Meiro & Salvany 2013). • Cobble stone: 20km from Matagalpa (Meiro & Salvany 2013). • Fine stone: 20km from Matagalpa (Meiro & Salvany 2013). • Selected material[††]: The transportation is allocated out of the systems boundaries since it is considered a "by-product". • River sand: San Isidro to Matagalpa 47km (Vianica.com 2013) • Beach sand: 5km from Matagalpa (Meiro & Salvany 2013). • Straw: 5km from Matagalpa (Meiro & Salvany 2013). • Clay: 20km from Matagalpa (Meiro & Salvany 2013). • Cement : 20km from Matagalpa (Meiro & Salvany 2013). • Concrete blocks: 70km from Matagalpa (Meiro & Salvany 2013).

[††] Material of various sizes ranging from fine to large, with some plasticity, making it easily compactable. It can also be called natural gravel and is generally used for construction of roads and refills (Navarro 2008).

4.4 Inventory results

Fossil CO_2 emissions for material production were calculated using the material's weight and values found in literature. To calculate fossil CO_2 emissions while transporting[‡‡] the materials, the materials' weight, the distance travelled by each material and the emission factor of $0.0786CO_2g$[§§] per kilogram per kilometre were taken into consideration. Calculations for each material group are presented in Table 3 for the cob house and in Table 4 for the concrete block house. Detailed calculations for fossil CO_2 emissions for the cob house and the concrete block house can be found in Appendix 1 and Appendix 2.

Table 3. CO_2 emissions for the materials (per group) used in the cob house.

	Material Group	Weight in kg	CO_2 emissions due to materials ($kgCO_2$)	CO_2 emissions due to transport ($kgCO_2$)	TOTAL CO_2 emissions ($kgCO_2$)
Cob house	Solvents/ adhesives paints Grupo Sur Company	51	1778	2	1781
	Wood	5670	0	27	27
	Cooked earth	10500	2271	203	2474
	Steel – Aluminum - Zinc - Iron	101	440	1	441
	Glass	162	97	2	99
	Other bullding materials	186680	1656	1863	3519
	TOTAL	**203163**	**6242**	**2099**	**8340**
	TOTAL in tonnes	**203,16**	**6,24**	**2,10**	**8,34**

Table 4. CO_2 emissions for the materials (per group) used in the concrete block house.

	Material Group	Weight in kg	CO_2 emissions due to materials ($kgCO_2$)	CO_2 emissions due to transport ($kgCO_2$)	TOTAL CO_2 emissions ($kgCO_2$)
Concrete block house	Solvents/ adhesives paints Grupo Sur Company	10	350	0	350
	Wood	30	0	0	0
	Cooked earth	0	0	0	0
	Steel – Aluminum - Zinc -Iron	721	7823	8	7831
	Glass	162	97	2	99
	Other bullding materials	52645	9740	505	10245
	TOTAL	**53567**	**18010**	**515**	**18525**
	TOTAL in tonnes	**53,57**	**18,01**	**0,51**	**18,52**

The results show that even though the cob house used more materials than the concrete block house, (Cob house: 203,16 tonnes, concrete block house: 53,57 tonnes),

[‡‡] CO_2 emissions for transport in tables Table 3 and Table 4 is in kilograms and in tonnes, whereas in Appendix 1and Appendix 2

CO_2 emissions for transport is in grams.

the total CO_2 emissions are lower for the cob house than for the concrete block house (Cob house: 8,34 tonnes fossil CO_2, concrete block house: 18,52 tonnes fossil CO_2).

