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Innovative Building Materials:
A Report on Oriented Strand Board, Plywood, CO₂
Absorbing Concrete, and Reactive Powder Concrete

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Bachelor of Science, Sustainable Building and Engineering
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The purpose of this report is to investigate what are some emerging building materials which could be of benefit in helping Finland’s Building Environment reach the goals set forth for greener buildings and their construction.

In this report we set forth a definition of what makes a building material sustainable and what is makes such materials either fit or unfit for the Finnish Building Environment.

Our main body of research was divided into four categories: Oriented Strand Board, Plywood Materials, CO₂ Absorbing Concrete, and Reactive Powder Concrete.

Based on the results of our research and we can make a recommend that all four of these materials fit out definition of not only what makes a material sustainable or “Green”, but also that they all four have applications which will be of benefit in the Finnish Building Environment. Most of these products utilize materials that are currently considered to be a waste material and do so in such a way as to provide a product that performs as well as or better than more traditional building materials. This is not to say that we feel these products are able to entirely replace their traditional counterparts, There are still applications where either through cost or requirements, traditional building materials will still provide the needed service in a more efficient manner. However we feel these materials are a step in a greener direction, and ready for use now.
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## Reactive Powder Concrete

### 6.1 What is Reactive Powder Concrete?

### 6.2 Why is it a Sustainable Material?

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1 Introduction

It is well-known that wood and concrete are two very old and basic product of construction environment. Keeping that fact in mind, we have to be aware of that they are improved all the time, and new materials are produced, and the traditional materials are manufactured in different technics to achieve a better quality, strength and environmental and economic impact.

Wood and concrete finishes in existing buildings provide opportunities for physical and psychological benefits and can tap into our biophilic desires, leading to interiors that are often described as warm and homey. In this report we are trying to emphasize some technical facts about these materials, their history and sustainability aspects.

2 What Makes a Material Sustainable

2.1 Sustainable Material

The definition of a sustainable development was set forth by the United Nations in June of 1987 to be as follows.

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.\footnote{1}

To this we would add only this: A sustainable material is one which through the course of its life cycle, provides service to all generations in excess of that which they must put forth to implement it.

2.1.1 Life Cycle

What is the life cycle of a material? This encompasses every single aspect of a material, from its initial removal as a raw material to its creation implementation and eventu-
ally disposal including all costs of transportation involved every step of the way.

![Chart showing life cycle factors](chart.png)

Therefore the lifecycle of many new emerging materials cannot be fully judged at this time as they have not reached the end of their life cycle. How then are we able to judge that the life cycle of these materials is an improvement on existing materials? We are able to make an educated guess based upon the beginning stages of these materials production and implementation. If you are able to produce a material that utilizes waste materials, outperforms existing materials, or both, then you have already bettered the beginning stages of this materials lifecycle. Attention must then be given to the useable lifespan of your material.

![Picture 2. Showing how to judge if the lifespan of your material is an improvement](judging_lifespan.png)
Using these simple guidelines it is quite easy to judge if you have found a material which over the course of its life span proves to be more sustainable than existing materials.

3 Oriented Strand Board

3.1 History of OSB

Although Oriented Strand Boards were invented not so long ago, they are already well-known among construction workers and carpenters all around the world. Many of us can see OSB in hardware stores and might have seen a variety of products from these boards. Some people may actively use OSB, some may not. And only a few know how and when this material was invented.

Oriented strand boards were invented in Canada in the second half of the 1970’s. The birth of OSB technology was a result of development of so called waffle board production. Waffle boards look similar to OSB and are still used in construction in the North America, in a quite lower amount, though. The technology of waffle board production was invented in 1954 by Dr. James D'Arcy Clark. He was a scientist-ecologist and was making a research on a problem of utilisation of low-grade timber in the North-West of USA. The problem was quite acute, as after clearcutting to harvest pine, spruce and larch had a lot of aspen. It was not possible to sell it in that amounts because there was not applicable for production of lumber, or veneer or for cellulose. So it was just left to rot in the woods.

Clark was familiar with the technology of particleboard production. Sohe decided to create a technology that would allow to do wooden boards from aspen. It was necessary for these plates to have a feature and make an interest to the market. The only type of wood-based panels, applicable for construction at that time was plywood made of Douglas fir. The market always had a high demand for it. Clark tried to find a way to make Aspen plates with high strength characteristics, so that they could at least partially replace the plywood. For this purpose it was necessary to maximize the strength of aspen wood fibers. Once Clark was sharpening a pencil and got an idea: "What if I do a chip thin and wide, neatly cutting it off along fibers?" To do this, it was necessary
to upgrade a chipping machine, which was used for CPD production. By that time nobody had ever tried to produce a board from a thin chip only. So, he upgraded the machine so that it produced chips 50mm wide, 70mm long and 0.7-0.8 thick.\(^4\)

In the mid-50s of the 20th century first waffle boards were born. The test results exceeded all expectations. Waffle boards were much stronger than the CPD and could really be used in construction.

Clark’s chief, inspired by the invention, soon built a small plant in Idaho, where he began producing the first waffle boards and selling them to local builders. 7 years later, in 1961, several businessmen from Saskatchewan (province in Canada), who wanted to use cheap aspen, which is abundant in northern Canada, bought the patent from James Clark. A little later, they organized a company "Vicewood Limited", which began producing waffle boards in industrial quantities. Plant for the production of waffle boards was built in Hudson Bay, in the northern forests of Canada. The government, wishing to strengthen the economy of low-income agricultural province, provided the company with an excessive amount of very good quality timber.

