A comparison of the sustainability of common construction materials

Based on embodied carbon data and materials specification of a single-family house.

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Abstract

In the light of the modern age global concerns for environmental issues, specifically global warming, this thesis purports to sketch a material profile of traditional structural construction materials – concrete, wood, fired clay bricks and steel – based on a specification of a single-family house. It calculates materials' embodied carbon, reviewing other sustainability parameters as well, such as recycling potential and fire resistance. The thesis also explores options of substitution with more carbon neutral materials, revealing other possible benefits. Each study displays the origins of materials' burden on the environment and is focused on an owner-builder's view on single-family house construction.

The building's embodied carbon totaled at 208 tonnes. Fired clay bricks displayed the largest share of this value – 98 tonnes of carbon dioxide. 67 t of CO_2 were contributed by concrete, 40 t by steel and 3 t by wood. Wood's sustainability depends on its source – the specific forest. Therefore, this part of the study is based on evaluation of two largest forest certification programs – PEFC and FSC. The latter is concluded to be a more reliable one.

A number of alternative materials is presented in this paper, with estimates of potential carbon emissions savings. They include blended and geopolymer cements, engineered wood products (CLT), AAC blocks, CEBs and straw bales. All of them potentially cut the building's embodied carbon drastically, without compromising the performance. General recommendations for sustainable material selection are provided.

Language: English Key words: global warming, construction, building, embodied carbon, concrete, cement, wood, timber, steel, bricks, forest certification, engineered wood products, CLT, CEB, AAC, straw bales, sustainability

Preface

I would like to thank my supervisor, Anna Granberg, for the help she provided. I would also like to thank the whole campus Raseborg for letting me have one of the best times in my life and giving me a chance to meet so many wonderful people, some of whom have become dear friends of mine. I am also grateful to my friend Vladimir Kuznetsov for providing me with the material for the thesis. And last but not least I would like to thank my brother Pavel Evtushenko and my friend Dmitry Grachev, whose love and support have made the whole endeavor possible.

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Glossary

Acidification - is mainly caused by the interaction of nitrogen oxides (NO_x) and sulfur dioxides (SO_x) with air components. The acidification may lead to the movement of heavy metals, may affect water, animals and plants and may cause the corrosion of buildings.

Black Carbon (BC) – the most strongly light-absorbing component of particulate matter (PM), and is formed by the incomplete combustion of fossil fuels, biofuels, and biomass.

By-product – a secondary product of an industrial process.

Cement – a powdery product made from limestone and small amounts of other raw materials, heated to form clinker, which is then ground to a powder with small amounts of cement.

Clinker – a hard substance produced in cement kilns which is ground with gypsum and other additives to make cement.

CO_2e – carbon dioxide equivalent.

CoC – chain-of-custody certificate. For example, FSC CoC certificate verifies material from FSC certified forests through the production process – from the forest through processing companies, manufacturing, to the consumer.

Concrete – a building material made from a mixture of sand and rocks bound together with cement.

Dioxins – an informal term for the family of polychlorinated dibenzo dioxins and related polychlorinated dibenzo furans.

FCAG – forest certification assessment guide.

Feedbacks (between the carbon cycle and the climate system) – critical aspect of climate projections. For example, if the warming leads to enhanced rates of decay of organic matter in soils, or a reduction in oceanic carbon uptake, then the concentration of CO_2 in the atmosphere will rise more rapidly than it would in the absence of such (positive) feedbacks, and the rate of warming will be greater as well. Conversely, if increased CO_2 in the atmosphere enhances photosynthesis and the storage of carbon in plants and soils, then CO_2 levels will rise less rapidly than in the absence of this (negative) feedback, and climate change will also be slower as a result.

FSC – Forest Stewardship Council.

GATT – The General Agreement on Tariffs and Trade.

Geopolymer – a Si/Al inorganic polymer.

GGBS – ground-granulated blast-furnace slag.

GJ – gigajoules (one billion joules). Joule – a derived unit of energy, work, or amount of heat in the International System of Units.

Gypsum – a naturally occurring mineral, hydrated calcium sulfate.

HCVF – high conservation value forest.

IFL – intact forest landscape.

LCA – life-cycle assessment is a technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave.

LCI – life-cycle inventory analysis involves creating an inventory of flows from and to nature for a product system.

Limestone – a common naturally occurring rock, primarily composed of calcium carbonate, often containing trace amounts of other minerals.

NO_x – oxides of nitrogen, the sum of nitric oxide (NO) plus nitrogen dioxide (NO_2). Although other oxides of nitrogen occur, such as nitrous oxide (N_2O), they are normally excluded from this definition. It is part of acidification potential calculations.

NSAI – National Standards Authority of Ireland.

OPC – ordinary Portland cement.

PAHs – polyaromatic hydrocarbons.

PCBs – polychlorinated biphenyls.

PEFC – The Programme for the Endorsement of Forest Certification.

PfA – policy for association.

Pozzolan (pozzolana) – a siliceous or siliceous and aluminous material which, in itself, possesses little or no cementitious value but which will, in finely ground form and in the presence of water, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. Artificially produced materials are usually called pozzolans, while naturally occurring – pozzolana.

Primary forest (primeval, old growth) – forest of native species where there are no clearly visible indications of human activities and the ecological processes have not been significantly disturbed.

RCC – rapid climate change.

R-value – (reciprocal of U-value) a measure of thermal resistance used in the construction industry. It is the ratio of the temperature difference across an insulator. The higher the value of R, the better the building insulation's theoretical effectiveness.

SCM – supplementary cementitious material, such as fly ash, blast furnace slag, silica fume, burnt shale, metakaolin, rice husk ash, diatomaceous earth, volcanic ashes and pumices.

SFM – sustainable forest management.

SO_x – oxides of sulfur: the sum of sulfur dioxide (SO_2) and sulfur trioxide (SO_3). It is part of acidification potential calculations.

Thermal mass – defines the time it takes for a building to heat up during daytime and to cool down at night. High thermal mass allows buildings to have a relatively steady indoor temperatures, which reduces maintenance costs and carbon footprint related to external heating and cooling.

U-value – (reciprocal of R-value) a measure of thermal conductance used in the construction industry. It measures the rate of heat transfer through a building element over a given area under standardized conditions. The higher the U value the worse the thermal performance of the building envelope.

W/mK – a measure of thermal conductivity in watts per meter kelvin. Multiplied by a temperature difference (in kelvins, K) and an area (in square meters, m^2), and divided by a thickness (in meters, m) the thermal conductivity predicts the power loss (in watts, W) through a piece of material.

WTO – The World Trade Organization.

1 Introduction

The cyclic recurrence of human life on Earth is reflected in ancient civilizations, like Hindu and Greek, for example (Onvlee, 2015). In ancient Hindu cosmology cyclical life on Earth equals to one precession of the equinoxes (a more modern name is axial precession), and is broken into four ages, or Yugas: Kali, Dwapara, Treta, Satya (Selbie & Steinmetz, 2011). The ancient Greek culture describes the same four age cycle as Iron, Bronze, Silver and Golden, where the Iron Age is the darkest one, and the Golden age is the age of enlightenment (Onvlee, 2015).

According to the philosophies, we have just left the material (Iron, Kali) age and entered the Bronze Age, or Dwapara yuga, often also referred to as the age of electricity and the atom. We are still very materially oriented, but already started to harness our finer forces and to understand the subtle forces just behind matter. We are beginning to realize that progress is not simply building and producing more and more things. It is unlikely that any human is willing to embrace future composed of identical blocks, flooded with dirty cars, littered with landfills and suffocating from pollution. Nor Earth itself is able to sustain this way of life for long. (Selbie & Steinmetz, 2011)

Whether humans do or do not have a free will is a popular subject of discussions. Evidently, we are influenced by our physical needs and circumstances. But we also have the ability to control our intellectual powers by living our lives productively or destructively, healthy or unhealthy. Just like there are “iron age” people today, those who subdue their lives solely or predominantly to material consumption and accumulation, there are also people of enlightenment, those who do not limit themselves with material concerns and have more holistic view on things. The latter are growing in numbers day by day. Gradual progress of our civilization based on knowledge accumulation has been boosted incredibly by unprecedented spread of information access and sharing in the last couple of decades, ascending humanity into the age where it would embrace many benefits of nature and live in harmony with it.

Assessing materials based not only on the user qualities of a finished product, but also on how much energy was used to produce them, how well they perform along their lifecycle, how wasteful and recyclable they are, is one of the most important steps for our civilization to take in order to advance to that next stage of evolution.

2 Purpose

Construction materials is what often comes to mind first when we think of materials as such. Around 40 percent of all industrial economy’s material throughput is taken by a building sector (Milani, 2005, 2). Most important structural (load-bearing) construction materials are concrete, steel, wood and masonry (clay bricks). They are considered to be traditional materials, and are used extensively in residential house construction.

The purpose of this thesis is to present a review of the sustainability of traditional structural materials from a point of view of a contemporary owner-builder. The focus of the work is materials' embodied carbon. It can be of use to an owner-builder wishing to construct an abode in trend with the modern day concern over a climate change, specifically human contribution to global warming. It aims to assist in decision making over materials selection and presents a real-life example of materials' embodied carbon.

The idea behind using a reference project is to present an actual example of how much carbon can be embodied in a typical modern single-family house built with traditional industrial materials. Additionally, the work presents an estimation of how much carbon could be saved in case of substituting materials with greener alternatives. The purpose here is to give a simple comprehensible example of the savings without going into details of specific design.

Economy decarbonization has become a centerpiece of modern day environmental policies in the developed world (IPCC, 2014). Acquiring construction materials with less embodied carbon is the choice to make by a responsible owner-builder. Two materials in this work, concrete and wood, are reviewed somewhat more thoroughly than the others.

Concrete is perceived as a pinnacle of modern age construction industry. However, it is also well-known for being an energy intensive material. The work studies this characteristic and attempts to assist an owner-builder's decision over the extent of the use of concrete in his/her project, as well as review some options for reducing its carbon footprint.

Wood appeals to be sustainable by default. This work examines this appeal. The wood chapter reflects on the dangers of unsustainable forestry practices and ways for a customer (owner-builder, for instance) to tell if he/she is purchasing a wood product that originates from a sustainably managed forest. The focus of the examination is a comparison of the two largest forest certification programs in terms of their stringency and effectiveness of the systems.

3 Method

This work is mostly based on the electronic literature review available through free public access or semi-free, i.e. electronic libraries, as well as information from official websites. Material profiles are cited most often from the 4th edition of "Construction Materials: Their Nature and Behaviour" by Peter Domone and John Illston (2010). The book gives a clear and comprehensive perspective on the whole range of modern construction materials, their origin, production processes, and their properties. The latest edition has been updated with the focus on materials' contribution to sustainable construction practices, from production stage to reuse and recycling. It is aimed as a broad-based, yet sufficiently deep materials textbook for Civil and Structural engineering, architecture and other students.

Within the frame of this work, an actual construction project is used as a subject for material breakdown. It is a two-storey 237 square meters floor area single-family house with three bedrooms. It has a light wood frame and masonry walls of fired clay brick. The foundation is steel reinforced concrete and piling. The walls of the house are insulated with mineral wool and the roof is covered by bitumen shingles. The façade is finished with clinker tiles.

The house is marketed under the brand name “Ruan” and is a part of a gated community outside of Moscow, Russia. The community consists of 43 houses of 5 different types, among which Ruan is the most common one (13 houses). Figure 1 shows the front and back side views of the Ruan house.

Figure 1. Ruan house front and back views. Source: Petrovo.ru

The material breakdown is based on the final estimates attached to the contract (see the Appendix). The estimates table is split into two stages. The first stage covers expenses and materials specification for below the zero mark construction, mainly foundation. Stage two covers the same for construction above the zero mark, including frame, walls, roof, plumbing, finishes, etc.

The basic evaluation parameter is *embodied carbon* (EC), also more broadly referred to as the carbon footprint. Even though embodied carbon and embodied energy (EE) have a broad correlation, EC is a preferred measure of impact on the climate because EE is more dependent on the specific energy source used for a material’s processing. (Domone & Illston, 2010)

EE/EC can be calculated differently based on different boundary conditions. *Cradle to grave* is the most extensive one, a result of product’s Life Cycle Assessment (LCA), a short summary of which is presented in Figure 2. LCA incorporates the product’s energy consumption from the extraction of raw materials (including fuels) until the end of the product’s lifetime. The c*radle to site* boundary condition excludes maintenance and disposal. The c*radle to gate* data, most commonly available at a product level, ends at the factory’s “gates”, excluding the transportation to the point of use and further costs. (Hammond & Jones, 2008)

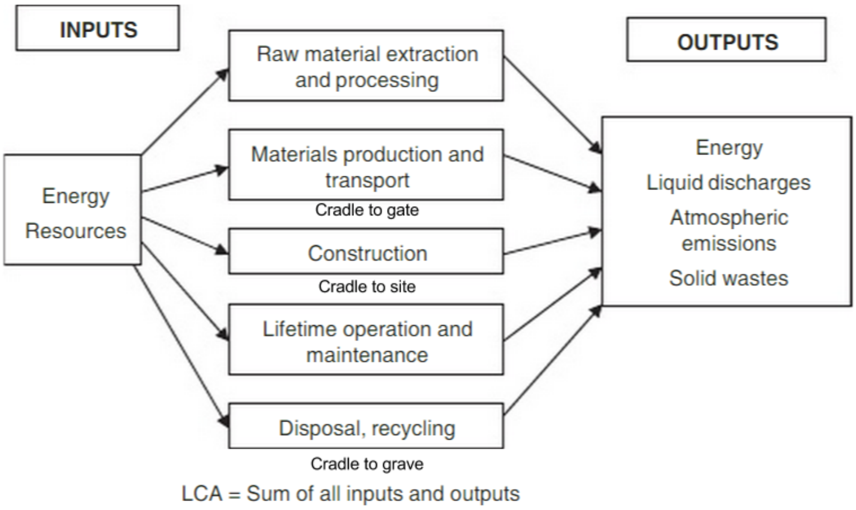

Figure 2. Summary of the life-cycle assessment procedure. Source: (adapted) Domone & Illston, 2010.

The (BRE) analyses a number of environmental impacts of building materials, such as fossil fuel and ozone depletion, transportation, human and ecological toxicity, waste, water consumption and pollution, acid rain potential, smog contribution and mineral extraction. Among all the impacts, global warming potential has by far the largest weighting factor (36%). (Broome, 2007, 177)

Several databases on EE/EC coefficients for building materials are available, both free and commercially distributed. National databases, such as the German oekobaudat.de and the Dutch Nationale Milieudatabase (NMD), or commercial databases, such as the Ecoinvent and the GaBi construction database, have not been considered in this work. Two extensive databases that are in English and available publicly are the BRE Global's Green Guide to Specification and University of Bath's Inventory of Carbon and Energy (ICE) Database. (Anderson & Thornback, 2012)

For this work the Inventory of Carbon and Energy (ICE) database was selected. The data for it was collected from secondary resources in the public domain, including journal articles, LCA's, books, conference papers, etc. The data was aligned to fit the cradle to gate boundary condition. This work uses version 2.0 of the database last updated in 2011. (Hammond & Jones, 2008)

The following two material qualities are briefly reviewed in order to supplement the sustainability assessment:

- *Fire resistance.* It defines the building's response to fire and is governed by the material's mechanical properties. This quality might be giving sustainability a rather literal meaning, but safety is an important factor in the material selection.

- *Recycling potential*. How much waste the building is likely to generate at demolition is an important long-term sustainability parameter.

The Embodied carbon in the ICE database is commonly presented in the *carbon dioxide equivalent (CO_2e)* (Hammond & Jones, 2008). Different greenhouse gases (GHGs) have different lifetimes in the atmosphere and different heat absorption abilities. In order to evaluate GHGs within the same framework, the CO_2e measure is used. For any quantity and type of a GHG, CO_2e signifies the amount of CO_2 which would have the equivalent global warming impact. A quantity of GHG can be presented as CO_2e by multiplying the amount of the GHG by its global warming potential (GWP). GWP is an index indicating the amount of warming a gas causes over a given period of time, generally a 100 years (Brander & Davis 2012). Up to date GWP indexes for some of the main GHGs are given in Table 1.

Table 1. GWP of common GHGs.

GHG	Chemical Formula	Lifetime (Years)	GWP 20-year	GWP 100-year
Carbon dioxide	CO_2	N/A (highly varied)	1	1
Methane	CH_4	12.4	84 (±30%)	28 (±40%)
Nitrous oxide	N_2O	121	264 (±20%)	265 (±30%)

Source: IPCC, 2013

As follows from Table 1, an amount of a common GHG, methane, is estimated to have 28 times greater GWP than the same amount of CO_2 (over a 100 years). Fossil fuel is any hydrocarbon source, combustion of which in combination with industrial processes is the major contributor of anthropogenic GHG in the atmosphere in the form of CO_2 (65%) (IPCC, 2014).

ICE data separates the embodied carbon emissions derived from fossil fuels and from biomass (Hammond & Jones, 2008). This work assumes that wood and wood products originate from a sustainably managed forest, therefore burning biomass fuel is considered to be carbon neutral and the EC_{bio} index is discarded.

ICE data on timber doesn’t include carbon sequestered within wood itself. Authors believe it should not be included in the cradle to gate data. ICE data includes material properties table where material densities can be found (Hammond & Jones, 2008). This data was used when volume to mass conversion was required. Rounding to the next higher is used in the calculation of cumulative values.

Among the variety of engineered wood products available today, only those that can be used in structural application are included. It is done so that the comparison to other structural materials could be possible. Clay bricks, as any masonry, have structural limitations. They have high compressive, but low tensile strength. However, when reinforced by a frame (wooden light-frame usually), the combination has a high structural capacity. Substitution of materials is calculated on a simple volume for volume basis. Foundation calculations for alternative materials are based on masonry-concrete weight relation and weight-EC relation of the Ruan's house concrete (0.7 and 0.22 respective coefficients). Steel reinforcement is included in all masonry calculations for comparative reasons, although it might not be needed in alternative masonry examples given.

4 Global warming

The industrialization era has brought exponential increase in production and materials exploitation in the name of economic growth and life quality improvement. However, such explosion of production has taken its toll on the environment. Many of the harmful emissions of the industries have, eventually, been addressed and eliminated, at least on the local level. Nonetheless, effects of resources exploitation and harmful emissions of materials production on a global scale have been acknowledged not that long ago.

In 1987, *Our Common Future*, also known as the Brundtland Report, defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). In the following years extensive monitoring, analysing and forecasting have revealed alarming effects of industrialization, particularly of energy production, carbon emissions and global warming. This is likely to be the hottest topic of discussions on a global scale over the past decade or more, and chances to find a modern person today unaware of it are rather slim. Nonetheless, for the sake of this thesis, a brief outline and a few arguments on the issue follows.

Solar radiation is absorbed by the earth's surface and is converted into heat energy, causing the emission of long-wave (infrared) radiation back to the atmosphere. Some of it is absorbed and re-emitted by the greenhouse gases (GHG) molecules (water vapor, carbon dioxide, methane, nitrous oxide, ozone, etc.). The greenhouse effect provides climate warm enough for life to exist, however too much of such gases lead to higher temperatures, i.e. *global warming*. Levels of atmospheric carbon dioxide are growing at an increasing rate since the 1800s, which coincides with the increase of CO_2 emissions caused by burning fossil fuels for energy production. The global surface air temperatures are increasing at a seemingly unprecedented rate, causing concerns about its effects on climate change, rainfall, sea level and their consequences. Yet the extent of anthropogenic effect on global warming, as well as the magnitude of the latter, are the matters of considerable debate. (Domone & Illston, 2010)

The Intergovernmental Panel on Climate Change (IPCC), which was established by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) in 1988, outlines four major potential impacts of climate change (IPCC, 2014):

- Food and water shortages
- Increased poverty

- Increased displacement of people
- Coastal flooding.

It is worth noting, however, that climate varies continually, "each year, each decade, each century, each millennium, since long before any question of impact of human activity", as stated by Hermann Flohn, a founding father of the climatology (Lamb, 1984, 25). Figure 3 shows climate variations on the grand scale of the last 420 Kyr based on the analysis of the Antarctic ice core samples. Long glacial and shorter interglacial "spikes" can be seen in Figure 3, as well as the correlation between temperature and CO_2 concentrations. At the same time, modern age (2003) global temperature has not reached peaks of prior interglacial periods, despite CO_2 concentrations being far beyond historical marks.