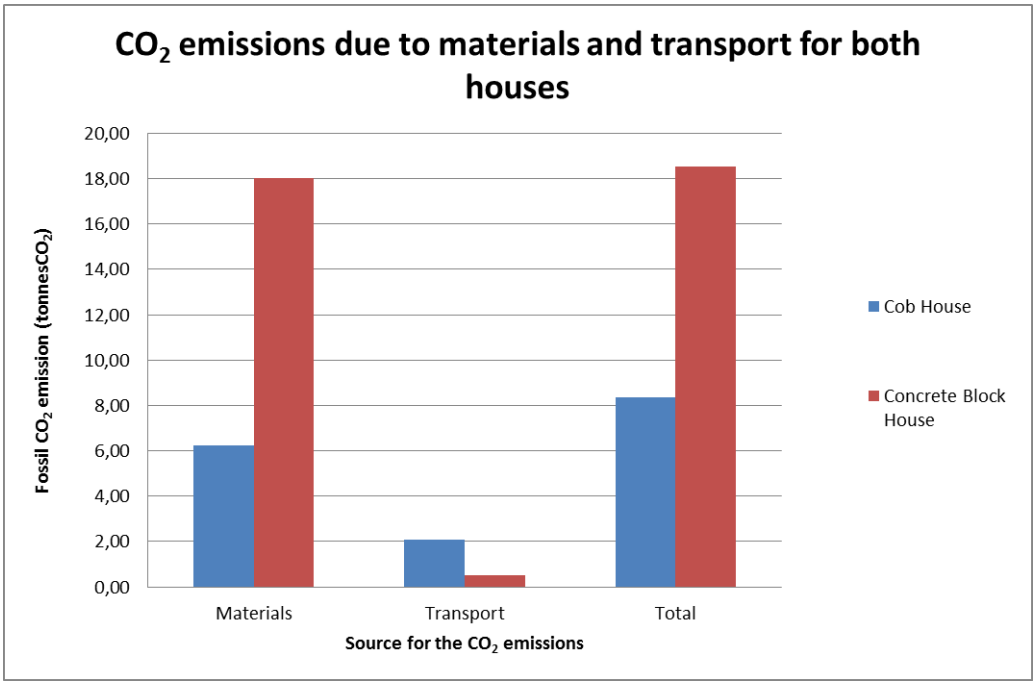

Figure 6. CO_2 emissions due to materials and transport for both houses

The highest CO_2 emissions in the cob house were generated by the material groups "Solvents/ adhesives paints Grupo Sur Company", "cooked earth" and "other building materials". CO_2 emissions from the concrete block house are mainly generated by material production, see Figure 6, and especially by the "Steel – Aluminium – Zinc – Iron" group (a lot of iron is used in the building) and the "Other building materials" group (a lot of concrete blocks with high CO_2 emissions are used in the building), see Figure 7. Although transport gives raise to low CO_2 emissions when compared to those generated by the materials, the transport of building materials in the cob house is higher than for the concrete block building.