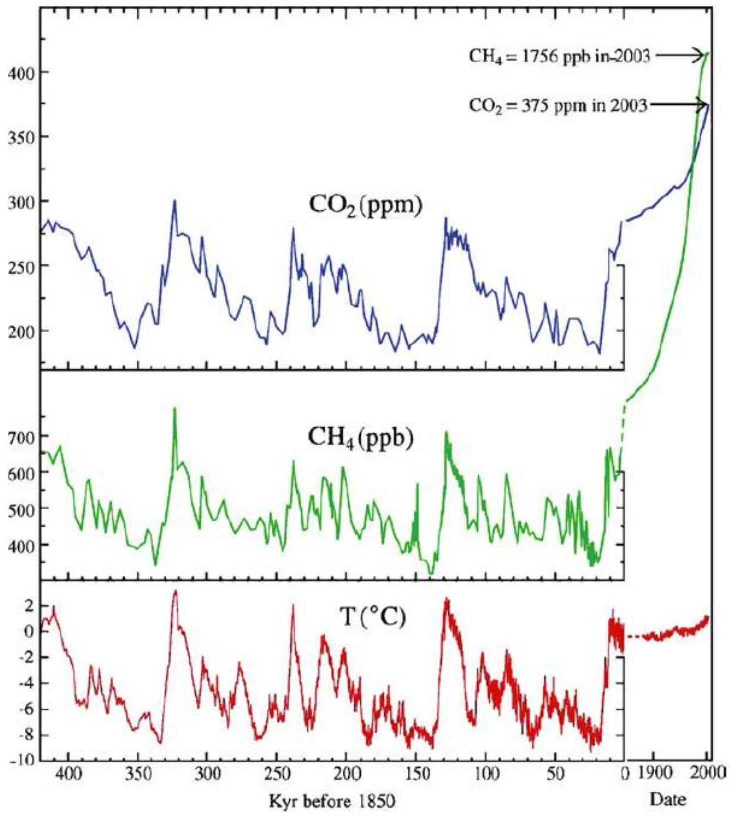

Figure 3. Record of atmospheric CO_2, CH_4, and temperature. The temperature zero-point is the mean for 1880–1899. Source: Hansen, 2005

In ice core samples studies researchers discovered an occasional lag (several hundred years) between the rise of temperature and the increase in CO_2 concentrations (Monnin et al., 2001; Fischer et al., 1999). This does not undermine the importance of CO_2 as a temperature amplifier. It might, however, explain why previous temperature peaks haven't been topped yet.

An examination of approx. 50 globally distributed paleoclimate records revealed six periods of rapid climate change (RCC) during the Holocene, which is the current interglacial period (from 11,500 cal yr. B.P.). Forcing roles of CO_2 (as well as CH_4) during most of the period are concluded to be negligible. Concentrations of these gases, however, were minor compared to those experienced during the glacial-interglacial transition and over the last century. Few large shifts in gases concentrations did occur during the pre-anthropogenic Holocene. However, they are likely to be more the result than the cause of RCCs. (Mayewski et al., 2004)

The six RCCs allocated by Mayewski et al. (2004) are “Glacial Aftermath” RCC (9000–8000 cal yr B.P.), “Cool poles, dry tropics” (6000–5000, 4200–3800, 3500–2500, 1200–1000 cal yr B.P.) and “Cool poles, wet tropics” RCC starting at ~600 cal yr B.P. Solar variability is suggested to be the most plausible forcing for most of them, with minor contributions from volcanic aerosols and greenhouse gases. (Mayewski et al., 2004, 252)

Mayewski et al. conclude that Holocene climate has been highly variable, with multiple contributors to the fact. They also observe a fairly regular quasi-patter of its RCCs, with increased frequency since the middle Holocene. RCCs appear to be large and abrupt enough to have significant effect on ecosystems and humans, likely to have contributed to the collapse of some of the civilization. (Mayewski et al., 2004)

Hoyt and Schatten (1997) urges not to disregard the effect solar activity variations have on the climate. They suggest that the increased solar activity of this century fits global temperature records perhaps even better than the variations in atmospheric carbon dioxide. Certainly, climate changes of the past can be expected to be influenced by sun activity rather than anthropogenic carbon dioxide, which is a relatively recent phenomenon. That is not to suggest that anthropogenic changes are unimportant, but a balance in studying both is essential in understanding such a complex system which Earth’s climate is. (Hoyt & Schatten, 1997)

Both works mentioned above assert the need for significantly more research into the potential role of solar variability on the climate. Mayewski et al. also emphasize the need to study Holocene RCCs as invaluable source for modelling and prediction of the climate. (Hoyt & Schatten, 1997; Mayewski et al., 2004)

In 1998 Dahl-Jensen et al. published a study of past temperatures of Greenland measured down through the Greenland Ice Core Project (GRIP) borehole, at the summit of the Greenland Ice Sheet, and at the Dye 3 borehole 865 km farther south. Figure 4 presents the resulting reconstruction.

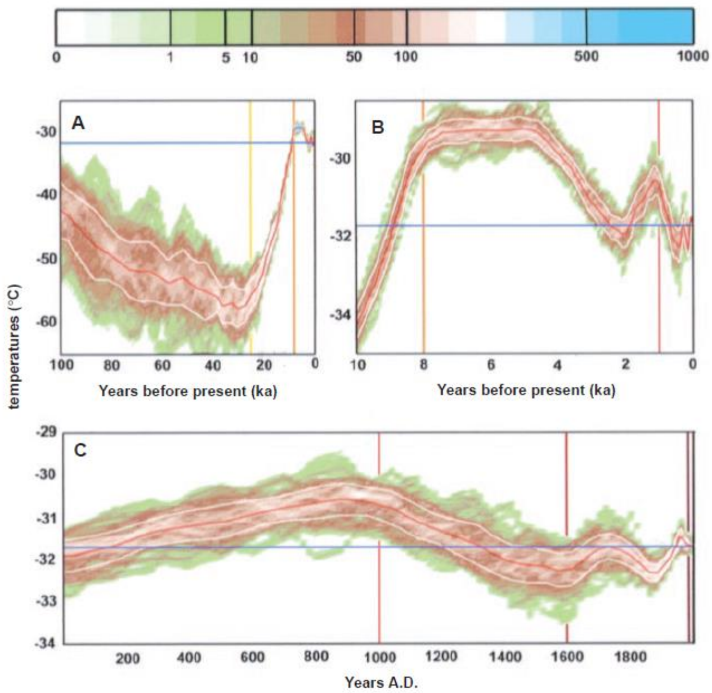

Figure 4. The contour plots of all the GRIP temperature histograms as a function of time describes the reconstructed temperature history (red curve) and its uncertainty. The white curves are the standard deviations of the reconstruction. The present temperature is shown as a horizontal blue curve. Source: Dahl-Jensen et al., 1998

From the reconstruction we can see that the overwhelming part of the Holocene Greenland, and, probably the whole high-latitude North Atlantic region, was actually significantly warmer than today. The temperatures in general have decreased since the Climatic Optimum. For the time of the study, it concluded that no warming in Greenland was observed in the most recent decades. The Dye 3 temperature history is nearly identical to the GRIP one, but with a 1.5 higher amplitude, indicating higher climatic variability. (Dahl-Jensen et al., 1998)

According to the study, temperatures of the Holocene are compared to the present one as (Dahl-Jensen et al., 1998):

- the Last Glacial Maximum (26.5 to 19 ka BP) -23 °C
- the Climatic Optimum (9 to 5 ka BP) +2.5 °C
- the Medieval Warm (950 to 1250) +1 °C
- the Little Ice Age (1350 to about 1850) -0.7 °C
- the 1930s period +0.5 °C
- the 1940-1995 period - cooling, unspecified.

In 2013 Marcott et al. published a more spaced out reconstruction of surface temperatures for the past 11,300 years based on analysis of 73 globally distributed temperature records. It describes Holocene as warm early period (10000 to 5000 years BP), known as Medieval

Warm period, followed by ~0.7°C cooling through the middle to late period (<5000 BP), reaching its coolest temperatures during the period known as the Little Ice Age (about 200 years BP). The Little Ice Age cooled down North Atlantic region by ~2 °C, and during this period glaciers were at their largest extent over the whole Holocene. It concludes that the peak temperature of the Holocene has not yet been reached, however every plausible IPCC projection model indicates exceeding this peak already by 2100. (Marcott et al., 2013)

Professor Hansen, well known for his research in the field of climatology, agrees that the prehuman climate change was dictated by the variations in the Earth's orbit, which altered the atmospheric composition and the surface properties (albedo effect). However, today, he asserts, humans are in control of the last two things. The current levels of CO_2 (and CH_4) are far beyond the ranges that existed for hundreds of thousands of years (see Figure 5). (Hansen, 2005)

Figure 5 shows the anthropogenic carbon dioxide emissions growth over the industrial period. As it can be clearly seen, any noticeable CO_2 emissions from fossil fuels burning start from around the end of the 1800s. And only in the 1950s the dramatic increase in emissions takes off.

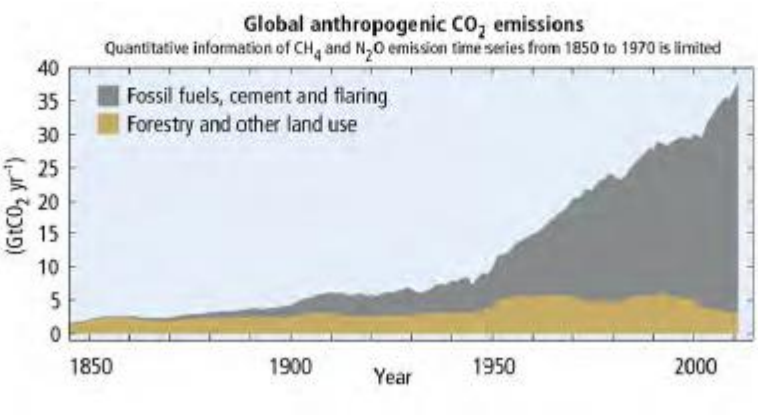

Figure 5. Global anthropogenic CO_2 emissions ($GtCO_2$/yr) and cumulative CO_2 emissions ($GtCO_2$). Source: IPCC, 2014

The IPCC asserts that human influence on the climate system is clear and is the dominant cause of the observed warming since the mid-20th century. Stabilising the climate system will require substantial and sustained reductions of CO_2 emissions. Decarbonising the economy is a key mitigation component. (IPCC, 2014)

The "business as usual" model predicts a global temperature rise between 3.7 to 4.8 °C (2.5 °C to 7.8 °C if climate uncertainty included) above pre-industrial levels by 2100 (high confidence). The policy target is not to exceed 2 °C global temperature rise over the 21st century, relative to pre-industrial era. Almost half of this limit has been already expended, as the current temperature rise is 0.85 °C. Levels of CO_2 in the atmosphere are targeted to 450 ppm or below - likely to maintain 2 °C or below warming (high confidence), with up to 530 ppm - more likely than not to achieve that goal. For comparison, the IPCC provides the CO_2 concentration estimate in 2011 to be 430 ppm (uncertainty range 340 ppm – 520 ppm). (IPCC, 2014)

Admittedly, the available carbon budget may actually be higher if non-CO_2 forcings are reduced. CH_4, N_2O and BC aerosols have potentially a high impact on the level of constraints that are needed for CO_2. Hansen and Sato (2004) suggest that "a reward approach for emission reductions, analogous to that used for Montreal Protocol Trace Gases, could achieve much reduced CH_4 emissions at low cost." (Hansen & Sato, 2004, 16114)

Most climate projection models are based on the assumption that terrestrial carbon sinks (for example, the fixation of atmospheric CO_2 into sugar through photosynthesis) will not only retain but will expand along with the emissions growth. Indeed, over the past ~150 years both oceanic and terrestrial sinks have generally increased with remarkable stability. However, Houghton is concerned that recent sinks in the land and ocean may decline in the future. Reasons for it are feedbacks between the carbon cycle and the climate system, namely positive feedbacks of temperature on respiration and of increased CO_2 on oceanic uptake. (Houghton, 2007)

5 Concrete

Concrete is second only to water in total volumes consumed annually by humanity. It is a composite material, essentially a mixture of cement (usually about 12%), aggregate (e.g. sand, gravel) and water. The formed fluid mixture is easily shaped and, with time, is set into a durable stone-like material. (IEA/WBCSD, 2009)

Concrete is also one of the oldest construction materials in the world. The earliest known case of concrete construction dates up to about 9800 years back. The village in Yiftahel, Israel, being arguably the oldest permanent village discovered to date, featured floors made of concrete. It is argued to be made by burning (calcining) limestone to make quicklime and mixing it with water and sand, although thorough examination by construction specialists was yet to be done (Kanare et al, 2009). Similar concrete mixtures were used by ancient Egyptians and Greeks (Domone & Illston, 2010). Modern studies suggest that parts of the pyramids of Egypt were actually constructed *in situ* using concrete technique (Barsoum *et al*, 2006; Túnyi & El-hemaly, 2012).

Be that as it may, it is ancient Rome that is most well-known for mastering the cement based concretes and mortars construction. They are known to be the inventors of hydraulic cement, i.e. the one that reacts chemically with a water mix, and, therefore, can be hardened under water (Domone & Illston, 2010). White points out though (according to Delatte, w.y.) that Roman construction methods varied widely, depending on local soil conditions and available materials, and concrete techniques varied largely as well, applying both hydraulic and non-hydraulic cement, which is cheaper but less durable.

Structures in direct contact with water, such as harbors, aqueducts, baths, bridges, and those of high importance to the society, such as theatres, arenas, temples, were erected using hydraulic cement containing volcanic earth materials, known as pozzolana. Skillful application of these materials is the main reason for many magnificent structures of ancient

Rome to stay intact for over 2000 years, even those submerged in an aggressive seawater environment. (Delatte, w.y.)

International research team conducted a recent study of Roman concrete obtained from a breakwater in Pozzuoli Bay, near Naples, Italy. The study investigated the structure of ancient concrete recipe with volcanic materials (ash, tuff, pumice), which stayed coherent within the seawater environment for over two centuries. They studied the backbone of the concrete's durability - cristalline Al-tobermorite - a rare hydrothermal mineral, which is eventually formed in Roman maritime concrete over the hydration process. Production of such concrete does not require the use of kiln-fired cement, which means that this less energy intensive process can produce concrete that is, on top of that, superior to common modern concretes. (Jackson et al, 2013)

With the decline of the Roman Empire most of the knowledge gained in the use of high performance concrete seems to have gone almost completely. The patenting of Portland cement by Joseph Aspdin in 1824 is thought of as a milestone for the comeback of a concrete era. Although it was rather later contributions to the technology that actually opened so many possibilities for concrete applications (BCA, 1999). In the mid-18th century the process was upgraded by Isaac Johnson, who raised the temperature at which the cement was fired, enhacing its properties, and made the process continuous, which increased the scale and, thus, lowered the price of cement (Domone & Illston, 2010). Following idea by Joseph-Louis Lambot has led to the development of what is now known as reinforced concrete (BCA, 1999).

The cement, binding agent, is the definitive component in concrete. Ordinary Portland cement (OPC, or simply Portland cement) based concrete is by far the most popular building material in the world today. Over 30 materials are known to be used in the manufacture of Portland cement, which vary from facility to facility. Combinations of limestone or chalk and clay or shale are commonly used (Domone & Illston, 2010). These materials are quarried, mixed into raw meal and are chemically combined through pyroprocessing, the core of Portland cement production process, which can be divided into three main stages (Domone & Illston, 2010):

1. Pre-heating and pre-calcining, raising energy efficiency of the whole process;

2. Calcination (from 900°C), breaking about 90% of calcium carbonate ($CaCO_3$) down into calcium oxide (CaO, or lime) and carbon dioxide (CO_2);

3. Reaction (1400-1500°C) of the oxides in the burning zone of the rotary kiln, to form cement clinker.

The process is presented graphically in Figure 6.

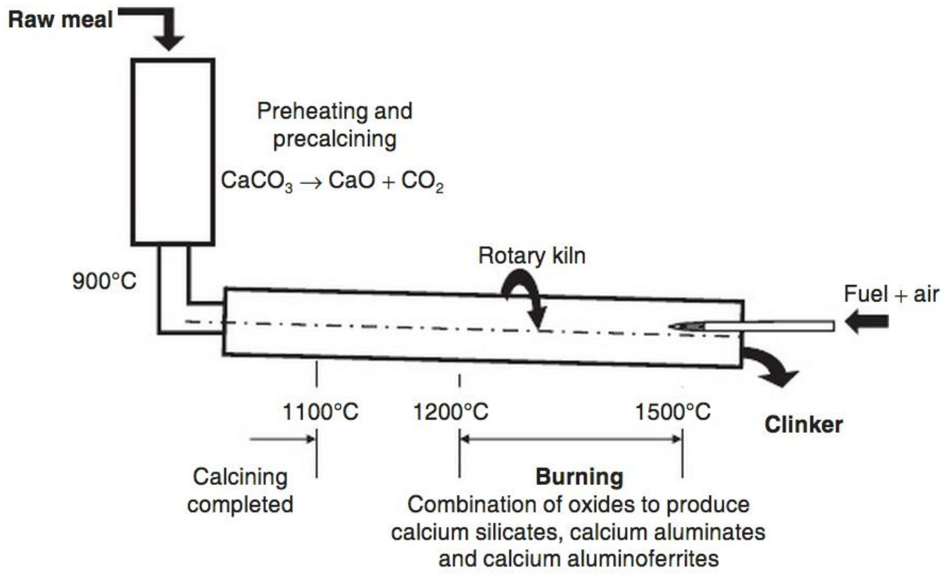

Figure 6. The main process of raw meal heating to produce Portland cement clinker. Source: Domone & Illston, 2010.

Coal is the most common fuel used in the process, but oil and natural gas are used as well. Organic waste is often added to the main fuel (Domone & Illston, 2010). The resulting substance, clinker, consists of gray (sometimes white), glass-hard small spherically shaped nodules (EPA, 1995). Primarily it is comprised of calcium silicates, calcium aluminates and calcium aluminoferrites. Then clinker is grinded into fine grey (or white) powders to become Portland cement (Domone & Illston, 2010).

Cement industry alone is responsible for approximately 5% of global anthropogenic carbon dioxide emissions. Global average emission of CO_2 per 1 tonne of cement is 800 kg. Yet this number is for all kinds of cement, 79% clinker content average. The actual number depends on particular process and facility’s energy efficiency. (IEA/WBCSD, 2009)

Production process CO_2 emissions come from two main sources (NRMCA, 2012):

- Calcination, when calcium carbonate is heated, breaking it down into calcium oxide (lime) and CO_2 (over half of emissions)
- Burning of fossil fuels (the rest of emissions)

Beside carbon dioxide, primary emissions of the Portland cement production process include particulate matter (PM), nitrogen oxides, sulfur dioxide and carbon monoxide. Among possible minor emissions are volatile organic compounds (VOC), ammonia, chlorine, hydrogen chloride, methane, heavy metals and others. They may be generated both from the raw materials and from the fuel. (EPA, 1995)

According to the survey of the Portland Cement Association (PCA) members, total average CO_2 emitted from calcination and fuel combustion is 918 kg for every 1000 kg of Portland cement produced in the U.S. The Portland cement EE weighted average is 4.8 GJ/tonne. (Marceau et al., 2006)

The most important determinant of EE is cement content in a mix, be that concrete, masonry, tiles, pavement or else. Non-production process related energy consumption figures are an order of magnitude smaller (Marceau et al., 2007):

- aggregate production consumes approximately 0.05 GJ/m^3,
- concrete plant operation - 0.04 GJ/m^3,
- transportation - 0.08 GJ/m^3.

As cement content in the mix increases, so does the embodied energy of the mix (Marceau et al., 2007). The relation is shown in Figure 7. The amounts of CO_2 emissions are also primarily a function of the cement content in a concrete mix (Marceau et al., 2007). For this reason the relation shown in Figure 7 is expected to be essentially the same for embodied carbon.

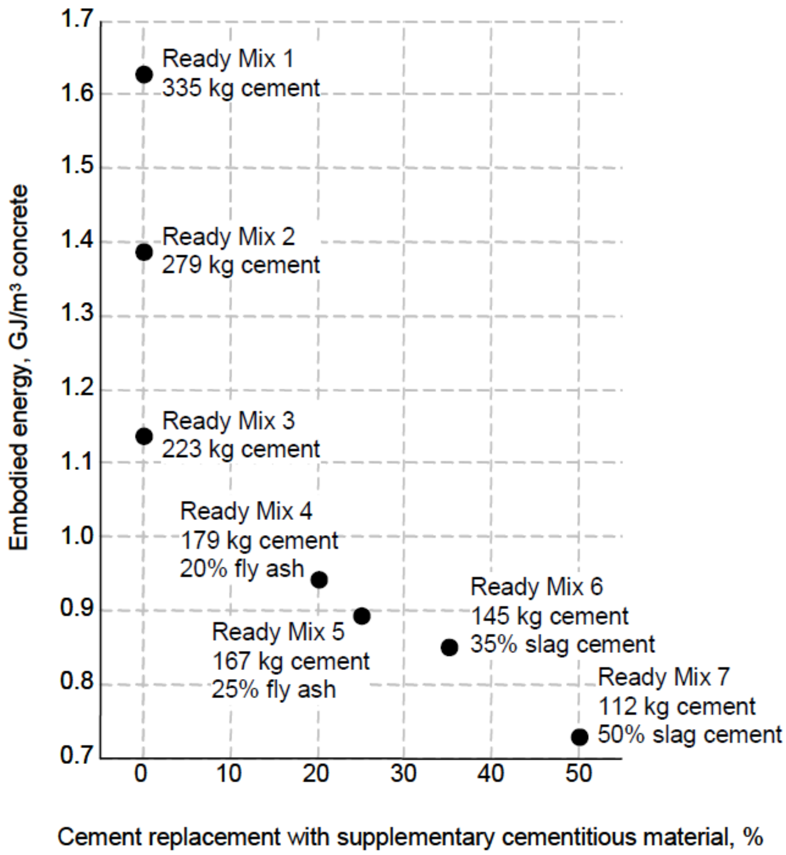

Figure 7. The embodied energy reduction by replacing Portland cement with supplementary cementitious materials like fly ash and slag cement. Source: Marceau et al., 2007.

It has to be noted, however, that concrete offsets part of its carbon footprint with time. Carbonation process is known to offset significant part of CO_2 emissions produced during manufacturing of cement through reabsorption into concrete during the product life cycle. One research study estimates that up to 81% of the CO_2 emitted from calcination can be reabsorbed this way over a 100-year life cycle. (Pommer & Pade, 2006)

As for the cement industry in general, The International Energy Agency (IEA) and the Cement Sustainability Initiative (CSI) member companies have a strategy to reduce CO_2 emissions of the industry in half by 2050. Its key reduction levers are (IEA/WBCSD, 2009):

- Thermal and electric efficiency (keeping production technologies up to date).
- Alternative fuels use (including wastes intended for incineration).
- Clinker substitution (with supplementary cementitious materials (SCMs) or limestone).
- Carbon capture and storage (CCS) implementation.

As for CCS, it is potentially possible to capture 90% of CO_2 emissions with currently available technologies, although it requires substantial investments and use of additional electricity. CCS is estimated to increase production costs by 25-100% (CEMBUREAU, 2013).

When no alternative to Portland cement based products is available, a responsible customer can aim at products substituting Portland cement with supplementary cementitious materials (SCMs) at least partially. SCMs include a range of artificial materials and natural materials. Artificial materials include some that are produced intentionally (e.g. metakaolin), but most of them are obtained as waste products from other industries (blast furnace slag, fly ash, silica fume, burnt shale). Natural materials include volcanic ashes and pumices, rice husk ash, diatomaceous earth. SCMs of artificial origin are usually referred to as pozzolans, of natural origin – pozzolana. Cements where part of clinker is substituted with SCMs are called blended cements. (Bhatt & MacGinley, 2013)

The European Standard EN 197-1:2011 “Composition, specifications and conformity criteria for common cements” acknowledges 27 common cement products and categorises them into 5 types based on their composition, as shown in Table 2. All but Portland cement (CEM I) are blended cements. (Müller, 2012)

Table 2. Portland cement categories according to EN 197-1:2011.

Type of cement	Name	Clinker proportion class	Clinker content, %	Average clinker content, rank (low to high)
CEM I	Portland cement	-	95-100	10
CEM II	Portland composite cement	A B	80-94 65-79	9 7
CEM III	Blast furnace cement	A B C	35-64 20-34 5-19	4 2 1
CEM IV	Pozzolanic cement	A B	65-89 45-64	8 6
CEM V	Composite cement	A B	40-64 20-39	5 3

Source: (adapted) Bhatt & MacGinley, 2013.

According to Bhatt & MacGinley (2013), cement type compositions are:

- CEM I is an ordinary Portland cement and up to 5% of minor additional constituents, usually gypsum.
- CEM II is an OPC and up to 35% of SCMs and/or limestone.
- CEM III is an OPC and higher proportions of blast furnace slag than in a CEM II cement.
- CEM IV is an OPC and a mixture of SCMs.
- CEM V is an OPC and a higher proportions of SCMs.

The type of cement, as well as other information on its essential properties, can be found in the product coding on the package. An example is given in Figure 8. All the cement types except CEM I are followed by a letter (A, B or C) indicating clinker proportion class.

Confusingly enough same letters designate different clinker content range for each cement. (Cemex, w.y.)

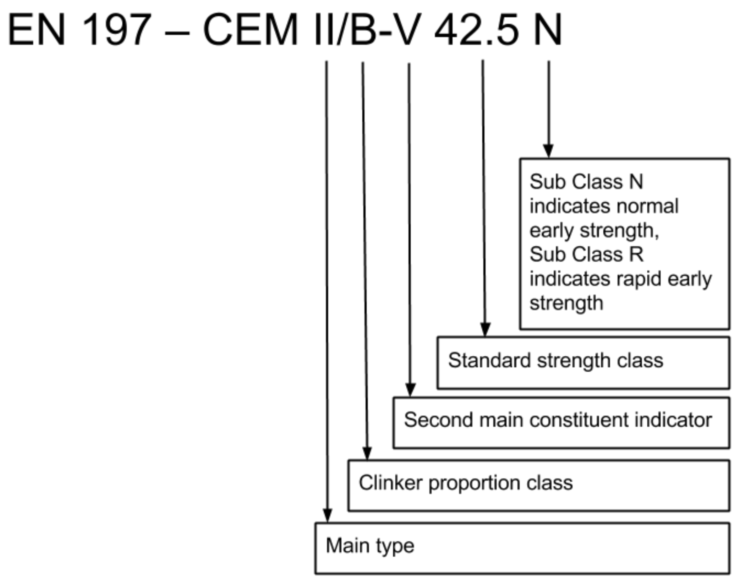

Figure 8. Example of cement product coding with description according to the EN 197-1. Source: (adapted) Cemex, w.y.

In general, all cements conforming to the European Cement Standard EN 197-1 are suitable for the manufacture of concrete according to the appropriate concrete standard (EN 206-1). However, some of them are excluded from the use in parts of Europe due to lack of building experience or because there have been no scientific investigations into the use of these cements. (Müller, 2012)

Choosing blended cements over OPC, in addition to CO_2 emissions abatement and resources conservation, grants performance and other benefits relevant to the application, such as:

- Improved workability,
- Better long-term compressive strength (Siddique & Khan, 2011),
- Improved durability (Müller, 2012),
- Competitive initial and lowered life-cycle costs (Gilliland, 2011).

Durability of blended cements is enhanced by two major factors (Müller, 2012):

1. Lower porosity, not allowing harmful substances, e.g. water, acids, sulfates and chlorides, penetrate concrete through the pore systems.
2. Low moisture content, evading the risk of corrosion of reinforced and prestressed concrete, with the depth of carbonation within an acceptable range.

The above is likely to have a role in CEM I giving up its lead on the market in favor of CEM II, which now has over half of European market. CEM III and CEM IV each have just under 10% of the market, while CEM V and other cements' shares are even less. (CEMBUREAU, 2012)

SCMs are assumed to replace a cement in concrete on a one-to-one basis. A 1% replacement of cement with fly ash or slag cement results in approximately 1% reduction in energy consumption per unit of concrete (Marceau et al., 2007). And, as it has been mentioned, all cements conforming to EN 197-1 are suitable for standard concrete production (Müller, 2012). Therefore, basic rule in order to reduce one's carbon impact would be choosing the type of cement with the least amount of clinker available. There also are general specifications and guidelines aiming to optimize the use of cement according to specific application needs. For example, according to standard specification for Portland cement (ASTM C150):

- CEM I is used when no special properties are required.
- CEM II is for general use or when moderate sulfate resistance is desired.
- CEM III is for use when high early strength is desired.
- CEM IV is for use when a low heat of hydration is desired.
- CEM V is for use when high sulfate resistance is desired.

Crushed concrete (recycled coarse aggregate, or RCA) can be used in structural applications, including new concrete. In this case, only the coarse aggregate sizes are used, because finer material has a high absorption (Domone & Illston, 2010). However, most of concrete waste tends to be downcycled into uses like base material for roads or drainage material around pipes. This is mostly due to contamination of concrete waste with other materials (e.g. plaster, masonry) and varying concrete mix compositions. (Milani, 2005, 152)

Concrete retains some strength for a reasonable time at high temperatures. Its fire resistance properties vary and depend on several factors, such as time of exposure, maximum temperature reached, size of exposed element, concrete's strength, density, moisture content and concrete's constituents. (Domone & Illston, 2010)

Siliceous aggregates (gravel, granite, flint) have higher thermal conductivity and, hence, a tendency to spall. Calcareous aggregates (limestone) are more stable. Best thermal properties belong to lightweight concrete (with SCMs). Lightweight concrete's thermal conductivity (0.8 W/mK) is less than half that of a normal weight concrete. Normal weight concrete starts to lose strength from around 300℃, half of it is lost close to 650℃, and complete loss of strength occurs by about 900℃. Lightweight concrete numbers are higher - 500℃, 720℃ and 1000℃ respectively. (Gillie, 2014)

The spalling of concrete is dangerous mainly because it can expose reinforcement. Without insulation provided by concrete, reinforcement deteriorates under high temperatures much faster. Spalling is usually caused by buildup of water pressure. The higher is the concrete strength, the lower permeability ratio is has, hence, the harder it is for moisture to escape and, eventually, the higher is the pressure buildup. Therefore, chances to spall increase with the increase of concrete's strength. (Yehia & Kashwani, 2013)

5.1 Ruan

In the Ruan house, Portland cement (CEM I) was mainly used in B25 (class) reinforced concrete, B25 reinforced concrete pilings, and M100 (brand) cement mortar (incl. cement plaster). Labels represent the compressive strength grade, in MPa for concrete class and in kg_F/cm^2 for masonry mix brand. Cement plaster properties are similar to cement mortar. For this reason no distinction is made between them in this work.

5.1.1 Concrete

Density of reinforced dense concrete in the ICE database is 2300 kg/m^3 (Hammond & Jones, 2008). Therefore, concrete weight can be calculated from its total volume:

$$123.47 \text{ m}^3 * 2300 \text{ kg/m}^3 = 283981 \text{ kg}$$

According to the ICE data (Hammond & Jones, 2008), embodied carbon of CEM I reinforced concrete (RC) 20/25 MPa, excluding reinforcement, can be calculated as:

$$EC_{concrete} = 283981 \text{ kg} * 0.132 \text{ kgCO}_2\text{e/kg} = 37486 \text{ kgCO}_2\text{e}$$

5.1.2 Piling

Piling estimates are given as a total length - 315 m. To convert this into volume, piles are assumed to be 0.3 m each side:

$$315 \text{ m} * 0.3 \text{ m} * 0.3 \text{ m} = 28.35 \text{ m}^3$$

Piles are assumed to be also made from B25 concrete. Using the same density ratio as above, piling weight would be:

$$28.35 \text{ m}^3 * 2300 \text{ kg/m}^3 = 65205 \text{ kg}$$

Using the ICE data (Hammond & Jones, 2008) as above for CEM I reinforced concrete (RC) 20/25 MPa, piling concrete embodied carbon would be:

$$EC_{piling/c} = 65205 \text{ kg} * 0.132 \text{ kgCO}_2\text{e/kg} = 8607 \text{ kgCO}_2\text{e}$$

5.1.3 Mortar

According to the ICE materials properties (Hammond & Jones, 2008), cement mortar density range from 1650 to 1900 kg/m^3. Using the average index, 1775 kg/m^3, cement mortar weight can be calculated from its total volume:

$$64.03\ m^3 * 1775\ kg/m^3 = 113653\ kg$$

In accordance with the ICE (Hammond & Jones, 2008), embodied carbon of mortar (1:4 cement:sand mix) can be calculated as:

$$EC_{mortar} = 113653\ kg * 0.182\ kgCO_2e/kg = 20685\ kgCO_2e$$

5.2 Alternative

Parallel to specifying products alternative to energy intensive regular cement, owner-builder should also consider designs with limited use of cement products. Such designs are not uncommon. A foundation of a house can be as small as 900mm deep. However, if there are trees nearby and/or ground is not stable enough, recommended depth of a foundation is about 3 meters. Ground stability can be compromised if the soil is too wet, if it is loose fill (e.g. debris filled), or there is a waste pit or a mine nearby. Two options can be suggested, which radically limit the use of concrete and generally are cheaper and easier than continuous foundations (Broome, 2007):

- Concrete piles with no ground beams, but suspended timber ground floor bolted to the base using galvanized steel shoes.
- Timber frame standing above the splash zone on a concrete stool set on a concrete bed.

It is important to note that heavy brick cladding is not suitable for light foundation designs, and a damp-proof membrane (e.g. polyethylene) is required between the foundation and the timber. There are additional financial and aesthetical benefits of building above ground, such as eliminating the need to level the ground, meaning substantial savings on earth-moving, for a self-builder in particular, and preservation of the natural landscape (Broome, 2007, 223).

5.2.1 Blended cements

As it has been stated, substituting clinker in cement, above other benefits, can lower concrete's embodied carbon substantially. The following abatement options are based on the fact that cement is the definitive component for EC of construction mixes. (Marceau et al., 2007)

The ICE database (Hammond & Jones, 2008) can be used to assess CO_2 abatement using some cements with reduced OPC content. For example, if Ruan house instead of CEM I based concrete (incl. piling) used the same 25 MPa concrete based on 50% blast furnace slag cement replacement (CEM III), EC abatement would be:

$$0.132 - 0.077 = 0.055 \text{ kgCO}_2\text{e/kg}$$

Therefore, such substitution would save 42% of CO_2 emissions from concrete.

Beside several concrete ready mixes, the ICE database (Hammond & Jones, 2008) offers EC indexes for specific cement types as well. This can be used to calculate potential EC of the mix prepared on site. A few market examples revealing some of the available substitutes for ordinary Portland cement with emphasis on maximum CO_2 abatement are included below.

5.2.1.1 Ecocem

This European brand represents blended cements and is available in bags, blogs and ready mix. Ecocem is a blend of Portland cement and ground granulated blastfurnace slag (GGBS), CEM III/A according to the EN 197-1. In 2009 the company was certified by the National Standards Authority of Ireland stating that direct and indirect energy emissions of CO_2 during GGBS manufacture are 0.029 kgCO_2e/kg. This is a fraction of CEM I's 0.95 kgCO_2e/kg (Hammond & Jones, 2008). The content of Ecocem in the mix can vary, although recommended and most commonly used proportion of OPC and GGBS is 50/50 (Ecocem, w.y.). With this in mind, substituting half of CEM I with Ecocem potentially lowers CO_2 emissions by close to 50%.

5.2.2 Geopolymer cements

Aside from substituting part of clinker with SCMs by purchasing a standardized blended cement (CEM II - CEM V), there is an opportunity to avoid OPC clinker completely by purchasing a geopolymer cement. Professor Joseph Davidovits and the Geopolymer Institute he is a head of are active promoters of geopolymer cements production. They claim it to be "a real alternative to conventional Portland cement for use in transportation infrastructure, construction and offshore applications" (Davidovits, 2013). In comparison to Portland cement, its main benefit is drastic cuts in CO_2 emissions, 70-90% announced, as calcium carbonate is avoided and about 50% less heat is required for the process (Davidovits, 2013). It is also claimed to have significant performance advantages over ordinary Portland cement concrete, including improved durability, lower shrinkage, increased fire resistance, higher flexural and tensile strength. (Davidovits, 2011)

In 2011 a study was conducted in Australia in order to compare costs and carbon emissions for geopolymer pastes in comparison to OPC using life cycle approach. Even though, the study argues, a simple sustainability comparison between the two is impossible to make due to completely different economic reality for each, there seems to be significant potential for geopolymer cement to be cost effective and to reduce the climate change impacts of cement production. The study estimates 44-64% reduction of GHG emissions over OPC for the proposed "typical" Australian geopolymer product, while costs for this product can be twice of those of the OPC. The bottom-line states that location largely determines benefits which can be as positive as a 97% reduction of GHG emissions, or as negative as a 14% growth. (Mclellan et al, 2011)

This type of cements is produced from alumina- and silica-containing raw materials. Relatively low heating (up to 750°C) transforms them into silico-aluminates. Blending them with alkaline reagents and SCMs provides cements with high rate of strength gain and high long-term strength (Domone & Illston, 2010). The scheme shown in Figure 9 gives a general idea about geopolymer cements production process.

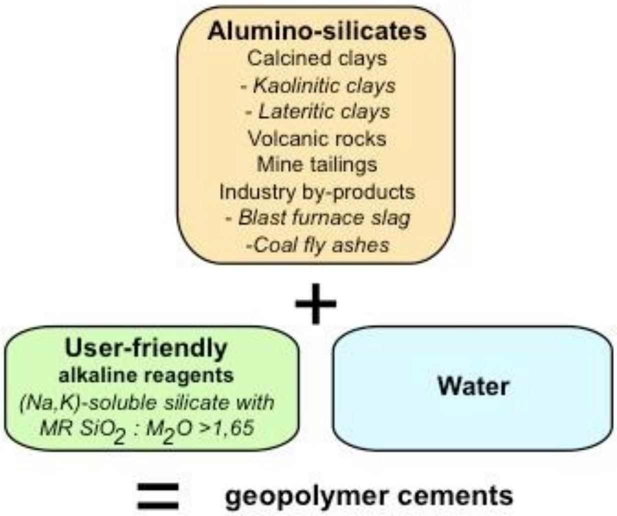

Figure 9. Geopolymer cements production scheme. Source: Davidovits, 2013.

Geopolymer cements are sometimes confusingly referred to as alkali-activated cements. According to Joseph Davidovits (2011), conventional alkali-activation (zeolitic method) with the use of pure sodium hydroxide present user-hostile conditions, while (Ca,K,Na) geopolymerization is a user-friendly process. Geopolymerization also provides better compressive strength than alkali-activation for a given fly ash (Palomo et al, 2004).

Despite its benefits, geopolymer cement industry is still in its infancy. Only a few commercial products are available on the market today. This is mostly due to a lack of acknowledged industrial standards base and the fact that CO_2 emissions quotas are not strict enough to provide enough incentives for manufacturers to substitute OPC production with better options (Deventer et al, 2012). While OPC production relies on single key ingredient - limestone - which is available worldwide, geopolymer cements have a broad range of potential feedstocks, meaning different production technologies for different parts of the world. This complicates standardization and adds challenges for manufacturers. Yet the main challenge is, as usual, the price. As mentioned above, even with the most appropriate source of feedstock and with the cheapest transportation available, the cost of geopolymer cement can be up to twice as high as OPC. However, emerging technologies tend to be more expensive than established ones. At first they occupy only niche markets. But if benefits are strong enough and subsidies are not against it, the price gradually goes down, as more and more applications become available and the market expands. Time will tell if this is the case with geopolymer cements industry.

5.2.2.1 EFC

For Australian customers looking for an OPC concrete alternative, it should be relatively easy to purchase Earth Friendly Concrete (EFC). Wagners Composite Fibre Technologies Manufacturing Pty Ltd claims EFC to be the most environmentally advanced concrete available in the world today. EFC uses a geopolymer binder made from the chemical activation of blast furnace slag and fly ash. According to Wagners, it supersedes OPC in almost every performance parameter, as can be seen in Table 3. (Wagners, w.y.)

Table 3. Performance comparison of EFC and OPC based concrete.

Property	EFC performance (compared to Portland Cement Concrete)
Compressive strength	equivalent
Flexural tensile strength	30% higher
Early age strength	good
Shrinkage	Lower (average 300 με)
Acid resistance	higher
Sulphate resistance	higher
Chloride resistance	higher
Heat of hydration	VERY low
Fire resistance	higher

Source: Wagners, w.y.

EFC is offered to customers as a precast, or as a ready mix within a limited supply area. For large orders Wagners offers production on site. Manufacturer states 60-70% reduction in CO_2 emissions, providing the following numbers for 4 categories of product classified by compressive strength (Wagners, w.y.):

- 25 MPa EFC saves 154 kg/m^3 CO_2
- 32 MPa EFC saves 184 kg/m^3 CO_2
- 40 MPa EFC saves 220 kg/m^3 CO_2
- 50 MPa EFC saves 270 kg/m^3 CO_2

If Ruan house used 25MPa EFC instead of OPC based concrete, savings in CO_2 would be:

$$(124 + 28)\ m^3 * 154\ kg/m^3 = 23408\ kg$$

Total concrete CO_2 emissions of the Ruan house are 46093 kg, which means that about 50% CO_2 could potentially be saved. This is somewhat less than advertised 60-70%, but substantial nonetheless.

5.2.2.2 banahCEM

Banah UK Ltd., based in Northern Ireland, offers their customers a direct OPC replacement product sold under banahCEM trade mark. It has a distinctive visual character - a rich terracotta color - and all the common benefits of a geopolymer cement. Table 4 presents its general properties according to the manufacturer. (Banah, w.y.)

Table 4. Typical properties of banahCEM.