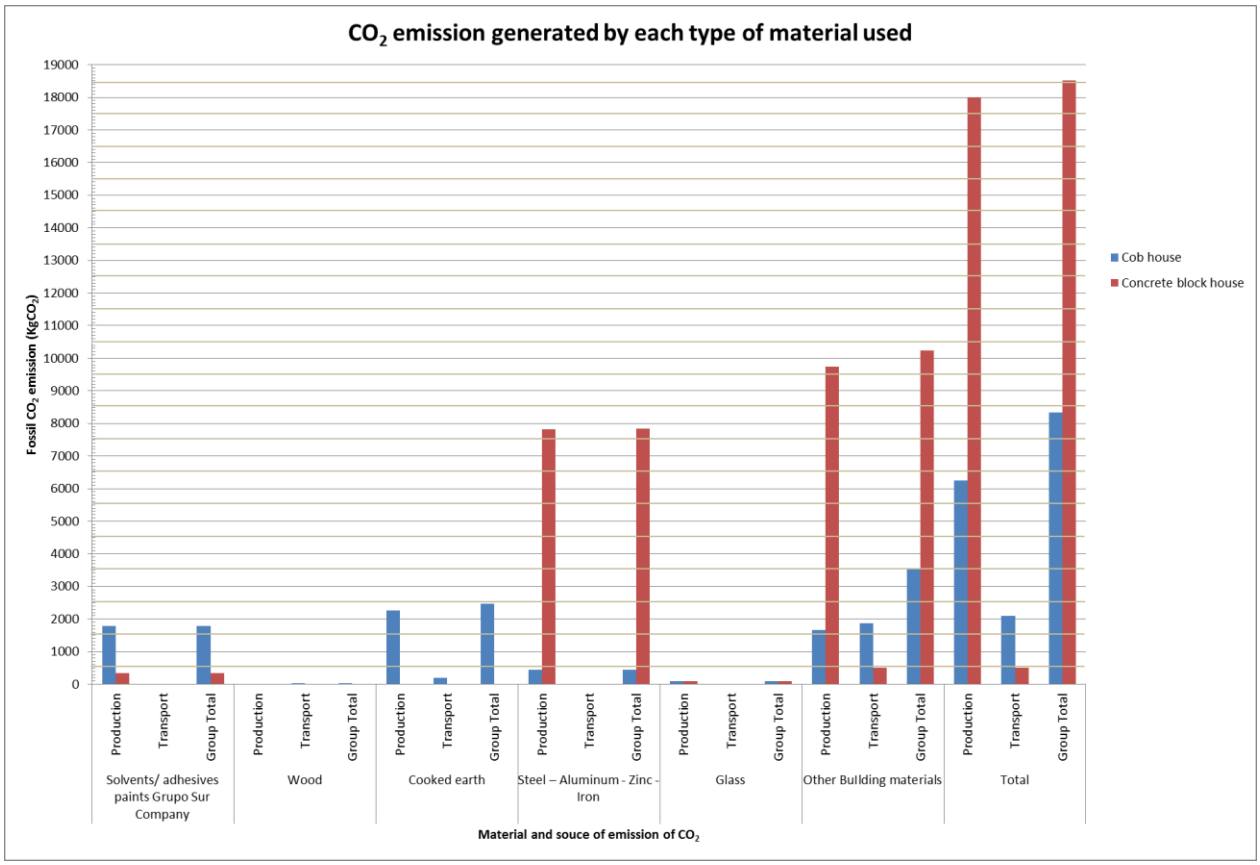

Figure 7. Fossil CO_2 emissions generated by each group of materials used.

4.5 Discussion of LCA part

For both houses, the main source of CO_2 emissions was connected to the production of the materials used. Transport contribute to a smaller part of the total emissions for both houses, but transports give a larger impact for the cob house compared to the concrete block house.

In the cob house results, the Grupo Sur Company products, the Cooked earth and the Other building material groups are the ones that contribute the most, while in the concrete block house results it is the Steel – Aluminium – Zinc –Iron and the Other Building Material groups the ones that contribute the most.

In the cob house, the chemical products used to treat the wood (Grupo Sur Company products) have high fossil CO_2 emissions as well as the clay tiles (Cooked earth) used for roofing; but the emissions of the cob itself represented in the "other building materials group" and the other groups were lower compared to the fossil CO_2 emissions of the concrete block house, see Figure 7. For both houses a combination between the materials used and the transport needed made the "other building

materials" group to be the group with the highest fossil CO_2 emissions. The cob house uses large amounts of building materials that are heavy and makes transport difficult. One way to reduce fossil CO_2 emissions due to transport is to pick the location of the house taking into account material supply that can be easily extractable from the surroundings. It will also be recommended to reconsider the use of clay tiles ("cooked earth" group) and to avoid using chemicals to treat wood as the ones included in the "Solvents/adhesives paints from Grupo Sur Company" group; since both groups accounted for the highest fossil CO_2 emissions due to production in the cob house. On the other hand, the CO_2 emissions from the concrete block house are mainly due to large quantities of iron ("Steel – Aluminium – Zinc – Iron" group) and concrete blocks ("other building materials" group) used for the walls and the ceiling. Both materials have high CO_2 emissions during their production.

The cob house uses more material than the concrete block house. This is represented in the total weight of the house that is nearly four times heavier than the concrete block house (Cob house approx. weight: 203,16tonnes; Concrete block house approx. weight: 53,57 tonnes). The fact that the cob house uses materials with little or no industrial processing reduces fossil CO_2 emissions significantly when compared to the concrete block house. In this case, the builders chose a clay tile roof which has proven to not be a very good environmental choice, but there are other options for the roof such as wood and straw that will, quite likely, reduce CO_2 emissions since no cooking is needed, or materials found nearby to reduce CO_2 emissions due to transport.