Property	Value
Active Content of Hardener	approx. 48%
Powder Particle Size	d50 = 18µm d90 = 55µm
Appearance of Hardened Cement	Terracotta colour
Max Compressive Strength	110 N/mm^2
Mass Loss after 45 days in 5% HCl	12%
Mass Loss after 45 days in 10% H_2SO_4	12%
Setting Time	30 mins to 2.5 hours*
Strength Gain (based on % of 28 day strength)	50% at 18 hours 85% at 7 days
Manufacturing CO_2 emissions (per tonne)	approx. 100kg
Freeze Thaw Resistance (50 cycles)	No visual degradation <8% Strength Loss
Typical Shrinkage	0.05 mm/m
Max Structural Temperature	approx. 800°C

* Dependant on Temperature

Source: Banah, w.y.

This product also has a peculiar two component supply system – the powder component and the liquid component. They have to be mixed on site, along with aggregates, in proportion to a desired strength of the final product. However banah UK LTD claims to be developing a dry mix version of banahCEM, making it more user friendly. (Banah, w.y.)

According to the data from the manufacturer (Table 4), emissions per 1 kg of banahCEM are approx. 0.1 $kgCO_2e$. The ICE average EC index for CEM I is 0.95 $kgCO_2e/kg$ (Hammond & Jones, 2008). Hence, if Ruan house was built with mixes substituting CEM I with banahCEM, cement products' CO_2 savings could be close to 90%.

6 Wood

Wood (or timber) is a product of nature, time and mechanized labor required for cutting, sawing and transporting. As material it is extremely variable (color, texture, density), but cheap and effective. It can generally be described as low-density, cellular, polymeric composite. It has the best strength/cost ratio among all the fiber composites available. (Domone & Illston, 2010)

Arguably no other raw material has been so useful for human civilizations as wood. Wood seems like a perfect building material in many ways because it is (Risen, 2014):

- durable yet easy to work with;

- very versatile;
- 100% recyclable;
- waste can be used for many wood products (panels, package material, paper, fuel) and is 100% biodegradable;
- widely available in many regions;
- far more insulative than other structural materials, e.g. 5 times more than concrete and 350 times more than steel.

Wood has a very good resistance to mild acids and many chemicals, even in the face of competition from stainless steel. However, it is vulnerable even to mild alkalis and to high acidic compounds like iron salts in the presence of moisture (Domone & Illston, 2010). Durable wood does not require treatment, unless used in constantly damp conditions. Non-durable wood can be improved through preservation and finishing treatments. Common finishing treatments include a variety of paints, varnishes and water-repellent solutions. They protect wood from weathering elements by applying a physical barrier. Chemical barrier is provided by preservatives, which can be designated for either general or restricted use. (Khatib, 2009)

General-use preservatives include copper naphthenate, copper 8 quinolinolate, 3-iodo propynyl butylcarbamate, zinc naphthenate, sodium octaborate tetrahydrate and others. These chemicals are considered to be less hazardous than restricted-use preservatives, which can be divided into three groups: creosote (coal tar), pentachlorophenol (penta) and inorganic arsenicals. None of the restricted-use chemicals can be applied indoors, and they are required to be used by licensed professionals. (Thomasson et al, 2006)

Alkaline copper based preservatives are free from chromium or arsenic, but they fix to the wood less strongly and are corrosive to steel. Borat preservatives are of low toxicity to humans, but can leach if exposed repeatedly to water that flows away (Thomasson et al, 2006). Owner-builder is encouraged to look out for advancements in preservation methods (e.g. acetylation) and materials (e.g. silicate-based), including natural (linseed oil), in order to choose the most benign one available.

Sound wood and wood based sections are suitable for reuse. Recycled wood is substantially cheaper than new. It is easy to sort and doesn’t require reprocessing. Wood waste can be recycled for the use in particleboard, horticulture, animal bedding or simply as a fuel. (Domone & Illston, 2010; Khatib, 2009)

Wood is a naturally combustible material, performing poorly in ‘spread of flame’ and ‘heat release’ tests. However, it supersedes steel in at least one fire resistance parameter, which is the maintenance of strength with increasing temperature and time (Domone & Illston, 2010). Ignition threshold for wood is 250 °C in presence of a pilot flame. Without one, the surface temperature can rise up to about 500 °C before it ignites. Though it is the time of exposure to ignition temperature which is critical to wood structural stability. In this sense, wood has a distinct advantage over steel, which loses its load-bearing capacity immediately on reaching critical temperature. The formation of char protects the unburnt timber. According to Eurocode 5 part 1-2: General Rules - Structural Fire Design, softwood charring rate is 0.8 mm/min for timber of a stated minimum dimension (smaller sections char faster) (Domone & Illston, 2010). Loss of strength in wood sections can be considered proportional to its charring rate (Gillie, 2014). Structural support failure of wood occurs only when the cross-sectional area of unburnt core becomes too small to support any load (Domone & Illston, 2010). In summary, combination of a low thermal conductivity (0.16 W/mK) and a protective layer of char allows wood to perform decent in fire situations. In addition, timber does not expand and has no threat to masonry when adjacent to. (Gillie, 2014)

Falk (2009) states two main reasons why wood is a great material from a sustainable point of view:

- It is a renewable source;
- It has a low level of embodied energy relative to many other materials used in construction.

However, wood renewability is not immediate. While renewable energy sources, such as solar and wind, are virtually infinite in the instance, wood renewability takes time. Therefore it depends on the man’s use or misuse of the nature’s product. Uncontrolled logging practices and land conversion can easily impair wood’s renewability.

Deforestation releases CO_2 into the atmosphere through combustion of forest biomass and decomposition of remaining plant material and soil carbon. Even though its contribution to atmospheric carbon dioxide is far less than that from fossil fuel combustion and appears to be in decline (Figure 5), it still is one of the largest anthropogenic sources of CO_2 in the atmosphere (van der Werf et al., 2009).

Biomass of the forest removes and stores carbon from the atmosphere through the photosynthesis process. FRA (2010) estimates that the world’s forests store 289 gigatonnes (Gt) of carbon in their biomass. Sustainable forest management can help to sustain carbon stocks in forest biomass, however they are still in decline with an estimated loss of 0.5 Gt annually during the period of 2005-2010, mainly because of a reduction in the global forest area (FAO, 2010). 49% of wood dry weight is carbon (Khatib, 2009). It is released only as a result of decomposition or burning. If a tree has been cut into lumber and used in construction, the carbon is sequestered for the life of the product (Falk, 2009).

Logging can also damage or destroy ecosystem’s biodiversity. Biodiversity, primarily a trait of species richness, evenness, composition and interactions, defines ecosystem value and resilience. The higher is an ecosystem’s value, the more ecosystem goods (e.g. food, fiber, genetics) and services (regulating, cultural, supporting) to society it provides. Old growth forest accommodate richer ecosystems than new growth. Thus, primal forests require an extra careful management and control to maintain high biodiversity levels. (Gibson et al., 2011)

Studies by Wilcove et al. (2013) of logging impacts on biodiversity of Southeast Asian forests in most cases concluded that the species richness in primary forest was mostly retained in selectively logged forest, although sometimes in reduced abundances. Even though Wilcove et al. admit that “there are some critical unknowns about the long-term value of logged forests for biodiversity” for now it is fair to perceive well-managed selective logging as green, i.e. sustainable one. (Wilcove et al., 2013)

An important point is that even though primary forests are substantially more biodiverse than degraded ones (Gibson et al., 2011), it is conversion of forests into agricultural mono plantations (e.g. palm oil, rubber) that is far more detrimental to species biodiversity (Wilcove et al., 2013). That is without mentioning conversion into croplands and pastures, which eliminates forest ecosystems entirely.

Practice of forest clear-cutting and conversion into agricultural lands has highest implications in rainforest territories - richest biodiversity depositories and a source of most durable wood on the planet. Numerous species of plants, fungi, insects, birds and animals are being wiped off along with the forests they live in, many of which are disappearing without even being discovered first. Almost two thirds of all species occur in the tropics, largely in the tropical forests (Pimm & Raven, 2000). Medicine, for example, relies on ecosystem biodiversity. As estimated by the WHO, perhaps 80% of the world’s population relies on traditional, largely plant-based, medical systems for their health care needs, and is important not just for developing, but developed countries as well (Farnsworth et al., 1985). Most of all new drugs introduced in past decades have been derived from natural products, primarily from rainforest ecosystems (Newman & Cragg, 2007).

Forests are critical to rural livelihoods in both tropical and temperate areas. Beside medicines, they provide people with food, shelter and even serve the culture, (e.g. sacred groves) (Shanley et al., 2008). With this in mind, unsustainable woodcutting practices can be condemned as high as crimes against humanity.

In summary, wood sustainability depends on the source and logging methods used. And normally a customer would not be able to tell if the wood product he/she is about to purchase was harvested sustainably, without significant damage to ecosystems. Forest certification programs are meant to assist in making a sustainable choice.

6.1 Certification

In theory, the goal of forest certification systems is to provide customers with assurance that the extracted wood used low impact methods that conserve the forests ecological and social values (Gouyon, 2003). The system is economically viable on the premises that consumers are willing to pay extra for good wood products (Archambault, 2006).

Certified wood and wood products come from managed forests that comply with the standards of Sustainable Forest Management (SFM) developed by independent organizations and accredited by third-party certifiers. In 2013 the world’s certified forest area has topped the 10% mark of total forest area. Although there are many certification schemes operating globally today, the dominating schemes are the Programme for the Endorsement of Forest Certification (PEFC) and the Forest Stewardship Council (FSC). By May 2013, the global area of certified forest endorsed by them amounted to 417 million hectares. While PEFC certified forests cover more territory, the FSC leads in the number of certificates issued. (UNECE/FAO, 2013)

Both FSC and PEFC are international non-profit forest certification and labelling systems that were established to offer a single, easily recognizable label for wood and forest products that consumers can trust. They both oversee third party, voluntary certification of forests and issue certificates for well managed forests.

According to the information presented on the Forest Stewardship Council website, the FSC Founding Assembly was held in 1993 with 130 participants from 26 countries, where first certificates were issued. World Wide Fund for Nature (WWF), Greenpeace and the Rainforest Alliance are founding members of the FSC. It now has over 800 members in over 80 countries on 5 continents. Members are divided into 3 chambers - environmental, social and economic - each with the same number of votes. These chambers are further split by geographic lines, North and South. Among the long-term FSC supporters are such companies as IKEA, Marks & Spencer, Kingfisher and Tetra Pak. (FSC, w.y.)

Examples of 3 types of labels found on products from FSC certified manufacturers are displayed in Figure 10. Format, colours and language can vary, but within the FSC requirements. According to the FSC (w.y.):

- 100% label marks products with material from FSC certified forests.
- MIX label marks products with material from FSC certified forests, recycled material or other controlled sources.
- RECYCLED label marks products containing post-consumer material, with share indicated under the mobius strip.

Figure 10. Example of FSC on-product labels. Source: FSC, w.y.

As follows from the PEFC website, the organisation was founded in 1999 as an alternative certification scheme, based on interests and context of European forest owners (PFC, w.y.). According to the state of affairs on October 2014, PEFC consists of 38 national and 22 international stakeholder members with voting rights, and 5 extraordinary members as consultants. National members include national governing bodies and such endorsed certification systems as Sustainable Forestry Initiative (SFI), Malaysian Timber Certification Council (MTCC), Brazilian Forest Certification Programme (CERFLOR), Chile Forest Certification Corporation (CERTFOR), Australian Forest Certification Scheme (AFS) and, as of March 2014, China's National Forest Certification System (CFCC). International stakeholder members represent mostly forestry and trade companies and their associations. (PEFC, 2014)

Certified companies can access label generator on the PEFC website, which has a few design options available. Label example is given in Figure 11. Elements 4-6 are optional, with option 4 indicating the percentage of PEFC certified material in the product (at least 70%). (PEFC, w.y.)

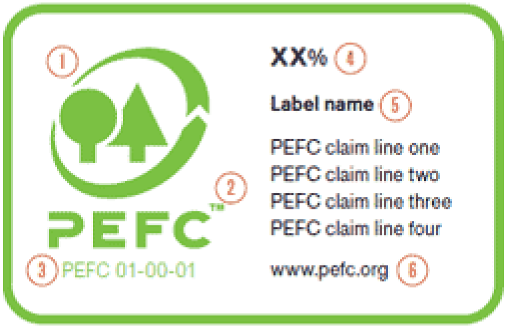

Figure 11. Example of PEFC on-product label. Source: PFC, w.y.

While FSC remains to be the only forest certification system that has been internationally recognised by major environmental organisations and social movements, environmental groups also state concerns over a risk of FSC label losing its integrity. Greenpeace claims that the system has consistency issues applying its standards, as well as other issues. (Greenpeace, 2013)

In order to highlight FSC's major problems, as well as accomplishments, Greenpeace publishes a series of case studies exposing the system's controversial and best conducted operations. Examples of how FSC certification has successfully led to a substantial improvement in forest management practices are presented in case studies of Mendocino Redwood Company and Ecotrust Canada (Greenpeace, 2014).

A case study from Finland exposes inability of companies using FSC MIX label to control sources of so called 'controlled' wood, FSC CW. Field investigations by Greenpeace revealed that Finland's largest forestry companies, UPM, Metsa Group and Stora Enso, use wood from endangered species habitat and old-growth forest, high conservation value forests (HCVF), which are being clear-cut by the Finnish state forestry company, Metsahallitus. (Greenpeace, 2014)

Another case study from Arkhangelsk region of northwest Russia, revealed major violations of FSC's criteria and principles by five companies which are or have been FSC-certified, or are in the process. The companies are shown to be using destructive "wood mining" model, causing destruction and fragmentation of the intact forest landscape (IFL), the Dvinsky

Forest (Greenpeace, 2014). As an outcome, one of the primary issues Greenpeace urges the FSC to deal with is to get rid of confusing MIX label and uncontrolled 'controlled' wood (FSC CW) altogether (Rodrigues, 2013).

In 2011, a report based on 21 on-the-ground case studies around the world, which are causing concerns about the PEFC, was published by a number of environmental groups. It showed violations of even the most fundamental requirements of sustainable forest practices among PEFC certified entities, including (Ford & Jenkins, 2011):

- uncontrolled logging or destruction of important habitats and old-growth;
- conversion of natural forests to monoculture plantations;
- violations of the rights of indigenous peoples or local forest communities;
- soil loss and watershed damage in forests and plantations;
- dangerous levels of biocides in forest management.

In 2009 FSC has adopted the Policy for Association (PfA), the mechanism intended to protect the FSC brand from organizations associated with FSC that are deliberately and systematically being involved in unacceptable activities. However, the mechanism has issues, for example with identification of organization’s involvement in such activities (FSC, 2014). PEFC has no such mechanism (Greenpeace, 2014).

To sum it up, Greenpeace states that “while the FSC faces challenges, we believe that it contains a framework, as well as principles and criteria, that can guarantee socially and ecologically responsible practices if implemented correctly” (Greenpeace, 2014). And that “[PEFC] lack the robust requirements to protect the social and ecological values of forests, compounded by inequitable and weak stakeholder involvement in national standard development and the on-the-ground certification process” (Greenpeace, 2014).

In collaboration with the World Bank, WWF developed the Forest Certification Assessment Guide (FCAG), a methodology to assess the credibility of certification schemes. Following the assessment commissioned in 2008, in its statement from September 2011 WWF acknowledged substantial progress revisioning the PEFC standards in addressing requirements like protection of critical forest areas and other habitats, prevention of natural habitats conversion, protection of indigenous people’s rights, monitoring and assessment of required management activities. However, according to WWF, major gaps remained in the new PEFC standards, such as balance and effectiveness of stakeholder participation, transparency of certification, requirements for field visits in the accreditation process. Above that, PEFC standard still allows products from mixed sources to include wood harvested in violation of human rights or with damage to HCVF. As for FSC, WWF asserts that it covers such sources of wood at least on the standard level - FSC CW. (WWF, 2011)

With the differences in mind, WWF claims to continue supporting the FSC system as currently the best one to promote responsible forest management (WWF, 2011). In the results chapter a summary comparison table of the two certification systems according to the WWF and Greenpeace can be found (Table 7).

A comparative study of two certification systems has been published in 2011 by the ITS Global, an Australian based business consultancy agency. According to the summary of the report, PEFC supersedes FSC in almost every point of comparison. FSC, it is claimed, is a part of NGO groups' broader political program to pressure businesses to adopt the FSC system under threats of damaging their public profile, whilst PEFC is all about stakeholder consensus (mentioned multiple times) (ITS Global, 2011). At the same time, unbalanced stakeholder involvement in the decision process is one of the major critique points of PEFC by the same NGO groups (WWF, 2011).

The study also asserts that FSC "standards are based on the deliberations of FSC members" (ITS Global, 2011), arguably implying that FSC members ignore science in the decision making, unlike PEFC, requirements of which are "based on inter-governmental processes and scientific research" (ITS Global, 2011).

To put things into context, ITS Global further faults FSC for that it "defines HCVF arbitrarily, using non-specific definition" (ITS Global, 2011). While also claiming that HCVF protection is "not prescriptive and do not have objective indicators" (ITS Global, 2011). One is free to decide what is more notable here, the controversy in those two statements or the suggestion that HCVF protection cannot be objective.

At the end though, it could be useful to see how forest certification deal with, arguably, one of the easiest to assess indexes of unsustainable forestry practices – deforestation. Not to attempt a proper assessment of certification impact on forests protection, but to get at least an idea of its potential. Unfortunately, with just over 10% of forests certified globally today (UNECE/FAO, 2013) it is, probably, just too soon to tell. However, in Western Europe, where almost 60% of forests are certified (UNECE/FAO, 2013), it does seem to be working. According to Global Forest Resources Assessment, based on data presented by national correspondents, forest area in Europe has not only been preserved, but has been slowly expanding since 1990s (FAO, 2010).

Be that as it may, there are different perspectives on the matter. A more recent study on global forest change has been published in the Science magazine in 2013 (Hansen et al). Incidentally, the study claims that quantification of forest cover change "has been lacking despite the recognized importance of forest ecosystem services" (Hansen et al, 2013). In order to close this gap, the study used fine-scale resolution images obtained from the Earth observation satellite's (Landsat) to map global forest loss and gain. According to the calculations, among European countries only Ireland, Hungary, Bosnia and Herzegovina, Serbia and Moldova had more total gain in forest cover extent than losses during the study period of 2000 to 2012. Therefore, it is claimed that forest cover on the most part of Europe during this period sustained overall losses. (Hansen et al, 2013)

The contradiction between two studies can be at least partially explained by difference in forest definitions. Definition used by many national forest agencies is not tied to forest cover and its change. Cycles of planting and harvesting are not seen as changes to forest area.

Hansen et al (2013) used method of spectral reflectance signature of trees, where trees were defined as “all vegetation taller than 5m in height” (Hansen et al, 2013). And the interest of the study was to see absence or presence of trees on the land cover. In continuation, Hansen et al (2013) also cannot account for forest loss if it was simply replaced by plantations of palm oil, rubber, eucalyptus and other cultures taller than 5m (Hansen et al, 2014, 981). However, it is concluded that combining data from this study with others (e.g. forest type, protected area, etc.) can have valuable applications (Hansen et al, 2014, 981).

Both studies are unanimous at displaying serious losses in world’s most valuable forest ecosystems - tropical and subtropical forests (Hansen et al, 2013; FAO, 2010). Tropical forest domain was the only one to exhibit a trend - forest loss increasing by 2101 square kilometers per year. Brazil’s significant slowdown in deforestation rates was offset by countries like Indonesia, Malaysia, Paraguay, Bolivia, Zambia, Angola and others. Intensive forestry in subtropical forests resulted in highest rates of forest change globally. (Hansen et al, 2013)

6.2 Ruan

Softwood, specifically pine, is the type of wood used in the Ruan house. Some part of pine sawnwood estimates is given as a surface area only - 155 m^2. In order to convert the index to volume, its thickness is assumed to be 35 mm (average among common products found on the internet similar to the item):

$$150 \text{ m}^2 * 0.035 \text{ m} = 5.25 \text{ m}^3$$

Density range of pine wood in the ICE database is 510-650 kg/m^3, averaging at 580 kg/m^3 (Hammond & Jones, 2008). Therefore, sawnwood weight can be calculated from its total volume:

$$13.59 \text{ m}^3 * 580 \text{ kg/m}^3 = 7882 \text{ kg}$$

Plywood estimates is also given as a surface area - 280 m^2. Thickness of plywood is assumed to be 15 mm, devised the same way as above. Therefore, plywood volume is:

$$280 \text{ m}^2 * 0.015 \text{ m} = 4.2 \text{ m}^3$$

Plywood density range is 540-700 kg/m^3, averaging at 620 kg/m^3. Therefore, plywood weight is:

$$4.2 \text{ m}^3 * 620 \text{ kg/m}^3 = 2604 \text{ kg}$$

According to the ICE data (Hammond & Jones, 2008), embodied carbon of sawnwood and plywood used in the Ruan house can be calculated as:

$$EC_{sawnwood} = 7882 \text{ kg} * 0.2 \text{ kgCO}_2\text{e/kg} = 1576 \text{ kgCO}_2\text{e},$$

$$EC_{plywood} = 2604 \text{ kg} * 0.45 \text{ kgCO}_2\text{e/kg} = 1172 \text{ kgCO}_2\text{e}.$$

6.3 Alternative

Despite all the benefits wood (timber) as a material still has a number of deficiencies (Domone & Illston, 2010):

- properties vary a lot from type to type;
- strength along the grain is higher than across it;
- dimensionally unstable in presence of humidity;
- dimensions are limited.