Some materials such as minerals, plastic, zinc and wine bottles were reused and the CO_2 emissions generated during their production were not accounted in the CO_2 emissions due to materials reported in this study. It was assumed that the first activity where these materials were used is responsible for the CO_2 emissions of material production. When the materials were used in the cob house they were "given a second chance" reducing the CO_2 emissions due to materials. If completely new materials were used instead of the reused ones the CO_2 emissions due to materials would change, increasing the overall CO_2 emissions of the cob house. If instead of the allocation process an expansion of the system was done probably the result would be different but undoubtedly it is always better to reuse materials than to create them from scratch.

4.6 Conclusions from the LCA part

- The CO_2 emission from the studied cob house was about a third compared to the concrete block house.
- CO_2 emissions due to transport of materials are not as high as CO_2 emissions due to material extraction and production
- The material groups that emitted the most CO_2 during the construction phase of the cob house were the "other building material" group, the "cooked earth" group and the "solvent/adhesives paints" group
- Cob buildings to some extant use raw materials avoiding CO_2 emissions since there is no need to process the materials before the construction phase, whereas the concrete block buildings require a larger amount of pre-processed materials.

5 Rate of adoption

The cob building technique is popular in some parts of the United Kingdom, and Ireland, but in most places, including Latin America, cob buildings are uncommon even though the cob technique is similar to traditional techniques such as adobe and wattle-and-daub which are both commonly used in Latin America. The cob house was assessed towards the five perceived attributes of innovations in Rogers's theory, see section 2.2. The assessment is to a large extent build on experiences by the owners of the case study building (Meiro and Solvany 2013), with complementary information from some inhabitants from Matagalpa and literature.

5.1 Results

5.1.1 Relative advantage

Among the relative advantages of the cob technique that makes it an interesting alternative when compared with other building techniques is that with cob houses can be built with little money and a lot of manual labour that can be done by untrained men, women, and even children; since there are different stages in the building process that don´t always require great physical strength. If the cob house is built in an area where the materials can be easily found and extracted there is less need for transporting materials. Cob houses are considered safe since they are resistant to earthquakes, don't burn and are not eaten by insects; and have the potential to be shaped in different forms and even create rounded structures allowing different building shapes and sculptures to be made enhancing the cob house´s appearance and adapting it to the final user; (Smith 2000). With cob, the owner can build furniture, Figure 8, such as benches and beds or even niches or bookshelves (Weismann and Bryce 2011) that may help reduce costs since there is no need to buy them elsewhere, and they can be made even after the house is finished. It is possible to add cob furniture to the building or to create niches or bookshelves after the wall has been built (Weismann and Bryce 2011).

The cob technique is more suitable for one floor single family houses (LILI 2012) and in areas where there is land and low density development. At a large scale, local materials will be a limiting factor so material transport and manual labour are increased (Seyfang 2010).

The material is usually found at or nearby the construction site; reclaimed materials can be incorporated into the design very easily, the construction is reported to use 60% less timber than a stud-frame house; rounded shapes allow for a more efficient use of space, many of the used material are biodegradables, it has a low embodied energy, it is non-toxic, it can be recycled, combined with other natural materials (stone, straw bales, timber, lime), materials can be found nearly for free, it keeps stable temperatures and good air quality, it is strong but flexible and it is easy to repair (LILI 2012).

Adobe and wattle-and-daub use similar materials but in a different way thus changing the characteristics of the final house. Adobe and wattle-and-daub houses are not as flexible as cob houses because of right angles formed at the vertex of the walls, for reparation purposes it might be needed to repair a whole section instead of only the damaged part, and due to the thickness of the walls (walls in adobe and wattle-and-daub houses are thinner than in cob houses) the temperature indoors fluctuates more than in cob houses and the use of space is not as efficient as in a rounded shaped houes.

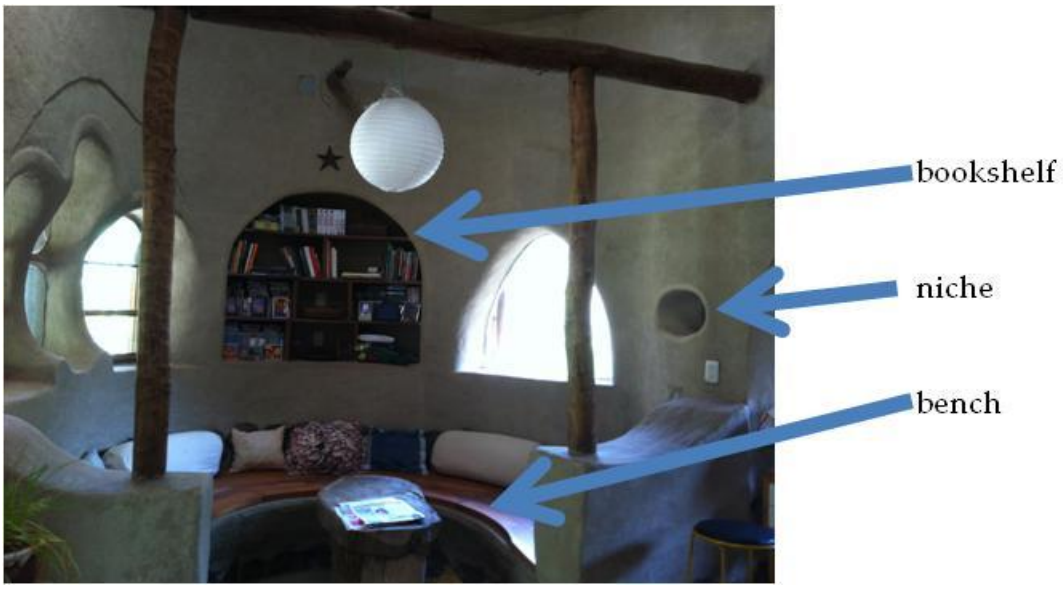

Figure 8. Example of the furniture that can be made in a cob house. The bookshelf and the niche are carved in the cob walls and the bench is additional to the main structure.

5.1.2 Compatibility

The cob technique seems to be consistent with the existing values, experiences, and needs of the people from Matagalpa since people in the area used to build houses in adobe or wattle-and-daub so they are accustomed to work with earthen materials.

Cob is an economically affordable technique to build houses in Matagalpa since materials in the area are cheap (most of the materials needed for a cob construction may be found in the surroundings), in contrast with the high prices of imported materials; and even though cob technique is labour intensive and thus may take long to build a house, inhabitants in the area have the time to overcome this issue due to Nicaraguan reality of cheap labour*** caused by unemployment and poverty.

Cob, due to its flexibility, can be combined with other building techniques, such as earthbag technique, wood frame, concrete, straw bale, adobe, wattle-and-daub, etc. in order to reduce costs, time, or to improve its performance according to the surroundings, the labour work and the materials available (Smith 2000).

5.1.3 Complexity

People are likely to understand that earth is an option for building houses but not many people in Matagalpa or even in Nicaragua know how to build with cob technique so some training and guidance is needed. The cob mixture can be made with a variety of soil types and does not require heavy or specialized machinery, which makes it easy to work with and affordable. Cob may be useful in a country where people tend to build their own houses and use low tech technology (Smith 2000) as in the case of Nicaragua.

5.1.4 Trialability

There is only one finished house in Matagalpa and many people don´t know about it. This may make it hard for others to know that there is an existing cob house in the area and miss the opportunity of visiting and "trying" it. The cob building technique is easy to "try" since small things such ovens or benches can be built easily and relatively fast, giving the user the opportunity to get familiar with this technique.

*** Although unemployment in Nicaragua is of 10.5%, the percentage of people living in poverty is of 46% and people living in extreme poverty is of 15% (BCIE 2011)

The Latin American and Caribbean Forum on Best Practices (Foro Iberoamericano y del Caribe sobre Mejores Prácticas in Spanish) developed a program called CYTED in order to improve the transfer of better practices regarding a wide variety of topics including housing (the HABYTED subprogram) and integrating politicians, universities and the population (CENVI 2008). A similar program may be used in order to increase trialability and diffusion of the cob building technique

5.1.5 Observability

Since cob is not a widely spread technique and there is only one house built with cob in the area, the observability is limited. Currently there is a farm house in the country side of Matagalpa that is being built using cob so that will increase the opportunity of seeing a cob construction and trying it. It may also help people understand that the cob technique can be combined with other earth-building techniques such as the earthbag technique, see Figure 9, to make it easier to build when resources and/or the landscape requires it.

Figure 9. Earthbag technique used in the second cob house being built in Matagalpa, Nicaragua. Earthbags are used for the walls of the bottom floor.