To shrink such deficiencies, as well as to make the use of wood generally unsuitable for construction purposes, engineered wood products are being produced. Range of engineered wood product types is diverse, with each type being produced in several grades. However, variety of types used in structural applications is generally limited to high-grade plywood, glued laminated timber (glulam) and cross-laminated timber (CLT). Laminated veneer lumber (LVL), parallel strand lumber (PSL), laminated strand lumber (LSL) are similar to glulam in concept, although are made from smaller wooden components (veneers and strands). (Domone & Illston, 2010)

Several types of adhesive substances are employed by the engineered wood products industry. For dry end use a urea-formaldehyde (UF) adhesive is employed most commonly, while for humid conditions resorcinol-formaldehyde (RF) or phenol-formaldehyde (PF) resin is a preferred choice. (Domone & Illston, 2010)

Formaldehyde emissions are highest in freshly produced units, but fade over time. UF emits VOCs when sawn or exposed to moisture more readily than other adhesives, but it is rarely used in structural applications. PF is significantly more stable than UF, which is reflected on the price. RF cures faster than PF, but costs further more. Properly hardened polymeric methylene diphenyl diisocyanate (pMDI) is inert and well below any emission standard, but has limited use due to cost and special handling requirements. PF and RF emissions are also below levels considered to be harmful. All trials conclude that maximum formaldehyde emissions associated with composite lumber are equivalent to levels present in outdoor air of urban environments. Alternative to formaldehyde adhesives are being tested, e.g. soybean based products. (Green & Karsh, 2012)

Plywood is made from veneer sheets laid up with the grain direction at specific angles (usually at 90°) and glued together under pressure (Figure 12). Plywood boards are attractive because they can be (Domone & Illston, 2010):

- of very high tensile strength;
- stiffer than many other materials, including mild steel sheet;
- resistant to splitting (allowing nailing close to the edges).

Although not every plywood is intended for structural applications. It can also be used in decorative and general purposes. The latter varies in strength and bond quality a lot. (Domone & Illston, 2010)

Cumulative plywood production in Europe has a minor share of the wood-based panels market with just 6% (led by the particle board with 54%). China, however, is becoming a dominant plywood producer with 54% share of the global market. (FAO, 2010)

Glued laminated timber (glulam) is used frequently for structural purposes as arches, beams and columns. It remains to be the most popular among all engineered wood products in Europe. Germany and Italy are the leaders in glulam consumption, while Finland is among the largest producers (FAO, 2010). Glulam is made of stripes of laminated timber usually about 10-50 mm in depth each, glued together with adhesives (Figure 12). Laminates have to be end (finger) jointed and, for wider glulam, also edge jointed (Khatib, 2009). Side jointing can also be required depending on the design. Laminated timber has a number of advantages over regular timber, such as (Domone & Illston, 2010):

- higher uniformity and elasticity;
- ability to create curved or complex shapes;
- ability to use short timber parts.

Cross-laminated timber (CLT) is an innovative structural material with constantly growing market. Its excellent environmental qualities aligned well with the legislation-driven demand for "greener" materials, which assured growth despite overall slowdown in the construction industry. (FAO, 2010)

Conceptually, CLT combines principles of plywood and glulam manufacture. It consists of several layers (3 at least) of boards stacked crosswise at 90 degrees and glued together under pressure. Figure 12 shows basic concepts behind plywood, CLT and glulam technologies.

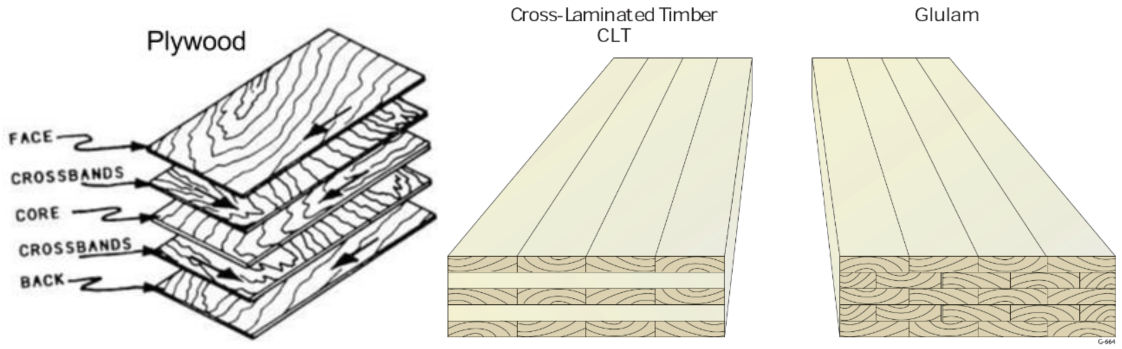

Figure 12. Plywood, CLT and glulam. Source: http://www2.wisd.net/it/PLYWOOD.htm and Gagnon & Pirvu, 2011.

CLT benefits in construction are (FAO, 2010):

- high load-bearing and energy-dissipation (e.g. earthquake safe) capacities

- high strength and insulation values along thin and light structure
- compatible with traditional design methods (brick, concrete and glass)
- can be assembled at the factory.

CLT application can be significantly different from that of sawnwood or glulam. While sawnwood and glulam both are used for some kind of structural framing, CLT buildings do not require frame – CLT walls provide necessary weight load by themselves, without external support. This makes it possible to erect even multi-storey buildings using CLT exclusively. (Gagnon & Pirvu, 2011)

Several examples of CLT buildings exist in the world, the tallest one for the moment is a 10-storey apartment building in Melbourne, Australia, called Forté. Furthermore, there is a ready proposal to erect a staggering 30-storey wooden residential tower in Vancouver, Canada (Michler, 2012).

Economically, multi-storey wooden structures are competitive with concrete (Michler, 2012). Their advantages seem to attract them even into city centers, traditionally dominated by concrete. As, for example, in Christchurch, New Zealand, where high-seismic durability, sustainability and aesthetics of wooden materials has put them into the spotlight for the city grand rebuild program after the city was devastated by an earthquake (Cathcart-Keays, 2014).

There is a trend in sustainable construction for resources minimization. At first glance, CLT systems appear wasteful as they use massive quantities of wood. However, CLT has excellent potential in disassembly and re-use, which mitigates this possible disadvantage. (Gagnon & Pirvu, 2011)

CLT systems are superior to concrete in terms of production CO_2 emissions. However, CLT panels are massive and have to be produced at the factory (prefab). This means that CO_2 savings depend on if the product has to be transported over long distances or not. (Gagnon & Pirvu, 2011)

Engineered wood products' fire resistance is the same as that of the timber it was made from. Results are comparable to non-combustible materials due to the inherent nature of massive wood products to slowly char at a predictable rate. Presence or absence of coating has no significant influence on performance. (Gagnon & Pirvu, 2011)

Austria, birthplace of CLT technology, is also the market leader with 70% of global CLT production. Other major producer is Germany, and the rest are UK, Sweden, Norway, Italy, Czech and China. (FAO, 2010)

Modern CLT production commonly employ formaldehyde-free adhesives based on polyurethane (PU), but UF and MF (melamine-formaldehyde) adhesives are still in use (Stauder, 2013).

Prefabrication of CLT panels is beneficial for the erection speed. In some cases erection takes less than a week per level. Among other benefits are no need for skilled labor on the construction site and less on-site waste. Because of large size of CLT components, such buildings have good fire resistance. In one case, test specimen was burning for 3 hours and 6 minutes until failure. (Stauder, 2013)

CLT can be used for the entire structure (floor, walls, roof). In two case studies of residential buildings CLT yield factor averaged 0.42 m^3/m^2. To get an idea of how much CO_2 would be embodied in a residential building of the same floor area as the Ruan if it was constructed with CLT, an average density index from Gagnon & Pirvu (2011) and glulam EC index from the ICE database (which should match the one for CLT) can be used (Hammond & Jones, 2011):

$$0.42\ m^3/m^2 * 237\ m^2 * 500\ kg/m^3 * 0.42\ kgCO_2e/kg = 20903\ kgCO_2e$$

This is about 17% of fired clay bricks EC of the Ruan house. Proper estimate should also include EC of foundations. CLT buildings require much lighter foundations.

7 Steel

Steel is an alloy of iron and carbon. Raw materials in the form of iron ore (rich in iron oxides) and coke and limestone (rich in carbon) are mixed and fed from the top of a furnace. 900-1300℃ hot air is blasted through the mix. In 6-8 hours the mix descends to the bottom of the furnace, while the mixture transforms into molten iron and molten slag. The result is a pig iron, which is relatively high in carbon (4-5%) and has some other impurities (silicon, manganese, phosphorus). Consequently, pig iron is very brittle and has to be further refined using the secondary process. (Domone & Illston, 2010)

Current primary steelmaking route is basic oxygen furnace (BOF). In it, furnace converter is loaded with up to 30% of scrap metal and the rest is filled with the molten metal from a blast furnace. Oxygen is then blown into molten metal through a lance. Exothermic reaction with impurities takes place and a solid waste, slag, is produced. This process takes about 20 minutes. The alternative, electric arc furnace (EAF), is particularly suitable for reprocessing of scrap metal, which can form 100% of load. (Domone & Illston, 2010)

Iron-carbon equilibrium is set in accordance to specific application. In construction low-carbon (or mild) steel is used commonly, which contains 0.04-0.3% carbon by weight. Such composition makes it most usable for welding. Steel reinforcement is used in form of bars and welded mesh to compensate for concrete's low tensile strength. (Domone & Illston, 2010)

As follows from above, steel production requires significant fuel combustion. CO_2 from fuel combustion is supplemented by the carbon dioxide released from the decomposition of limestone in the furnace (Domone & Illston, 2010). As a construction material, steel has many benefits. It is widely available, relatively inexpensive, durable, strong and ductile. The ductility of steel allows complex shapes with high failure resistance to be produced. (Khatib, 2009)

However, steel has a major drawback. Metals are prone to revert back to more stable lowest energy forms in which they exist within the earth, such as oxides or sulfides, through a natural process called corrosion. This effect of moisture and oxygen can be prevented by applying paints and greases, which, to some degree, increase cost and environmental burden of the product. There is also a way to impart corrosion resistance without the need of protective coatings, namely producing higher alloyed steels, such as stainless steels and weathering steels. However, production of such steels require more energy in the process, significantly increasing embodied carbon index (Khatib, 2009). Moreover, stainless steel production process may lead to emissions of heavy metals used in the alloy, such as chromium and nickel, causing more environmental damage (Broome, 2007).

Recycling of metals, because of their inherent value, is and have always been a major industry. Around 75% of new steel is produced from scrap material (Khatib, 2009, 149). Re-use is feasible, however, is relatively rare because of corrosion problem, design inconsistencies (Domone & Illston, 2010, 77), absence of guidelines and government incentives (Khatib, 2009, 170).

Steel has a high thermal conductivity - approx. 54 W/mK. Therefore, main structural steel members require insulation. Steel is also known for a significant thermal expansion coefficient. If adjacent to, for example, masonry wall, it is potentially able to cause collapse of a structure in fire situation, as well as in post-fire operations in result of contraction (Gillie, 2014).

Strength loss of steel is generally accepted to begin at about 300°C. Most of it is retained up to 482℃, beyond which a rapid decrease of strength occurs (Yehia & Kashwani, 2013). Reinforcement steel loses strength more rapidly than structural steel. However, insulating properties provided by concrete cover protect reinforcement from reaching critical strength losses. (Gillie, 2014)

7.1 Ruan

Steel in the Ruan house is used as reinforcement for concrete and piling, mesh in masonry and wire for both applications. In order to calculate embodied carbon of concrete reinforcement, index for steel bar & rod (‘rest of the world’ typical) is applied:

$$EC_{reinf/c} = 12774.3 \text{ kg} * 1.95 \text{ kgCO}_2\text{e} = 24910 \text{ kgCO}_2\text{e}$$

Taking into consideration reinforcement estimates, piling reinforcement density is assumed to be higher than concrete, specifically 200 kg steel rebar per 1 m^3 of piling (YourSpreadsheets, 2015). Therefore, using modification factor presented in the ICE for reinforced concrete (Hammond & Jones, 2008), embodied carbon of piling reinforcement can be calculated as:

$$EC_{reinf/p} = 65205 \text{ kg} * (0.077 * 2) \text{ kgCO}_2\text{e/kg} = 10042 \text{ kgCO}_2\text{e}$$

Steel mesh is specified as a surface area. According to the Russian industry standard ГОСТ 5336-80, steel mesh with given properties (50x50x3mm), has weight of 2.42 kg per 1 m^2. Hence, steel mesh weight can be calculated as:

$$1057.08 \text{ m}^2 * 2.42 \text{ kg/m}^2 = 2558 \text{ kg}$$

With the lack of specific steel mesh index in the ICE, index for general steel (‘rest of the world’ typical) is used to calculate steel mesh embodied carbon (Hammond & Jones, 2008):

$$EC_{s.mesh} = 2558 \text{ kg} * 2.03 \text{ kgCO}_2\text{e} = 5193 \text{ kgCO}_2\text{e}$$

Calculation of steel wire embodied carbon uses uncertain index for wire from the ICE (Hammond & Jones, 2008):

$$EC_{s.wire} = 109.11 \text{ kg} * 3.02 \text{ kgCO}_2\text{e/kg} = 330 \text{ kgCO}_2\text{e}$$

8 Fired clay bricks

Bricks appeared in the Middle East and Europe circa 7000-6000 BC along with pottery development. Fired clay bricks are known to be first used around 5000-4500 BC, becoming more common by 3100-2900 BC with the building of the city of Ur. (Brojan et al. 2013)

Fired clay bricks is the most popular material in masonry, which is a generic term for laying down preformed units in a bed of mortar. Mortar is commonly based on Portland cement (Khatib, 2009). Bricks vary in shapes and sizes and come in several standard forms, such as solid, cellular, perforated, hollow and others. (Domone & Illston, 2010)

Raw materials (clays) for clay brick production are quarried. They are comprised mostly of silicon and aluminum oxides, as well as some iron and calcium oxides. Clays absorb water willingly, becoming more plastic and allowing various shaping techniques to be used. (Domone & Illston, 2010)

After initial shaping, clay bricks are fired at temperatures between 900 and 1050℃ (850-1300℃, according to Domone & Illston (2010)). This is done to give bricks their mechanical strength and durability by breaking down original clay minerals into formation of new crystalline materials. Most brick factories employ tunnel kilns for the process as a more efficient one. In this method, complete firing cycle from drying to cooling usually takes 2-3 days. (Khatib, 2009)

Masonry buildings, if constructed properly, have a very long life with very low maintenance costs. With adequate maintenance they can retain their qualities and value well over 100 years. Their whole life maintenance is likely to be better than those built in reinforced concrete. (Khatib, 2009)

However, clay bricks have even higher EC content than concrete, and quarries and factories also cause typical aesthetic and environmental problems. Approximately 85% of fired clay bricks EC is due to the firing process itself. On a positive note, same as the cement industry, brick industry is sought to optimize production process to minimize energy and raw material requirements. (Khatib, 2009)

Similar to cement production, use of waste materials in the manufacture of clay bricks is widely accepted. Some are used as fuel (e.g. sawdust, sludge), while others improve or modify specific brick properties (e.g. ash, slag, cullet). Such applications have potential to lower bricks EC and provide other benefits (Khatib, 2009).

In case a masonry building has to be demolished, reuse of bricks is problematic because Portland cement mortars adhere strongly to the bricks. Crushed mix of materials (bricks, mortar, plaster, concrete) can be recycled. However, the resulting aggregate (recycled aggregate, or RA) has to be downgraded to non-structural applications, such as low-grade fill material for road construction or as aggregate for low-strength concrete. This is because crushed masonry and plaster has low strength and high absorption. (Khatib, 2009; Domone & Illston, 2010)

Fire resistance is one of the strongest and most appreciated properties of masonry. Characteristics contributing to this fact are masonry's low thermal conductivity (0.65 W/mK), high heat capacity, zero flammability and refractory properties (retaining strength up to 1000 ℃) (Domone & Illston, 2010). Spalling effect depends on unit strength (density) in the same way as with concrete (Gillie, 2014).

8.1 Ruan

Two types of brick are used in the Ruan house: solid (regular) and perforated (porous). Some brick estimates are specified as surface area. Using given wall thickness, 120 mm, they can be converted to volumes:

$$50.22\ m^2 * 0.12\ m = 6\ m^3\ \text{(solid)}$$

$$372.5\ m^2 * 0.12\ m = 44.7\ m^3\ \text{(perforated)}$$

Because of uncertainties in brick type designation in the ICE material properties table (Hammond & Jones, 2008), brick density indexes for weight calculation are taken from the appropriate table by Domone & Illston (2010). Average of the range is applied.

Thereby, solid bricks weight is:

$$63.6\ m^3 * 2050\ kg/m^3 = 130380\ kg$$

And perforated bricks weight is:

$$157.3\ m^3 * 1765\ kg/m^3 = 277635\ kg$$

According to the ICE data (Hammond & Jones, 2008), EC of all clay bricks in the Ruan house can be calculated as:

$$EC_{bricks} = (130380 + 277635)\ kg * 0.24\ kgCO_2e/kg = 97924\ kgCO_2e.$$

8.2 Alternative

Along with tightening of construction regulations under the global warming agenda, processes and products are evolving towards better energy efficiency. One good example is autoclave aerated concrete (AAC). According to the ICE (Hammond & Jones, 2008), EC index of AAC blocks per kg varies in range (0.24 to 0.375 $kgCO_2/kg$), but is close to that of fired clay bricks. Their density, however, is less than half of those, which means that volume for volume they can offer substantial carbon emissions savings compared to fired clay bricks. Estimated EC value of AAC blocks matching the volume of bricks in the Ruan house would be (average of the EC index range is applied):

$$(63.6\ m^3 + 157.3\ m^3) * 750\ kg/m^3 * 0.31\ kgCO_2e/kg = 51\ 359\ kgCO_2e$$

This represents almost 50% less EC than that of fired clay bricks. Similar principle (less density/weight, less EC) can be applied to fired clay bricks with highly perforated designs (Khatib, 2009). Assuming the use of the same type and quantity of mortar as in the Ruan house, the number above can be supplemented with mortar's 21 tonnes and reinforcement's (for comparative reasons) 5 tonnes of CO_2e to get a number for the AAC masonry wall EC – 77 tonnes of CO_2e.

In addition, AAC blocks are as good as or better than regular dense concrete in terms of fire resistance. Two reasons for better performance are absence of aggregates, prime source of differential expansion leading to cracking and spalling, and the fact that closed pore structure resists heat transfer (Narayanan & Ramamurthy, 2000). AAC waste can be recycled for a number of applications, including new AAC blocks production, but transporting waste to the recycling facilities is problematic (Nielsen et al, 2012).

Another alternative is an ancient but still popular building method - mud bricks, or adobe. They can be produced with hand presses, although modern method employs hydraulic pressing machines. In this case adobe is called compressed earth block or CEB. Because of much less moisture content, CEB bricks do not require long curing periods, and can be produced on site using local raw materials (Milani, 2005). CEBs are made from soil that is 15-40% non-expansive clay, 25-40% silt powder, 40-70% sharp sand to small gravel content and little to no organic matter. Moisture content is 4-12% (Opensourceecology.org, 2015).

CEB press can make all the bricks for a large house in a day (Milani, 2005). In addition to avoiding the dominant contributor to EC of common bricks, which is the firing process, CEB also saves on transportation related carbon emissions if produced on site. Owing to on-site production, CEBs produce very low waste. Construction off-cuts or demolition debris can be immersed in water and converted back to clay suitable for other applications, e.g. in landscaping or as clay mortar, which can be used in walling again. Laying of walls can be undertaken by workers with little or no training. (Sutton et al., 2011)

CEBs are suitable for structural applications, however thicker walls are required in comparison to fired clay bricks, which have higher strength, stability and mortar is more bonding. However, this can be avoided by the use of sodium silicate mortars (sodium silicate, clay and sand) instead of clay mortars. CEBs also have weaker weathering protection than fired clay bricks and are more demanding to render and plaster types, which should be vapour-permeable, same as mortars. (Sutton et al., 2011)

In fire tests CEB walls perform excellent overall. Temperature of exposed walls stays in the 60-80° C range for 120 minutes. Peak temperatures are recorder at the cooling stage after around 240 minutes, but they never reach the prescribed limit for ISO curve (180° C). Cracking is to be expected, but without significant damage to wall integrity (Buson et al, 2012).