5.2 Discussion

As it can be seen from attributes and the fact that there is only one built house and one under construction the rate of diffusion of the cob technique is slowed down. But the other three attributes "relative advantage", "compatibility" and "complexity" may be used to promote and encourage the use of this technique since it seems to

meet the needs and capacities of the people living in Nicaragua at the same time that it gives a better alternative for housing when compared to existing options in the area.

If the two slowing attributes ("trialability" and "observability") want to be tackled then it is recommended to start with small projects like small ovens and benches in order to understand and become familiar with the techniques as suggested by Evans (2002), and then with the understanding of the basics, maybe build a cob house. Additionally some change agencies such as NGO´s could help establishing guidelines and educating decision makers since it seems that there are few or no institutions and policies promoting green building techniques in the area, minimizing the possibility for people to learn about building with cob or to have proper help or advice on the subject when needed. One way may be changing from top-down transfer of technology to a feedback model approach which includes the experiences of the users and includes them in order to enhance it (FAO 1997), but this approach would only work and benefit Nicaraguans if they are active and find ways to improve the cob building technique based on their specific needs

Cob technique faces barriers for it to be spread among Nicaraguans. Cultural, social, political, economic and technical barriers seem to be similar to the ones described by Seyfang (2010) in his study about building and spreading sustainable housing in the UK, where he proposes to enhance "community-led solutions"; this may help disseminate the technique among small communities and rural areas in Nicaragua. Innovations promoting more sustainable use of natural resources should be intensely communicated in Nicaragua. There is a need to improve citizen's quality of life but unfortunately, in many cases, this is linked to environmental degradation. The cob technique may be a way of decoupling these two aspects (citizen's quality of life and environmental degradation). Cob enables families to build affordable and customized houses at a low price when compared to other houses, and through the extraction of materials for the cob mixture and the reclaiming and reuse of other materials extensive and intensive damage to the environment can be minimized. But Seyfang (2010) explains in his paper *Community action for sustainable housing: Building a low-carbon future*, that "innovation refers to the successful exploitation of new ideas" however in order to exploit new ideas and diffuse them there has to be a technological and social behavioural change. One way to accelerate this change maybe be to take advantage of the niche the cob technique innovation already has in the area since it seems to be highly compatible with previous innovations (adobe,

wattle-and-daub). According to Rogers (2003) the connection between previous innovations and new ones may help to diffuse new technologies that use similar niches, so by using the adobe and wattle-and-daub niche the cob technique may be diffused. However a huge disadvantage this technique has in Nicaragua is that mass-produced housing bricks, concrete, concrete blocks and/or quarry stone are the norm, whereas cob houses are scarce, meaning that the niche for this development is mainly self-built houses by owner-occupiers (Seyfang 2010).

Innovators play a key role in the diffusion of innovations since they are the first to adopt an innovation and tend to be adventuresome and tend to have more cosmopolite social relationships, are able to cope with uncertainties due to an innovation and are interested and willing to try new ideas (Rogers 2003). In this specific case the innovators are people who have a higher level of education than the average rural Nicaraguan citizens, have access to accurate information and have the economic means to try the cob building technique. These innovators are the key to spread the technique, since the technique itself seems to comply in a high degree with three of the five perceived attributes of innovations (relative advantage, compatibility, complexity) and to some degree with the other two perceived attributes of innovations (trialability, observability). So, although Nicaragua and mainly Matagalpa seems to have a shortage on these type of people willing to take the risk of building a house with an uncommon technique in the area, there are some citizens that fit into the characteristics of innovators and are slowly spreading the cob technique in Matagalpa.

Since it is probable that a big obstacle for the diffusion of cob is the social system itself a better diffusion of this innovation could be done taking into account the Innovativeness and the Adopter Categories described by Rogers in his book Diffusion of Innovations. Based on my results it may be considered to direct efforts to the innovators and early adopters which are the one who will start using the cob building technique and promote it among others, but more research would be needed in this area.

5.3 Conclusions

- Cob technique from Rogers rate of adoption perspective (relative advantage, compatibility, complexity, trialability and observability) has a relative advantage when compared to other building techniques on the area, is compatible with the

needs and capacities of the people living in Matagalpa, Nicaragua and is a simple technique that can be implemented by anyone.

- Cob technique uses cheap materials and is labour intensive which is suitable for Nicaragua´s conditions.
- "Community-led solutions" may be an approach to improve local participation and to increase the rate of adoption among small communities and rural areas in Matagalpa, Nicaragua taking into advantage the niche used by the adobe and wattle-and-daub building techniques.

6. General discussion and findings

The cob technique enables the builder to combine other techniques, and depending on the surroundings and the materials found, different combinations are possible in order to improve the house both in structure and in beauty according to the builder/owner´s point of view. People who build with concrete block mainly uses this technique throughout the whole house, without using recycled materials or using other techniques.

Fairle (1996) presented a set of requirements for "low impact development". According to the results presented in sections 4.6 and 5.3 a cob house can be considered such a low-impact building, since it is temporary (in nature´s time scale), small-scale (cob houses are mostly small and compact), made with local materials (the proportions of the materials needed can be changed according to the quality of the local materials), protects wildlife and human wellbeing (no toxic materials are used and no aggressive processes are needed), it requires small amounts of non-renewable resources (the main activity that uses non-renewable resources is transportation which can be reduced), and, in many cases, it is linked to a living philosophy that aims to protect the environment. So when the cob house is built properly, taking into account the surrounding environment (inclination of the terrain, sun light, wind, etc) and using locally available materials (wood, clay,dirt,etc) it may be considered to be a "low-impact development" based on Fairle (1996) requirements.

Even if the extraction of materials for a cob house may alter the surroundings due to clear cutting and digging holes which are comparatively small when compared to those of open pit mining, these areas are easily rehabilitated due to their small size by filling in the holes and reforesting on top, or by filling up the holes with water creating a pond that could be used by animals and humans (Chiras 2002). Moreover the amount of timber needed in a cob house can be reduced to a minimum (LILI 2012) which is a big advantage in a country such as Nicaragua, where deforestation has altered the landscape drastically.

The materials of the concrete block house were mainly new, and large quantities of iron and concrete block accounted for high CO_2 emission. Unfortunately CO_2 emissions for these materials are hard to reduce due to the extraction and processing they undergo to transform natural materials into iron and concrete blocks.

Although the results shown in this study are based on fossil CO_2 emission other different environmental indicators may be used in order to have better information on the environmental impact of the construction. Depending on what type of information is required different tools can be used. Additionally it is essential to take into account that depending on the area where the cob building is done its environmental impact may vary.

7. General conclusions

- The CO_2 emission from the studied cob house was about a third compared to the concrete block house and CO_2 emissions due to material extraction and production for the cob house and the concrete block house where higher that those due to transport of materials.
- The material groups that emitted the most CO_2 during the construction phase of the cob house were the "other building material" group, the "cooked earth" group and the "solvent/adhesives paints" group
- Cob technique from Rogers rate of adoption perspective (relative advantage, compatibility, complexity, trialability and observability) has a relative advantage when compared to other building techniques on the area, is compatible with the needs and capacities of the people living in Matagalpa, Nicaragua and is a simple technique that can be implemented by anyone.
- When properly built the cob house may be considered to be a "low-impact development" but depending on the area where the cob building is done its environmental impact may vary

Recommendations

More research is recommended on the diffusion of innovation of the cob building technique, especially from the adopter point of view in order to be able to develop the best tactic for the diffusion of this technology. A suggestion to do this may be using the Adopter Categorization on the Basis of Innovativeness of Rogers.

Appendix 1

CO_2 emissions during material production and transport for the cob house.