The ICE does not specify indexes for CEB or any type of adobe (Hammond & Jones, 2008). Unfired earth bricks LCA carried out by Morton et al (2005) specifies 0.022 $kgCO_2e/kg$ of embodied carbon and 1769 kg/m^3 of density. Therefore, estimated EC value of CEBs matching the volume of fired clay bricks in the Ruan house would be:

$$(63.6\ m^3 + 157.3\ m^3) * 1769\ kg/m^3 * 0.022\ kgCO_2e/kg = 8597\ kgCO_2e$$

Which means that potential CO_2 savings in this case would be up to 91% compared to fired clay bricks. To get a number for the whole masonry wall mortar EC should be calculated. Lawrence et al (2012) specifies 0.018 $kgCO_2e/kg$ of embodied carbon for sodium silicate mortars. Based on wall specimen densities presented in Lawrence et al (2012), density index for sodium silicate mortars is assumed to be 2000 kg/m^3. Therefore, estimated EC of mortar to be used for CEB masonry wall would be:

$$64m^3 * 2000\ kg/m^3 * 0.018\ kgCO_2e/kg = 2304\ kgCO_2e$$

For comparative reasons 5 tonnes of reinforcement's EC is included in CEB masonry EC calculation, which sums up at 16 tonnes of CO_2e.

There is, however, an option to avoid masonry entirely, erecting walls from another abundant benign material which, unlike masonry, does not require extra insulation, possessing good insulation properties by itself. Straw bale is a relatively recent type of construction, starting back from the 1880s with the invention of a steam bale engine. Straws are a discarded part of grain agriculture, such as rice, wheat, rye, oats, barley, etc. This secures its abundance wherever there is a civilization. Straws are an agricultural waste, part of which is used for animal bedding or as a soil conditioner, but more commonly they are disposed of by burning or burying (Milani, 2005). Today, burning is forbidden due to environmental issues this process involves, and decomposition of buried straw takes a long time (Brojan et al. 2013).

Straw bales have modest load-bearing ability (although determined by displacement rather than material failure), but strength is sufficient for residential buildings of up to two storeys high. Render is important stiffness enhancer. It is also very important for decay protection and fire resistance. (Sutton et al., 2011)

Fire resistance is a common concern for straw bale construction. Loose straw indeed is a fire hazard, therefore appropriate measures should be applied on site. Finished straw bale wall, however, has surprisingly good fire resistance, with charring rate similar to that of timber (Sutton et al., 2011). Standard fire tests of up to 1000 °C show at least 160 minutes resistance, which meets building regulations. (Jones, 2007).

Straw bale is a comparatively simple construction method, easily handled by an owner-builder and in any DIY endeavour. Its lightness allows to save on high embodied carbon materials for a foundation (e.g. concrete). Although foundation and roof have to be designed carefully to avoid moisture accumulation in bales and rain driven saturation of render (Milani, 2005). Straws can be used for roofing as well. Traditional Danish thatched roofs is a well-known example. Although fire safety in this case is a concern.

The ICE has no EC index for straw, but it does specify its EE, which is 0.24 MJ/kg (Hammond & Jones, 2008). For the purpose of the study, a fairly broad assumption is made. It stands on the basis that wood and straw are both plant materials and, thus, their embodied energy indexes should relate to each other. Therefore, considering that sawn softwood has fossil fuels EE index of 3.2 MJ/kg and fossil fuels EC index of 0.20 $kgCO_2e/kg$ (Hammond & Jones, 2008), straw's index can be devised from this relation, equaling to 0.015 $kgCO_2e/kg$ of EC. Average density for structural straw bales is 120 kg/m^3 (Sutton et al., 2011). According to a comparative study, straw bale wall is even slightly thinner than fired clay brick wall with the same U-value (Brojan et al. 2013). However, for the calculation of estimated EC value of straw bales matching the volume of fired clay bricks in the Ruan house wall thickness is assumed to be the same:

$$(63.6\ m^3 + 157.3\ m^3) * 120\ kg/m^3 * 0.015\ kgCO_2e/kg = 398\ kgCO_2e/kg$$

As expected, this value is practically negligible. Straw bale walls framing (usually wood) and other materials are supposed to add to the EC value, but the addition is hardly to be significant.

Straw, same as wood, is completely organic, has low embodied energy and sequesters carbon until the end-life of a building. Straw bale construction, however, does require significant rendering (stucco, plaster), contributing somewhat to building's embodied carbon. Vapour-permeable rendering (lime or loam) should be used and applied carefully to allow sufficient moisture transport through the wall, as well as to protect from insects, rodents and improve fire safety. As a minor addition, bales' embodied carbon can be increased by the use of a non-degrading twining material, usually polypropylene, and, possibly, other reinforcing materials (steel) and parts (fixings, pegs). (Sutton et al., 2011)

9 Results

The global warming contribution of the Ruan's structural materials revealed their surprisingly high, considering relatively modest square area of the house, overall embodied carbon of 208 tonnes. Potential surprise is that almost half of it is contributed by bricks (98 tonnes CO_2), only followed by concrete's 67 tonnes of embodied carbon. Inclusion of steel and mortar within the appropriate construction entities adjusts the numbers, but generally keeps the proportion (Figure 13). Wood's insignificant 3 tonnes of CO_2 contribution was to be expected, as it was used for light framing only. In detail specification and EC calculation of materials are presented in the resulting Table 5.

Table 5. Ruan house structural materials specification and embodied carbon results.

Construction material:	Concrete, m^3	Piling, m^3	Mortar, m^3	Reinforcement (concrete), kg	Reinforcement (piling), kg	Steel mesh (masonry), m^2	Steel wire, kg	Sawn wood, m^3	Plywood, m^3	Solid clay bricks, m^3	Perforated clay bricks, m^3
Specification values:	27,40	*28,35*	2,01	3014,00		25,11	45,21	7,80	*4,20*	*6,00*	19,30
	31,60		0,81	3476,00		5,90	52,14	4,47		2,70	93,30
	4,10		5,79	455,40		71,50	6,83	1,32		18,60	*44,70*
	0,86		5,58	94,60		38,60	1,42	*5,25*		36,30	
	6,60		1,45	5500,00		37,20	3,51				
	50,75		27,94	234,30		18,15					
	2,16		14,90			186,26					
			1,17			111,75					
			4,69			406,30					
			0,50			134,78					
			0,29			21,53					
			0,91								
Total:	123,47	28,35	64,03	12774,30	-	1057,08	109,11	18,84	4,20	63,60	157,30
Total weight, kg:	283981	65205	113653	12774	*5670*	2558	109	7882	2604	408015	
EC index, $kgCO2_e/kg$:	0,13	0,13	0,18	1,95	-	2,03	3,02	0,20	0,45	0,24	
EC $kgCO2_e$:	**37486**	**8607**	**20685**	**24910**	**10042**	**5193**	**330**	**1576**	**1172**	**97924**	
Base material:	**Concrete**			**Steel**				**Wood**		**Bricks**	
Combined weight, kg:	462839			21111				10486		408015	
Combined EC, $kgCO_2e$:	**66778**			**40475**				**2748**		**97924**	
Overall EC, $kgCO2_e$:	**207925**										

Notes: Numbers in italics have been converted from other indexes (see appropriate chapter). Total weight of piling reinforcement have been calculated assuming 200 kg of reinforcement per 1 m^3 of piling. For EC of piling reinforcement calculation see text.

Figure 13 is a graphical representation of Ruan's house major EC contributors, in this case distributing mortar and steel within related materials – reinforced concrete and masonry. Steel is a major EC contributor, yet, in this case, it was not used as a stand-alone material but part of reinforced concrete and masonry.

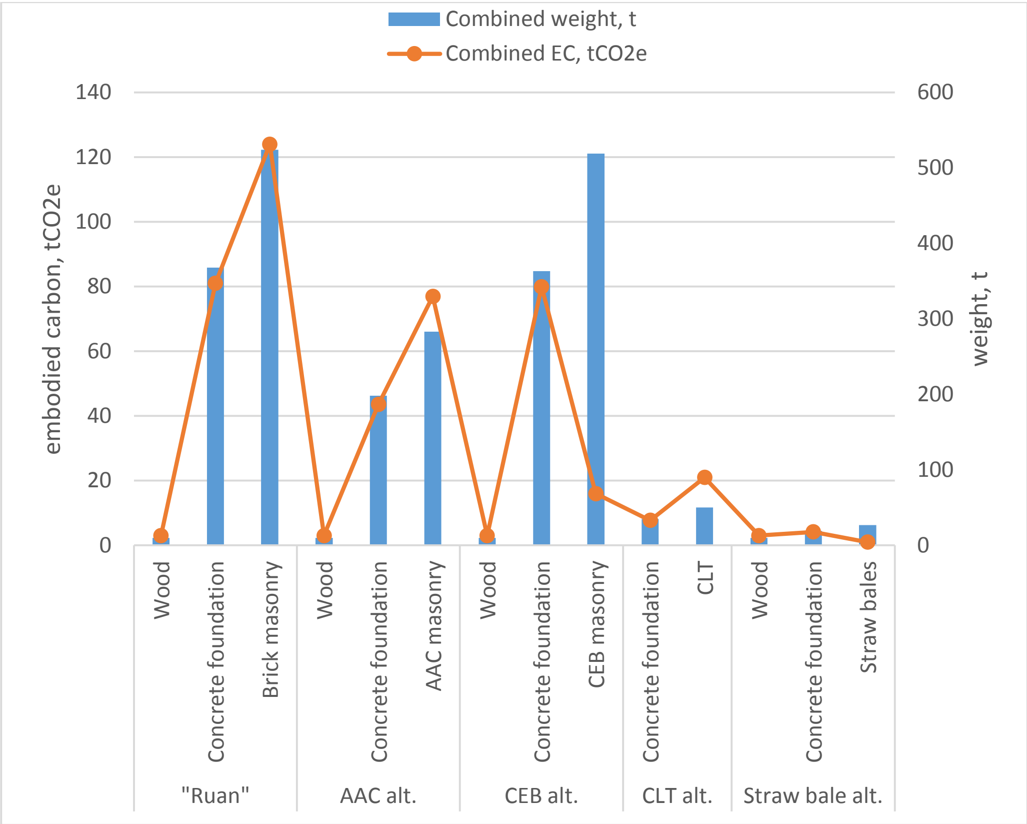

Figure 13. Weight and EC of structural materials of the Ruan house and of alternative designs.

Fired clay bricks prolong buildings life and lower maintenance costs. However, initial contribution to global warming from such buildings is off the charts. 85% of bricks EC comes from the production process which requires to sustain high temperatures over a long period of time. The rest is mostly transportation related carbon, since the material is very heavy and can be produced only at a factory. Even such a relatively small building as the Ruan house embodies almost a 100 tonnes of carbon in bricks only. This is a solid argument to consider alternative methods of construction.

If an owner-builder is certain about constructing his/her house with masonry walls, good choice is to substitute fired clay bricks with lighter masonry, such as AAC blocks, supplementing EC savings with lowered EC of lighter foundation. CEBs lower EC more markedly, even though they are close in weight to fired clay bricks, hence about the same need in heavy foundation and respective EC contribution. It is also a labor intensive method of construction, although no skilled labor is required.

Avoiding masonry can be very beneficial, at least by limited foundation requirements. CLT design offers high carbon emission savings, additionally excluding the need in framing materials. Most beneficial is straw bale design. For a 1-2 storey building it is a preferable choice, especially from an economical point of view. It is probably the lightest structural material available; it has even less EC than wood, and, same as wood, sequesters carbon for the lifetime of a building; unlike wood and, especially, masonry, does not require insulation; does not require skilled labour; is made of a side product. There are some downsides for these methods, however. Both materials have weaker fire resistance than masonry. In addition, CLT method can be expensive, while straw bale method has some design limitations (low-storey only, large roof overhangs, not any render is suitable).

CLT values can be roughly extrapolated upon wood, in case of using it as a primary structural material in the form of logs and sawnwood. They are of about the same density, hence weight as well. However, more wood generally would be required as it is structurally weaker than CLT. Although this would be somewhat compensated by the fact that wood has twice less EC than CLT. Note that all presented alternative calculations can lower down EC values further more in case of using low carbon cements in foundations and masonry.

Currently available CEM I substitutes have the potential to lower CO_2 substantially if not dramatically. Number of alternatives offer close to 50% CO_2 abatement, some can even save close to 90% of CO_2, as summarized in Table 6. Main obstacle on the way of broader application of CEM I substitutes in construction is the lack of updated standards, government initiatives and application experience of constructors. Nevertheless, CEM II has surpassed CEM I on the European market years ago. And if those obstacles are to be overcome, such tendency can be expected to extend to substantially more ecofriendly cements. At the moment, it is hard to expect a regular owner-builder to afford novel cement, no matter how ecofriendly it is, if it comes with all the usual constraints of a niche market product – price and availability. Whether or not they are going to be mass marketed depends on how serious the society is about committing itself to sustainable principles in the form of lowering GHG emissions, constructing to last and lowering maintenance costs. With smart incentives policy and “internalizing” costs of products, phasing out OPC should be relatively easy for the industry.

Table 6. Comparison of Ordinary Portland cement and its alternatives.

Class	Type	Availability	Specific feature	CEM I comparison		
				Potential CO_2 abatement	**Class specific**	**Common**
Portland	CEM I	Common	General use, Base price			
Blended	CEM II	Common	General use, Medium resistance	-10%	Lower heat; Comparable to higher resistance; Comparable price.	Higher rate of strength gain; Higher long-term strength; Higher durability; Lower shrinkage.
	CEM III (e.g. Ecocem)	Relatively rare	High early strength	-50%		
	CEM IV	Relatively rare	Low heat	-20%		
	CEM V	Rare	High resistance	-40%		
Geopolymer	EFC	Rare (Aus)	No clinker; White color	-50%	Higher tensile strength; Higher resistance; Much lower heat; Better finish; Higher price.	
	banahCEM	Rare (UK)	No clinker; Terracotta color	-90%		

Note: CEM II, IV and V abatement estimations are based on the clinker content.

Summing it up, ecofriendly cements have a number of performance advantages and environmental benefits. Their constraints come from the limits of the niche market they occupy, significantly limiting their application especially among owner-builders. Regardless of availability of low carbon cements, an owner-builder should always consider material optimization, avoid reinforcing of concrete and apply smart design features. Options limiting the use of concrete are always available (e.g. suspended timber base on light foundation).

It is clear that wood certification systems are not perfect. Yet it appears to be that FSC scheme is more uncompromised in terms of forest protection, as can be seen in the comparative summary in Table 7. PEFC system is more aligned with forestry companies and forest owners' interests, serving short-term national commercial interests. One could expect such tendencies from a mere look at their governance structures. FSC members represent a far greater number of stakeholders, meaning the system to be more aligned with democratic principles. Moreover, FSC voting power is equally split between Northern and Southern members, while PEFC voting balance is tilted towards North, largely Europe. This serves interests of transnational corporations, which are originally Northern, in exploitation of rich resource base of the South. Endorsing Southern national certification systems does not help forest protection much as overall weak/corrupt governance in many Southern countries provides ground for business as usual. FSC, however, also has issues. Yet they come mostly from faults controlling implementation of its standards, not so much from standards themselves. Hopefully, FSC will be able to work on its issues and improve continually. PEFC progress is notable, but unsatisfactory so far.

Table 7. Comparison of the FSC and PEFC certification systems.

Comparison points	FSC	PEFC
HCVF protection	Required	Suggested
Indigenous people rights protection	Required	Suggested
Control over mixed sources of wood (Controlled Wood)	Complete on standard level, but with gaps in monitoring	Incomplete
The Policy for Association (PfA), as a mechanism of protection from organizations deliberately and systematically involved in unacceptable activities.	Yes, but has implementation issues	No
Protection from conversion to monoculture plantations	Required	Required, but with exceptions and vulnerable to wide interpretations
Stakeholder involvement	Balanced, NGOs included	Unbalanced, industry dominated
Number of members (representativeness)	Over 800	60

As a result, a few recommendation on wood products can be given to an owner-builder. First of all, always consider second-hand wood. Second, prefer certified wood products over uncertified and avoid imported tropical wood unless it is certified. Third, when making a choice between certified wood products, choose those produced locally. Fourth, prefer FSC labeled products over PEFC, but, if possible, avoid FSC MIX labeled products. Last but not least, do not hesitate to specify engineered wood products. They are generally more sustainable than virgin wood because they make use of poor quality wood, of small sections of wood and of wood waste. Engineered wood products are lighter, stronger and more stable than sawnwood, offering many benefits and opportunities in construction. They do, however, embody more energy than sawnwood and might cause concerns over VOCs emissions, but the issues are insignificant. CLT has arguably the highest application potential among all. Almost entire buildings can be erected using but this single material. It has tremendous potential in lowering carbon emissions. Although their best economical potential is achieved in multi-storey building. A single family house might be more economically constructed with conventional materials, if speed and ease of erection are not a priority.

Table 8. Materials recyclability and fire resistance comparative performances, placed in descending order.

Recyclability	**Fire resistance**
CEB	Fired clay bricks
Wood and wood based products (CLT)	AAC
Straw	CEB
Steel	Concrete
AAC	Steel (insulated)
Concrete	Wood and wood based products (CLT)
Fired clay bricks	Straw bale

Table 8 places materials in accordance with their recyclability and fire resistance performances. Materials can perform better or worse than portrayed depending on a specific design. Masonry units are well-known for their fire resistance properties. Concrete's performance in fire depends on the constituents. Note that steel has to be insulated in load bearing applications, otherwise it loses strength faster than wood. Wood and straw bale have similar fire resistance, which suffices building regulations owing to low thermal conductivity and a protective layer of char. CEBs are made from on-site raw materials and can be turned back into earth (clay) they have been made from by immersion into water. Steel is commonly recycled but hardly reused. Concrete and fired clay bricks are basically on par with each other in terms of recyclability which is hindered by material contamination and varying composition of mixes.

10 Discussion

The global climate is at constant change all the time. IPCC asserts that human activity is a dominant cause of global warming since the middle of the previous century. As it has been shown our planet went through a number of large and abrupt RCCs long before any human involvement in the process was possible, even within the current interglacial. Five thousand years ago the temperature was as much as 2.5 °C higher than in 1995. Even the Medieval period was 1 °C warmer. The current global warming has not reached the Holocene peak temperatures, at least not yet. And if anyone questions the global warming itself as opposed to global cooling, then we have to remember that just about 200 years ago glaciers were at their maximum throughout the 10000 year period, hence global warming is to be expected in the situation which fits the cyclical nature of climate change.

Scientists suggest that solar energy variations is arguably the major force behind the regular climate change. This, of course, does not mean that GHG concentrations in the atmosphere should be taken lightly, as they are the amplification factor for global warming and their current concentrations in the atmosphere are at an unprecedented level. Meanwhile, it might be a little too rash to assign dominance to specifically human induced global warming and declare any discussions on the topic obsolete. Studies of the climate system of our planet are only in their infancy, and climate discussions should not be rendered final. Steps should be taken towards understanding of all the complexities of climate change processes, including atmospheric GHG and aerosol particles concentrations, volcanic activity, carbon sinks, system feedbacks, albedo effect, clouds, systematic alterations of ocean's circulations, solar energy variations and possible catastrophes involved.

We have to keep in mind also that global warming *per se* is far more preferable to global cooling. Civilizations' progress and prosperity are closely associated with warming periods, while their degradation or even disappearance usually took place during cold periods. Warmer periods bring higher and more widespread yields, ease up access to lands, accumulating wealth and, in turn, laying a strong foundation for science and culture. In addition, high atmospheric CO_2 concentrations promote faster and more abundant vegetation, benefiting crops once again. On the contrary, colder periods restrain wealth accumulation, with food shortages leading to malnutrition, which is a perfect ground for epidemics.

At the end though, current GHG levels are far beyond anything discovered throughout the period and there has never been 7 billion people on the planet, most of which live in the areas most sensitive to global warming - coastal zones. And since science presents evidence of unprecedented human involvement in the global warming, it is our duty to limit this involvement as much as possible in order to protect as much people as possible. As a side note, for the same reason we should also be researching and investing in methods mitigating climate change consequences, as they are to take place regardless of our success in limiting anthropogenic influence.

Concrete has a much longer history than one could imagine. A leap responsible for hurling concrete to where it is today was made back in the 19th century with the invention of Portland cement and its improvements. It did, however, hurl energy requirements of production processes as well. But technology keeps evolving. Modern concrete technology is seeking its way to decrease embodied energy through improving the production process efficiency and growing a share of clinker substitutions in modern cements. The latter, however, might seem to be a rather slow process, even though such cements present not only environmental benefits, but improved qualities as well, such as durability, user-friendliness, versatility. In addition, some environmentally harmful aspects of cement production are intrinsic to the process, e.g. mining of raw materials and particulate matter emissions. Although, on the bright side, concrete has a long-term ability to reabsorb carbon from the atmosphere, offsetting its embodied carbon significantly. This ability alone is remarkably beneficial for concrete's environmental image.

To keep calculations simple and representative, foundations of Ruan house alternatives are assumed to use the same CEM I based reinforced concrete as the Ruan house. As it has been revealed in this work, there is a number of low carbon cements available today. Employing them in foundations can cut carbon emissions further more. Additionally, CLT and, especially, straw bale designs are able to eliminate reinforced concrete completely, applying light foundations.