	Material	Quantity (Meiro & Salvany 2013)	Weight (All the weight data was gatheres from Meiro & Salvany 2013, except from the Solvents/adhesives paints GrupoSur	Total Weight (kg)	CO_2 emission in producing it ($kgCO_2$ per kg material)	Distance traveled (km)	Total gCO_2 emitted due to transport (CO_2g per kg per km)
Solvents/ adhesives paints Grupo Sur Company	Used oil	3 gallons	1gl=3,65kg (Grupo Sur Products 2009)	10,95	35	566	0,0786
	Anti termite product	3 gallons	1gl=4,72kg (Grupo Sur Products 2009)	14,16	35		
	Sealer (Coat)	3 gallons	1gl=3,65kg (Grupo Sur Products 2009)	10,95	35		
	Solvent	5 gallons	1gl=2,95kg (Grupo Sur Products 2009)	14,75	35		
	TOTAL			50,81	1778,35		2260,41
Wood	Bamboo	27 pieces	20kg	540	0	20	0,0786
	Beams and cross beams	10 units (2m x 0.5m)	10kg	100	0	5	
	Wooden posts	3 posts	1 post = 1012kg 2 posts = 678kg each	2374,96	0	5	
	Castilla canes	1800 units	0,6kg	1080	0	25	
	Pochote wood	35 planks	1 plank = 45kg	1575	0	5	
	TOTAL			5669,96	0		26739,53
Cooked earth	Bricks	500 units (dimensions 6 x 12 x 24)	3,0kg each	1500	0,176	40	0,0786
	Clay tiles	4500 units	2,0 kg each	9000	0,223	206	
	TOTAL			10500	2271		203023,80
Steel – Aluminum – Zinc - Iron	Nails (steel)			35,36	4	5	0,0786
	Fastening wire (steel)			27,2	4	5	
	Galvanized wire (steel)			32,2	4	5	
	Flat zinc sheet (mainly iron covered with zinc)	5 pieces		3	19,2	140	
	Aluminum			3,3	0,9	5	
	TOTAL			101,06	439,61		1270,93
Glass	Cristal			161,6	0,6	140	0,0786
	Wine bottles	15			0	0	
	TOTAL			161,6	96,96		1778,25
Building materials	Quarry stone	$32m^3$	$2.4gr/cm^3 = 2400kg/m^3$	76800	0	20	0,0786
	Cobble stone	$12m^3$	Approx. $1600kg/m^3$	19200	0	20	
	Fine stone	$17m^3$	Approx. $1200kg/m^3$	20400	0	20	
	Selected Material				0	0	
	River sand	$44m^3$	$1500kg/m^3$	66000	0	47	
	Beach sand			100	0	5	
	Straw			2190	0	5	
	Clay			150	0	5	
	Cement			1840	0,9	5	
	TOTAL			186680	1656		1863477,10
TOTAL				203163,43	6241,92		2098550,02

Appendix 2

CO_2 emissions during material production and transport for the concrete block house.

	Product	Quantity	Weight	Total Weight (kg)	CO2 emission in producing it (kgCO2 per kg material)	Distance traveled (km)	Total gCO2 emitted due to transport (CO2g per kg per km)
Solvents/ adhesives paints Company	Paint	10 gallons	1gl=5kg	10	35	5	0,0786
	TOTAL			10	350		3,93
Wood	Wood	3	10	30	0	5	0,0786
				30	0		11,79
Steel – Aluminum – Zinc - Iron	Flat zinc sheet (mainly iron covered with zinc)	30	1 sheet = 13kg	390	19,2	140	0,0786
	Iron		Structural iron: 270,708kg Soft iron wire: 60kg	330,708	4	5	
	TOTAL			720,71	7822,71		7930,67
Glass	Cristal	1		161,6	0,6	140	0,0786
	TOTAL			161,6	96,96		1778,25
Building materials	Cement			4800	0,9	5	0,0786
	Concrete blocks	1500	17,8	26700	0,203	70	
	River sand			21145	0	47	
	TOTAL			52645	9740,1		504823,43
TOTAL				**53537,308**	**18009,768**		**514536,28**

Acknowledgements

Thanks to my supervisors Henrik Haller and Morgan Fröling at Mid Sweden University for helping me during the whole process and challenging me to do my best. Thanks to Rubén and Martha who taught me about cob and shared with me their experience when building their cob house, without them this case study would not be possible. And thanks to Nicaraguan people, mainly the Matagalpinos I shared a lot of time with, for making my time in this city a great one, for making me feel at home and for sharing their knowledge, thoughts, experiences and time. Thanks to my friends and family, in heaven or on earth, who kept me company throughout the process helping me and cheering me up. Special thanks to SIDA (Swedish International Development Agency) that through the Minor Field Studies scholarship, made this case study possible.

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