The majority of steel is produced from scrap metal. However, steel production releases a lot of carbon into the atmosphere regardless of the feed. Alternative reinforcements are being introduced, e.g. composites, such as fiberglass, for high strength applications, or natural materials, such as bamboo, for low strength reinforcement. But it is unlikely, within the current state of affairs, that a viable large scale replacement for steel is to be available anytime soon. When constructing a single family house it is better to avoid heavy materials, avoiding the very need for reinforcement.

A study of certification systems by ITS Global bashes FSC system and praises PEFC. Although independency of the study is not clear. According to PEFC website, ITS Global is one of seven registered asserters of the system. In addition, its Managing Director is a former Chairman of the GATT (now the WTO), the organization known to be a spearhead of commercial interests around the world with a multitude of allegations in trumping down any social and environmental concerns under commercial interests of big businesses.

Both studies of forest cover change, presented in this work, have limitations - socioeconomic and ecological in Hansen et al (2013), and possible faults in national datasets due to weak governance in FAO (2010) report. However, European forests are not expected to be in serious danger. Unlike territories with minimal rates of forest certification.

Forest certification has yet to become a trend in most of tropical and subtropical countries. Brazil's positive advancement in forest protection is commendable. But in a big picture it is offset by prevailing detrimental changes of forest cover in other tropical countries. It can be argued that poverty and insecure land tenure are main reasons for lack of proper forest management in those regions. In developing countries local markets are not strong enough to demand certified products, wood is predominantly used for fuel and producers are not secure enough to invest in the future.

In conclusion, strong heavy materials of traditional industrialized society can look good and offer durability and low maintenance. Nevertheless, their production related embodied carbon is remarkably high. Many options are available, both traditional and modern, offering the same benefits and more. If for some reason masonry is the type of construction an owner-builder is certain to be the best option under the circumstances, then it is recommended to avoid fired clay bricks as a material of choice. AAC blocks and CEB masonry embody markedly less carbon and offer comparable or better user qualities. Variety of low carbon cements are recommended, especially for masonry house foundations, which can additionally help to avoid or minimize the use of reinforcement. CLT construction is a great option to consider, however, it might be too expensive for a moderate floor area. Best option for a low storey house is a straw bales structure, with minimal embodied carbon and great user qualities. A responsible owner-builder must consider those options to not only be a part of economy decarbonization, but to harness on satisfaction aroused from living in a quality dwelling built with little to no burden on the world outdoors.

10.1 Limitations of the work

This work does not include operational carbon analysis - energy use and associated carbon emissions along the lifetime of a building. Addition of operational carbon would mean a shift towards a Life Cycle Assessment (LCA, also known as Cradle-to-Grave analysis) and would present a more valuable data on the specific design. However, such shift and expansion of the thesis with addition of various LCA parameters (as well as complexity of the assessment itself), was not the intention.

Embodied carbon (EC) calculations are major part of LCA. However, EC values in the ICE database, used within this work, are not normally derived from an accurate LCA. Majority of data collected for the ICE comes from various sources prioritizing EE over EC calculations. Therefore, many of the EC coefficients were estimated by the authors using the typical fuel mix in the relevant UK industries. This means that deviations in fuel mix composition from factory to factory could affect the EC values. Additionally, subscription based sources were not used in the ICE. (Hammond & Jones, 2008)

Significant amount of assumptions is made when calculating EC of materials in this work. Although the ICE is arguably the most comprehensive materials EE/EC database to date (at least among those in public domain), it has a wide range of limitations. Data intricacies and inconsistencies encumbered maintaining the same boundary conditions for the entire inventory (Hammond & Jones, 2008). More assumptions by the author of this work had to be made while converting material volume data to weight, as many density values presented in the ICE are of wide tolerance.

This work could be improved by including actual empirical data on materials use in alternative designs. A volume for volume substitution and the foundation calculation method selected provide only a rough picture of potential benefits. The coherence of the work could be further improved by including minor materials used in the finishing of surfaces, insulating, plumbing, doors, windows, décor, etc. However, their contribution to cumulative EC of the Ruan house materials is expected to be small in comparison to structural materials and, therefore, was omitted from calculations.

It is also important to keep in mind that embodied carbon assessment of buildings and construction products is in its infancy. Reliable embodied carbon emission factors and assessment tools are emerging but further work is required.

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Appendix

ВЕДОМОСТЬ СМЕТНОЙ СТОИМОСТИ

Общестроительных работ по дому "РУАН" ниже отм. 0.000

Объект: Малоэтажная жилая застройка

Адрес:Московская область, Красногорский район, Петрово-Дальнее

№ п.п.	Параметры расчета стоимости	Ед. изм	Обьем	Цена	Стоимость
1	2	3	4	5	6
	Стоимость строительства 1-го этапа				
2	**Стоимость строительства жилого дома ниже отм. 0.000**				**2 114 582,65р.**
2.1	**Земляные работы**				**138 000,00р.**
2.1.1	*Разработка грунта механизированным способом*	$м^3$	*70,40*	*600,00р.*	*42 240,00р.*
2.1.2	*Доработка грунта вручную под ростверк*	$м^3$	*36,8*	*1 200,00р.*	*44 160,00р.*
2.1.3	*Доработка грунта вручную под устройство монолитной плиты перекрытия ниже 0.00 (пола основного дома), толщ. 0,05м*	$м^3$			
2.1.4	*Обратная засыпка песком*	$м^3$	*43,00*	*1 200,00р.*	*51 600,00р.*
2.1.5	*Обратная засыпка местным грунтом*	$м^3$			
2.1.6	*Вывоз и утилизация излишнего грунта*	$м^3$			
2.2	**Свайные работы**				**474 900,00р.**
	Под ростверк здания				
2.2.1	*Погружение свай дизель-молотом*	$м^3$	*28,98*		
2.2.2	*Сваи железобетонные*	*м/п*	*315,00*	*300,00р.*	*94 500,00р.*
	Стоимость свай железобетонных с [illegible]	*шт*	*63*	*4 000,00р.*	*252 000,00р.*
2.2.3	*Вырубка бетона из арматурного каркаса железобетонных свай*	*шт*	*63,00*	*300,00р.*	*18 900,00р.*
2.2.4	*Погружение и испытание свай на неосвоенных площадках*	*шт*	*3,00*	*16 500,00р.*	*49 500,00р.*
2.2.5	*Накладные расходы*	%			*60 000,00р.*
2.3	**Монолитные ж/б работы по устройству ростверков и стен**				**432 608,99р.**
2.3.1	*Устройство песчаной подготовки под ростверк толщ. 200мм*	$м^3$	*22,4*	*850,00р.*	*19 040,00р.*
2.3.2	*Устройство пенополистирольной прокладки под подошву ростверка толщиной 100мм*	$м^2$	*78,30*		*42 830,10р.*
	Работа	$м^2$	*78,30*	*30,00р.*	*2 349,00р.*
	Пенополистерол, 100мм	$м^3$	*8,61*	*4 700,00р.*	*40 481,10р.*
	Накладные расходы	%			
2.3.3	*Устройство монолитного ростверка из бетона B25*	$м^3$	*27,40*		*370 738,89р.*
	Работа	$м^3$	*27,40*	*5 500,00р.*	*150 700,00р.*
	Бетон B15	$м^3$	*27,81*	*4 800,00р.*	*133 492,80р.*
	Арматура (расход 110 кг на 1м³)	*кг*	*3014,00*	*27,50р.*	*82 885,00р.*
	Вязальная проволока (расход 1,65 кг на 1м³)	*кг*	*45,21*	*36,60р.*	*1 654,69р.*
	Эмульсол	*л*	*16,44*	*60,00р.*	*986,40р.*
	Механизмы	$м^3$			
	Опалубка (доска 150х40 +гвозди)	$м^3$	*0,15*	*6 800,00р.*	*1 020,00р.*
	Накладные расходы	%			
2.4	**Изоляционные работы ростверка**				**47 995,75р.**
2.4.1	*Оклеечная гидроизоляция в 1 слой*	$м^2$	*110,51*		*17 703,59р.*
	Материал "Гидростеклоизол"	$м^2$	*132,61*	*58,50р.*	*7 757,69р.*
	Прочие материалы	$м^2$	*110,51*	*30,00р.*	*3 315,30р.*
	Работа	$м^2$	*110,51*	*60,00р.*	*6 630,60р.*
	Накладные расходы	%			

2.4.2	Защитная обработка бетонных поверхностей битумным праймером	$м^2$	197,99		30 292,16р.
	Битумная мастика в один слой 1,5 кг - 1м²	$м^2$	296,98	62,00р.	18 412,76р.
	Работа	$м^2$	197,99	60,00р.	11 879,40р.
	Накладные расходы	%			
2.5	Утепление стен фундамента Пеноплексом (100мм)	$м^2$	43,40		31 207,50р.
	Работа	$м^2$	43,40	100,00р.	4 340,00р.
	Материал "Пеноплекс" толщиной 100 мм	$м^3$	4,77	4 700,00р.	22 419,00р.
	Тарельчатый дюбель. 5шт/м²	шт	217,00	10,50р.	2 278,50р.
	Расходные, механизмы и прочее	$м^2$	43,40	50,00р.	2 170,00р.
	Накладные расходы	%			
2.6	Устройство прижимной стенки				71 717,24р.
2.6.1	Устройство прижимной стенки из кирпича толщиной 120 мм	$м^2$	50,22		71 717,24р.
	Устройство кирпичных стен в 1/2 кирпича	$м^2$	50,22	700,00р.	35 154,00р.
	Стоимость кирпича керамического полнотелого М125	шт	2762,00	9,80р.	27 067,60р.
	Стоимость цементного раствора М100	$м^3$	2,01	3 800,00р.	7 638,00р.
	Стоимость сетки 50х50х3	$м^2$	25,11	61,98р.	1 556,32р.
	Расходные и прочие материалы	$м^2$	50,22	6,00р.	301,32р.
	Накладные расходы	%			
2.7	Устройство вводов коммуникаций				29 056,00р.
2.7.1	Устройство ввода слаботочных систем и электроснабжения (от перекрытия до 2м от стены)	шт	2,00		12 390,00р.
	Работа	к-т	2,00	4 500,00р.	9 000,00р.
	Труба гофрированная двухслойная "Электрокор" Ø63	м	30,00	105,00р.	3 150,00р.
	Расходные и прочие материалы	шт	2,00	120,00р.	240,00р.
	Накладные расходы	%			
2.7.2	Устройство ввода водопровода и канализации	шт	2,00		16 666,00р.
	Работа	шт	2,00	5 000,00р.	10 000,00р.
	Труба ПЭ-80 Ø40мм	м	22,00	58,00р.	1 276,00р.
	Труба канализационная ПНД, Ф100 мм (в т.ч. фасонные элементы)	м	19,00	270,00р.	5 130,00р.
	Расходные и прочие материалы	шт	2,00	130,00р.	260,00р.
	Накладные расходы	%			
2.8	Устройство монолитного перекрытия ниже отм. ±0.00 основного дома	м²	167,50		583 792,27р.
2.8.1	Песчаная подготовка h=150мм	$м^3$	25,13	850,00р.	21 356,25р.
2.8.2	Устройство пенополистерольной прокладки под плиту h=100мм	$м^2$	167,50		91 622,50р.
	Работа	$м^2$	167,50	30,00р.	5 025,00р.
	Пенополистерол 100мм	$м^3$	18,43	4 700,00р.	86 597,50р.
	Накладные расходы	%			
2.8.3	Гидроизоляция полов "Тефонд"	$м^2$	167,50		45 560,00р.
	Материал "Тефонд"	$м^2$	201,00	160,00р.	32 160,00р.
	Прочие материалы	$м^2$	167,50	30,00р.	5 025,00р.
	Работа	$м^2$	167,50	50,00р.	8 375,00р.
	Накладные расходы	%			
2.8.4	Монолитная плита толщиной 200мм	$м^3$	31,60		425 253,52р.
	Работа	$м^3$	31,60	5 500,00р.	173 800,00р.
	Бетон В25	$м^3$	32,07	4 800,00р.	153 955,20р.
	Арматура А I/А III Ø 6-20 мм (110 кг на 1 м³)	кг	3476,00	27,50р.	95 590,00р.
	Вязальная проволока	кг	52,14	36,60р.	1 908,32р.
	Механизмы	$м^3$			
	Накладные расходы	%			

2.9	**Устройство монолитного перекрытия ниже отм. ±0.00 крылец и террас**	**м²**	**27,50**		**81 742,34р.**
2.9.1	***Песчаная подготовка h=150мм***	***м³***	***4,13***	***850,00р.***	***3 506,25р.***
2.9.2	***Устройство утепления Пенополистеролом h=100мм***	***м²***	***27,50***		***15 042,50р.***
	Работа	*м²*	*27,50*	*30,00р.*	*825,00р.*
	Пенополистерол 100мм	*м³*	*3,03*	*4 700,00р.*	*14 217,50р.*
	Накладные расходы	*%*			
2.9.3	***Устройство гидроизоляции полов***	***м²***	***27,50***		***7 480,00р.***
	Материал "Тефонд"	*м²*	*33,00*	*160,00р.*	*5 280,00р.*
	Прочие материалы	*м²*	*27,50*	*30,00р.*	*825,00р.*
	Работа	*м²*	*27,50*	*50,00р.*	*1 375,00р.*
	Накладные расходы	*%*			
2.9.4	***Монолитная плита толщиной 150мм***	***м³***	***4,14***		***55 713,59р.***
	Работа	*м³*	*4,14*	*5 500,00р.*	*22 770,00р.*
	Бетон В25	*м³*	*4,20*	*4 800,00р.*	*20 170,08р.*
	Арматура А I/А III Ø 6-20 мм (110 кг на 1 м³)	*кг*	*455,40*	*27,50р.*	*12 523,50р.*
	Вязальная проволока	*кг*	*6,83*	*36,60р.*	*250,01р.*
	Механизмы	*м³*			
	Накладные расходы	*%*			
2.10	**Устройство лестниц входа**	**компл.**	**3**		**14 096,32р.**
2.10.1	***Наружные монолитные лестницы (3компл. по 2 ступени шириной 2,72м (2шт.), и 0,91м)***	***м³***	***0,86***		***14 096,32р.***
	Работа	*м³*	*0,86*	*5 500,00р.*	*4 730,00р.*
	Бетон В25	*м³*	*0,87*	*4 800,00р.*	*4 189,92р.*
	Арматура АI /АIII	*кг*	*94,60*	*27,50р.*	*2 601,50р.*
	Вязальная проволока	*кг*	*1,42*	*36,60р.*	*51,94р.*
	Эмульсол	*л*	*0,52*	*60,00р.*	*30,96р.*
	Механизмы	*м³*			
	Опалубка	*м³*	*0,30*	*6 800,00р.*	*2 040,00р.*
	Пленка п/л	*м²*	*10,00*	*45,20р.*	*452,00р.*
	Накладные расходы	*%*			
2.11	**Устройство кирпичной кладки наружных стен до отметки 0.00 толщиной 250мм**	**м³**	**2,70**		**23 477,68р.**
	Устройство кирпичных стен в один кирпич	*м³*	*2,70*	*3 500,00р.*	*9 450,00р.*
	Стоимость керамического кирпича полнотелого М125	*шт*	*1 080,00*	*9,80р.*	*10 584,00р.*
	Стоимость цементного раствора М100	*м³*	*0,81*	*3 800,00р.*	*3 078,00р.*
	Стоимость сетки 50х50х3	*м²*	*5,90*	*61,98р.*	*365,68р.*
	Расходные и прочие материалы	*м³*			
	Накладные расходы	*%*			
2.12	**Устройство облицовки цоколя**	**м²**	**28,80**		**88 464,00р.**
2.12.1	***Оштукатуривание по сетке (толщ. слоя 25мм)***	***м²***	***28,80***		***28 905,60р.***
	Работа (в т.ч. крепление сетки)	*м²*	*28,80*	*550,00р.*	*15 840,00р.*
	Сетка штукатурная	*м²*	*31,68*	*95,00р.*	*3 009,60р.*
	Сухая смесь, 1,9кг на 1мм/м²	*меш*	*46*	*200,00р.*	*9 120,00р.*
	Маяки	*м²*	*28,80*	*12,50р.*	*360,00р.*
	Прочее	*м²*	*28,80*	*20,00р.*	*576,00р.*
	Накладные расходы	*%*			
2.12.2	***Облицовка природным рваным камнем***	***м²***	***28,80***		***59 558,40р.***
	Работа	*м²*	*28,80*	*800,00р.*	*23 040,00р.*
	Камень природный рваный (60 шт на 1м²)	*м²*	*28,80*	*800,00р.*	*23 040,00р.*
	Грунтовка	*л*	*8,64*	*90,00р.*	*777,60р.*
	Клей для монтажа камня	*кг*	*230,40*	*50,00р.*	*11 520,00р.*
	Затирка	*кг*	*14,40*	*52,00р.*	*748,80р.*
	Прочие материалы	*м²*	*28,80*	*15,00р.*	*432,00р.*
	Накладные расходы	*%*			
2.13	**Устройство отмостки**	**м²**	**65,00**		**97 524,57р.**
2.13.1	***Утепление отмостки Пеноплексом (50мм)***	***м²***	***65,00***		***19 825,00р.***
	Работа	*м²*	*65,00*	*30,00р.*	*1 950,00р.*

	Материал "Пеноплекс" толщиной 50 мм	$м^3$	3,25	4 700,00р.	15 275,00р.
	Расходные, механизмы и прочее	$м^2$	65,00	40,00р.	2 600,00р.
	Накладные расходы	%			
2.13.2	***Устройство выравнивающей армированной стяжки с разуклонкой толщиной 100мм***	$м^2$	**65,00**		**77 699,57р.**
	Работа	$м^2$	65,00	600,00р.	39 000,00р.
	Сетка	$м^2$	71,50	61,98р.	4 431,57р.
	Бетон В25	$м^3$	6,60	4 800,00р.	31 668,00р.
	Механизмы	$м^2$			
	Расходные материалы	$м^2$	65,00	40,00р.	2 600,00р.
	Накладные расходы	%			

Итого стоимость работ 1-го этапа:

ЗАКАЗЧИК__________Н.Н. Тропынина

ПОДРЯДЧИК__________Н.П.Андрюшечкина

ВЕДОМОСТЬ СМЕТНОЙ СТОИМОСТИ

Общестроительных работ по дому "РУАН"

выше отм. ± 0.000

Объект: малоэтажная жилая застройка

Адрес: Московская область, Красногорский р-он, Петрово-Дальнее

№ п.п.	Параметры расчета стоимости	Ед. изм	Объем	Цена	Стоимость
1	*2*	*3*			
	Стоимость строительства 2-го этапа				
3	**Стоимость строительства жилых домов выше отм. ± 0.000**				**7 337 443,50р.**
3.1	**Внутренние стены**	**к-т.**			**359 290,70р.**
3.1.1	***Стены из поризованного кирпича формата 2NF марки 150 толщиной 250 и более мм***	***$м^3$***	***19,30***		***150 848,03р.***
	Устройство кирпичных стен	*$м^3$*	*19,30*	*3 500,00р.*	*67 550,00р.*
	*Стоимость кирпича керамического 2NF **М150***	*шт*	*4 053,00*	*14,20р.*	*57 552,60р.*
	Стоимость цементного раствора М100	*$м^3$*	*5,79*	*3 800,00р.*	*22 002,00р.*
	Стоимость сетки 50х50х3	*$м^2$*	*38,60*	*61,98р.*	*2 392,43р.*
	Расходные материалы, мех-мы, прочее	*$м^3$*	*19,30*	*70,00р.*	*1 351,00р.*
	Накладные расходы	*%*			
3.1.2	***Кирпичная кладка из полнотелого керамического кирпича*** (колонны, вентшахты, дымоходы, по три ряда под плитой перекрытия)	***$м^3$***	***18,60***		***161 521,66р.***
	Устройство кирпичных стен	*$м^3$*	*18,60*	*3 500,00р.*	*65 100,00р.*
	*Стоимость кирпича керамического полнотелого **М150***	*шт*	*7 440,00*	*9,80р.*	*72 912,00р.*
	Стоимость цементного раствора М 100	*$м^3$*	*5,58*	*3 800,00р.*	*21 204,00р.*
	Стоимость сетки 50х50х3	*$м^2$*	*37,20*	*61,98р.*	*2 305,66р.*
	Накладные расходы	*%*			
3.1.3	***Внутренние перегородки котельной толщ. 120 мм***	***$м^2$***	***36,30***		***46 921,02р.***
	Устройство кирпичных перегородок в 1/2 кирпича	*$м^2$*	*36,30*	*600,00р.*	*21 780,00р.*
	Стоимость кирпича керамического полнотелого М100	*шт*	*1 888*	*9,80р.*	*18 498,48р.*
	Стоимость цементного раствора М 100	*$м^3$*	*1,45*	*3 800,00р.*	*5 517,60р.*
	Стоимость сетки 50х50х3	*$м^2$*	*18,15*	*61,98р.*	*1 124,94р.*
	Накладные расходы	*%*			
3.2	**Наружные стены**	**к-т.**			**3 694 309,6р.**
3.2.1	***Стены из поризованного кирпича формата 2NF марки 150 толщиной 250 и более мм с утеплением минватой***	***$м^3$***	***93,13***		***724 733,93р.***
	Устройство кирпичных стен	*$м^3$*	*93,13*	*3 500,00р.*	*325 955,00р.*
	*Стоимость кирпича керамического 2NF **М150***	*шт*	*19 557*	*13,80р.*	*269 890,74р.*
	Стоимость цементного раствора М 100	*$м^3$*	*27,94*	*3 800,00р.*	*106 168,20р.*
	Минеральная вата толщ 100мм	*$м^3$*	*5,59*	*2 000,00р.*	*11 175,60р.*
	Стоимость сетки 50х50х3	*$м^2$*	*186,26*	*61,98р.*	*11 544,39р.*
	Накладные расходы	*%*			
3.2.1*	***Стены из поризованного кирпича формата 2NF марки 150 толщиной 120мм***	***м2***	***372,50***		***565 527,27р.***
	Устройство кирпичных стен	*м2*	*372,50*	*600,00р.*	*223 500,00р.*
	*Стоимость кирпича керамического 2NF **М150***	*шт*	*19 370*	*13,80р.*	*267 306,00р.*
	Стоимость цементного раствора М 100	*$м^3$*	*14,90*	*3 800,00р.*	*56 620,00р.*
	Стоимость сетки 50х50х3	*$м^2$*	*111,75*	*61,98р.*	*6 926,27р.*
	Расходные, механизмы и прочее	*$м^2$*	*372,50*	*30,00р.*	*11 175,00р.*
	Накладные расходы	*%*			
3.2.2	***Оштукатуривание фасада по сетке (толщ. слоя 25мм)***	***$м^2$***	***353,30***		***433 999,61р.***
	Работа (в т.ч. крепление сетки)	*$м^2$*	*353,30*	*550,00р.*	*194 315,00р.*
	Сетка штукатурная	*$м^2$*	*406,30*	*95,00р.*	*38 598,03р.*
	Аренда, монтаж-демонтаж строительных лесов	*$м^2$*	*353,30*	*220,00р.*	*77 726,00р.*
	Сухая смесь, 1,9кг на 1мм/$м^2$	*меш*	*559*	*200,00р.*	*111 878,33р.*
	Маяки	*$м^2$*	*353,30*	*12,50р.*	*4 416,25р.*
	Прочие материалы и механизмы	*$м^2$*	*353,30*	*20,00р.*	*7 066,00р.*
	Накладные расходы	*%*			
3.2.3	***Отделка фасадов клинкерной плиткой***	***$м^2$***	***171,46***		***520 381,10р.***
	Облицовочные работы	*м2*	*171,46*	*1 800,00р.*	*308 628,00р.*
	Клей для монтажа (1меш=25кг)	*меш*	*34*	*220,00р.*	*7 544,24р.*
	Затирка швов, наружная	*кг*	*514,38*	*52,00р.*	*26 747,76р.*

	Стоимость клинкерной плитки (Германия)	$м^2$	205,75	850,00р.	174 889,20р.
	Расходные, механизмы и прочее	$м^2$	171,46	15,00р.	2 571,90р.
	Накладные расходы	%			
3.2.4	***Монтаж уголка над проёмами***	***м***	***26,40***		***21 263,88р.***
	Монтаж уголка 100х100х8 над проемами	м.п.	26,40	260,00р.	6 864,00р.
	Уголок 100х100х8	кг	323,40	28,20р.	9 119,88р.
	Покраска полимерной краской уголка над проемами	м.п	26,40	200,00р.	5 280,00р.
	Накладные расходы	%			
3.2.5	***Отделка фасадов декоративными молдингами***				***1 375 470,62р.***
3.2.5.1	***Монтаж декоративных молдингов***	***м/п***	***506,20***		***1 327 480,62р.***
	Декоративные молдинги				
	-карниз (эл-т под кровлей осн.дома, h=270мм)	м.п.	65,00	3 165,72р.	205 771,80р.
	-угловой эл-т осн.дома, b=660мм	м.п.	113,20	1 967,88р.	222 764,02р.
	-наличник на оконных проемах, b=140мм	м.п.	142,00	1 527,25р.	216 869,50р.
	-подоконник, h=220мм	м.п.	30,00	1 836,13р.	55 083,90р.
	-эл-т отделки цоколя, h=450мм	м.п.	156,00	1 707,53р.	266 374,68р.
	-пилястра колонны (верх/низ), 8шт., b=195мм (12,16м.п.)	шт	8,00	3 000,00р.	24 000,00р.
	- декоративное пано (элемент над входом 1370х2440мм)	шт	1,00	25 000,00р.	25 000,00р.
	Клей (1туб 750мл)	туб	71	40,00р.	2 834,72р.
	Грунтовка	м.п.	506,20	90,00р.	45 558,00р.
	Работа по монтажу	м.п.	506,20	220,00р.	111 364,00р.
	Герметизация верхнего шва	м.п.	506,20	50,00р.	25 310,00р.
	Покраска фасадной краской, с материалами и расходными	м.п.	506,20	250,00р.	126 550,00р.
3.2.5.2	***Заделка стыков декоративных изделий***	***шт***	***357,00***		***23 370,00р.***
	Работа	шт	357,00	50,00р.	17 850,00р.
	Материал	кг	12,00	460,00р.	5 520,00р.
3.2.5.3	***Герметизация премыканий по периметру декоративных изделий***	***м.п.***	***1 071,00***		***24 620,00р.***
	Работа	шт	1 071,00	10,00р.	10 710,00р.
	Герметик	туб	107,00	130,00р.	13 910,00р.
3.2.5.4	***Накладные расходы***	***%***			
3.2.6	***Декоративная штукатурка фасада***	$м^2$	***18,72***		***52 933,16р.***
	Работа	$м^2$	18,72	900,00р.	16 848,00р.

	Поклейка сетки, нанесение клеевого состава	$м^2$	18,72	490,00р.	9 172,80р.
	Текстурная штукатурка	$м^2$	18,72	260,00р.	4 867,20р.
	Сетка	$м^2$	21,53	95,00р.	2 045,16р.
	Элементы примыкания, клей, расходные материалы	к-т.	1,00	20 000,00р.	20 000,00р.
	Механизмы	$м^2$			
	Накладные расходы	%			
3.3	**Устройство монолитного перекрытия**	**$м^3$**			***772 869,50р.***
3.3.1	***Перекрытие монолитное** на отм 3.130 и на отм 6,410 (толщ. 200мм)*	$м^3$	***50,00***		***772 869,50р.***
	Работа	$м^3$	50,00	6 000,00р.	300 000,00р.
	Бетон В25	$м^3$	50,75	4 800,00р.	243 600,00р.
	Арматура	тонн	5500,00	27,50р.	151 250,00р.
	Вязальная проволока	кг	82,50	36,60р.	3 019,50р.
	Опалубка	$м^3$	50,00	1 500,00р.	75 000,00р.
	Механизмы	$м^3$			
	Накладные расходы	%			
3.4	**Устройство сборных ж/б перемычек**	**к-т.**			**126 729,60р.**
3.4.1	***Перемычки оконных, дверных и гаражных проемов***	***шт***	***33,00***		***62 729,60р.***
	Работа	шт	33,00	300,00р.	9 900,00р.
	3ПБ 13-37	шт	8,00	961,20	7 689,60р.
	3ПБ 16-37	шт	18,00	1 188,00	21 384,00р.
	5ПБ 18-27	шт	5,00	3 196,00	15 980,00р.
	5ПБ 21-27	шт	2,00	3 888,00	7 776,00р.
	Устройство монолитных перемычек	шт	8,00	8 000,00	64 000,00р.
	Накладные расходы	%			
3.5	**Заполнение проемов**				**634 580,00р.**
3.5.1	***Окна деревянные окрашенные (коробка окна - сосна сращенная, створки окна - сосна массив, стеклопакет - двухкамерный, отлив окрашенный)***	$м^2$	***65,40***	***9 000,00р.***	***588 600,00р.***
3.5.2	***Внутренняя дверь в котельную***	$м^2$	***1,70***	***3 000,00р.***	***5 100,00р.***
3.5.3	***Входная дверь в котельную с шибером***	$м^2$	***1,91***	***8 000,00р.***	***15 280,00р.***

3.5.4	**Входные двери в дом металлическая с филенкой**	**$м^2$**	**3,20**	**8 000,00р.**	**25 600,00р.**
3.6	**Устройство скатной кровли**	**к-т.**			**1 348 609,76р.**
3.6.1	**Устройство гидроизоляции мауэрлата каркаса кровли**	**$м^2$**	**29,00**		**3 775,80р.**
	Материал "Гидростеклоизол"	$м^2$	34,80	58,50р.	2 035,80р.
	Работа	$м^2$	29,00	60,00р.	1 740,00р.
	Накладные расходы				
3.6.2	**Каркас**	**$м^3$**	**6,50**		**172 561,20р.**
	Работа	$м^3$	6,50	850,00р.	5 525,00р.
	Брус, доска и др.п/м	$м^3$	7,80	6 800,00р.	53 040,00р.
	Антисептирование пиломатериалов хвойных пород "Сенеж"	$м^2$	236,00	55,00р.	12 980,00р.
	Скобяные изделия, расходные материалы	$м^3$	6,50	680,00р.	4 420,00р.
	Механизмы	$м^3$			
	Монтаж металлических балок из швеллера №20	кг	920,00	83,33р.	76 663,60р.
	Устройство бетонных подушек под монтаж балок	$м^3$	0,20	8 000,00р.	1 600,00р.
	Изготовление и монтаж закладных под монтаж балок	кг	220,00	83,33р.	18 332,60р.
	Накладные расходы				
3.6.3	**Утепление чердачного перекрытия Пенополистеролом, толщина 200 мм.**	**$м^2$**	**117,20**		**251 674,81р.**
3.6.3.1	Устройство выравнивающей стяжки толщиной 10мм	$м^2$	117,20		79 461,60р.
	Работа	$м^2$	117,20	600,00р.	70 320,00р.
	Стоимость цементного раствора М100	м3	1,17	3 800,00р.	4 453,60р.
	Расходные материалы	$м^2$	117,20	40,00р.	4 688,00р.
	Накладные расходы				
3.6.3.2	Устройство пароизоляции перекрытия	$м^2$	117,20		16 459,10р.
	Работа	$м^2$	117,20	120,00р.	14 064,00р.
	Пароизоляция "Ютафол"	$м^2$	140,64	17,03р.	2 395,10р.
	Накладные расходы				
3.6.3.3	Утепление Пенополистеролом 200мм	$м^2$	117,20		53 443,20р.
	Работа	$м^2$	117,20	60,00р.	7 032,00р.
	Пенополистерол 200мм	$м^3$	25,78	1 800,00р.	46 411,20р.
	Накладные расходы				

3.6.3.4	Устройство выравнивающей армированной стяжки толщиной 40мм	$м^2$	117,20		102 310,91р.
	Работа	$м^2$	117,20	600,00р.	70 320,00р.
	Стоимость цементного раствора М100	$м^3$	4,69	3 800,00р.	17 814,40р.
	Сетка	$м^2$	134,78	70,40р.	9 488,51р.
	Механизмы	$м^2$			
	Расходные материалы	$м^2$	117,20	40,00р.	4 688,00р.
	Накладные расходы				
3.6.4	**Устройство покрытия кровли гибкой битумной черепицей серии "СУПЕР"по технологии компании "TEGOLA"**	**$м^2$**	**255,40**		**810 245,95р.**
3.6.4.1	Устройство обрешётки 70%	м2	255,40		133 254,95р.
	Доска 25x100 (заполнение 70%)	$м^3$	4,47	6 800,00р.	30 392,60р.
	Антисептирование пиломатериалов хвойных пород "Сенеж"	$м^2$	12,77	55,00р.	702,35р.
	Механизмы	$м^2$			
	Работа	$м^2$	255,40	400,00р.	102 160,00р.
	Накладные расходы				
3.6.4.2	Устройство основания из фанеры ФСФ толщ. 9 мм.	м2	255,40		194 614,80р.
	Фанера	$м^2$	280,94	320,00р.	89 900,80р.
	Крепежные : саморез Ø3x40	шт	2 043,20	1,25р.	2 554,00р.
	Механизмы	$м^2$			
	Работа	$м^2$	255,40	400,00р.	102 160,00р.
	Накладные расходы				
3.6.4.3	Устройство кровельного покрытия из гибкой черепицы	м2	255,40		222 198,00р.
	Работа	$м^2$	255,40	320,00р.	81 728,00р.
	Материалы, в т.ч. битумная черепица "Мозаика"	$м^2$	280,94	500,00р.	140 470,00р.
	Механизмы	$м^2$			
	Накладные расходы				
3.6.4.4	Устройство лобовой доски и подшивка карниза из строганной доски	м2	129,70		221 268,20р.
	лобовая	$м^2$	17,00		
	карниз	$м^2$	112,70		

	Скобяные изделия, расходные материалы	м^2	129,70	90,00р.	11 673,00р.
	Строганная хвойная доска класса "А"	м^2	155,64	680,00р.	105 835,20р.
	Механизмы	м^2			
	Работа	м^2	129,70	800,00р.	103 760,00р.
	Накладные расходы				
3.6.4.5	Покраска лобовой и карнизной доски	м2	129,70	300,00р.	38 910,00р.
3.6.5	**Желоба Аквасистем**	**м/п**	**88,00**	**794,60р.**	**69 924,80р.**
3.6.6	**Водосточные трубы**	**м/п**	**32,00**	**794,60р.**	**25 427,20р.**
3.6.7	**Огнебиозащита древесины со сдачей пожарному надзору**	**к-т.**	**1,00**	**15 000,00р.**	**15 000,00р.**
3.7	**Внутренние отделочные работы в котельной**	**к-т.**			**146 788,63р.**
3.7.1	**Выравнивающий керамзито-бетонный слой толщиной** 120-20-2-30= **68мм** (120-расст. от уровня перекрытия до ур.чист.пола (отм. 0.00), плитка 20мм, изол 2мм, 30 защитная стяжка)	**м^2**	**7,20**		**18 005,76р.**
	Керамзит	м^3	5,33	1 920,00р.	10 229,76р.
	Раствор М100	м^3	0,50	3 800,00р.	1 915,20р.
	Работа	м^2	7,20	800,00р.	5 760,00р.
	Расходные мат-лы	м^2	7,20	14,00р.	100,80р.
	Накладные расходы				
3.7.2	**Выравнивающая стяжка 30мм**	**м^2**	**7,20**		**5 450,40р.**
	Раствор М100	м^3	0,29	3 800,00р.	1 094,40р.
	Работа	м^2	7,20	600,00р.	4 320,00р.
	Расходные мат-лы	м^2	7,20	5,00р.	36,00р.
	Накладные расходы				
3.7.3	**Защитная обработка стяжки битумным праймером**	**м^2**	**7,20**	**60,00р.**	**432,00р.**
3.7.4	**Оклеечная гидроизоляция в 1 слой с заводом на стены 200мм**	**м^2**	**8,64**	**230,00р.**	**1 987,20р.**
3.7.5	**Штукатурка стен котельных, в т.ч. штробы под дымоход**	**м^2**	**36,30**		**33 214,50р.**
	Раствор М100 толщиной 25мм	м^3	0,91	3 800,00р.	3 448,50р.
	Работа	м^2	36,30	800,00р.	29 040,00р.
	Прочее	м^2	36,30	20,00р.	726,00р.
	Накладные расходы				

3.7.6	**Устройство покрытия пола из керамической плитки отечественного производства**	**м^2**	**7,20**		**12 928,32р.**
	Клей плиточный"Юникс плюс"	меш	3	300,00р.	864,00р.
	Плитка из керамогранита 30х30	м^2	7,92	600,00р.	4 752,00р.
	Затирка швов, наружная	м^2	2,16	52,00р.	112,32р.
	Работа	м^2	7,20	1 000,00р.	7 200,00р.
	Накладные расходы				
3.7.7	**Устройство плитки стен на высоту 15см**	**м^2**	**1,45**	**1 500,00р.**	**2 175,00р.**
3.7.8	**Шпаклевка с покраской стен котельной**	**м^2**	**34,85**		**24 663,07р.**
3.7.8.1	Шпаклевка	м^2	34,85		15 622,98р.
	Грунтовка	л	13,94	90,00р.	1 254,60р.
	Шпаклевка для наружных работ Боларс, расход 1,38/м^2, толщ. 3мм	кг	144,28	7,80р.	1 125,38р.
	Расходные и прочее	м^2	34,85	30,00р.	1 045,50р.
	Работа	м^2	34,85	350,00р.	12 197,50р.
	Накладные				
3.7.8.2	Покраска стен краской ВЭД	м^2	34,85		9 040,09р.
	Краска ВЭД	л	10.46	168,00р.	1 756,44р.
	Расходные и прочее	м^2	34,85	9,00р.	313,65р.
	Работа	м^2	34,85	200,00р.	6 970,00р.
	Накладные				
3.7.9	**Выравнивание потолка котельных ("Бетоноконтакт+Ротбанд")**	**м^2**	**7,20**		**4 861,80р.**
	Грунтовка бетоноконтакт	л	2,88	90,00р.	259,20р.
	Шпаклевка на цементной основе "Основит", толщина 15мм, расход 1кг/м^2 при толщине 1мм	кг	108,00	13,95р.	1 506,60р.
	Расходные и прочее	м^2	7,20	30,00р.	216,00р.
	Работа	м^2	7,20	400,00р.	2 880,00р.
	Накладные расходы				
3.7.10	**Шпаклевка с покраской потолков за два раза**	**м^2**	**7,20**		**6 146,58р.**
3.7.10.1	Шпаклевка	м^2	7,20		3 587,70р.
	Грунтовка	л	2,88	90,00р.	259,20р.
	Шпаклевка для наружных работ Боларс, расход 1,38/м^2, толщ 3мм	кг	29,81	7,80р.	232,50р.
	Расходные и прочее	м^2	7,20	30,00р.	216,00р.

	Работа	$м^2$	*7,20*	*400,00р.*	*2 880,00р.*
	Накладные				
3.7.10.2	*Покраска потолков белой краской ВЭД*	$м^2$	*7,20*		*2 558,88р.*
	Краска ВЭД	*л*	*2,16*	*168,00р.*	*362,88р.*
	Расходные и прочее	$м^2$	*7,20*	*5,00р.*	*36,00р.*
	Работа	$м^2$	*7,20*	*300,00р.*	*2 160,00р.*
	Накладные				
3.7.11	***Отделка откосов двери и окна котельной***	$м^2$	***3,10***		***36 924,00р.***
	Штукатурка откосов ЦПР	$м^2$	*3,10*	*11 000,00р.*	*34 100,00р.*
	Отделка плиткой на высоту 15см	$м^2$	*0,14*	*2 200,00р.*	*308,00р.*
	Шпаклевка с покраской откосов	$м^2$	*2,96*	*850,00р.*	*2 516,00р.*
	Накладные расходы				
3.8	**Кирпичная кладка труб и брандма́уэров, устройство закрытия труб дымоходов**	**к-т.**			**47 910,00р.**
3.8.1	***Отделка труб клинкерной плиткой***	$м^2$	**11,90**	**3 300,00р.**	***39 270,00р.***
3.8.2	***Оцинкованная окрашенная сталь RANNILA - закрытия вентиляционных труб и дымоходов***	$м^2$	**2,40**	**3 600,00р.**	***8 640,00р.***
3.9	**Устройство козырька перголы**				**159 147,50р.**
3.9.1	***Устройство деревянного каркаса из доски 250х30 строганной, клееной.***	$м^3$	**1,10**		***129 597,50р.***
	Работа	$м^2$	*37,00*	*2 000,00р.*	*74 000,00р.*
	Пиломатериал	$м^3$	*1,32*	*24 000,00р.*	*31 680,00р.*
	Скобяные и крепежные изделия (мебельные)	$м^2$	*37,00*	*500,00р.*	*18 500,00р.*
	Антисептирование пиломатериалов хвойных пород "Сенеж"	$м^2$	*98,50*	*55,00р.*	*5 417,50р.*
	Накладные расходы				
3.9.2	***Обработка досок краской "Tikkurilla" в 2-а слоя, в т.ч. грунтовкой***	$м^2$	**98,50**	**300,00р.**	***29 550,00р.***
3.10	**Устройство монолитной лестницы на второй этаж (ширина 1,2м)**	$м^3$	**2,13**		**47 208,24р.**
	Работа	$м^3$	*2,13*	*8 000,00р.*	*17 040,00р.*
	Бетон В25	$м^3$	*2,16*	*4 800,00р.*	*10 377,36р.*