However, everything went not as it was planned. Plywood sellers, who felt a threat to their business from cheaper waffle boards, refused to deal with them on the market, so that "Vicewood Limited" soon went bankrupt and the company was sold in 1963 to "Macmillan Bloedel Limited“ – the biggest manufacturer of cellulose, lumber and plywood in Canada.\(^4\)

The "Macmillan Bloedel Limited" had a well-developed marketing system across Canada, as well as ability to conduct all necessary product tests for much-needed construction certificates. This made it possible for the company to start production of waffle boards and successfully start the production. The plant in Saskatchewan, by the way, was equipped with a huge hot press, that allowed to make a board size 1220 × 4880 mm. Press, dryer, chip mixers and a line of molding equipment were modernized from the CPD production line. As a chipboard machine they used modernized chipper, which was more accurate when cutting the chips from wood chocks of 600 mm length. Nevertheless, waffle boards, coming on the market under the brand name "AspenitTM" had good strength and performance, and they were cheaper than plywood. Soon "AspenitTM" boards achieved considerable success and recognition in the market.
In the central Canada "Macmillan Bloedel" promoted "AspenitTM" as a building material for roofing, cladding walls and flooring. Material was actively sold for the construction of storage facilities for various purposes, livestock farms, garages, other buildings. In addition, "AspenitTM" was used in the construction of protective fences, temporary quick-construction, construction of grain storage in the production of packaging, and billboards. The research group of "Macmillan Bloedel" developed a tongue and groove joint boards for siding, concrete work and floor decking. The product quickly gained recognition among architects, engineers, designers and builders. Many builders who have begun to use waferboard in the 60 years of the twentieth century, still buy "AspenitTM" today.

In the mid 1970's the idea of board particles division in different layers, while production of boards, was born. A chip in each of these layers oriented in mutually perpendicular directions. In addition, to improve the strength characteristics of the board, it was decided to change the geometry of the chip. They made it longer and narrower, compared to that was manufactured before. So, gradually, was born the concept of production of a new kind of board materials, that is known nowadays as Oriented Strand Board.

The first plant, that began producing real Oriented Strand Boards, appeared in 1982, although the production of oriented strand waffle boards had already began in the late 70's. In fact, Oriented Strand Boards are waffle boards of the second generation. The first real OSB-board was made in Alberta (Canada) by "Edison OSB" plant, owned by the company "Pelican Somilz Limited". The first product test had shown a result of improvements in technology of physical mechanical characteristics of the new material caught up with the characteristics of softwood plywood. This allowed the "Edison OSB" plant to place OSB in the market as a complete analogue of the plywood and the material of a higher class than the waffle board.
3.2 Production process

The new material was called oriented strand board, because it had a difference from all known wood-based panels: the size of the chip and its orientation in the structure of the board. The chip was long and narrow compared to the chip waffle boards: the average size of the chip was 25 × 150 mm. Each board consisted of three layers. All the chips in a layer were placed parallel to each other and perpendicular to the chip in the neighboring layers. Thanks to the orientation of the chip in each of the layers, the OSB acquired unique properties that soon opened it a range of new applications.

The process of production nowadays has some aspects that need to be mentioned: orienting head of a forming machine for the outer layer of chips looks very similar to the farmer harrows. It consists of a series of circular discs, which direct the falling chips, aligning them parallel to the direction of travel of the chip mat on the conveyor. Orienting head of the inner chip layer is composed of clips in the form of stars with flat blades. Spinning, they align parallel to the width of the chip mat and perpendicular to the direction of the conveyor. Size of the components of orienting head and the distance between them is adjusted to the size of chips. Adjustment is performed so that the chips fall through the revolving wheels or rollers before they make it out of the orienting head.

Layers of oriented strand board are laid down on a moving conveyor sequentially, one after the other. The orientation of the chips in alternate layers as follows: longitudinal, transverse and longitudinal. Each layer is formed by orienting a separate head and spread out forming a separate machine. The accuracy of the orientation of the chips in the process of forming the carpet is a very important issue. This is very significant for a chip of the outer layers. The accuracy of chip orientation in layers directly affects the strength characteristics of the finished product.

A lot of problems for engineers are caused by the task of qualitative resinification of chips before molding. In the manufacture of OSB the same resin is used, that is used in the manufacture of waterproof plywood. But how accurately can you mix the thinnest chips with minimal damage? Thanks to the creative approach the issue was soon resolved. In modern mixer chips with the adhesive resin are sprayed with a rotating
The design of the was borrowed from painting cars. This simple at first glance decision was a breakthrough in resinification process, and allowed not only to reduce damage to the chips, but also significantly reduce the flow of resin. The advent of the first Canadian OSB production caused widespread interest around the world. The research began in Japan and even in China.

3.3 Materials and characteristics

![Oriented strand board sample](image)

As a raw material for waffle board produced by the original Clark's technology, only aspen, harvested in central Canada and northern United States, was used. However, in the late 1970's, when the first waffle board plant occurred in the South of US, they started using pine wood. In the early 80's, when waffle board has turned into OSB, and the consumption of and demand for these boards began to grow rapidly, they started using white birch, maple, amber wood and yellow poplar. They also started using some other hardwoods, but only in small proportions. Canadian factories began to successfully manufacture OSB from larch and white pine in the east. On the west there was built a plant that runned on a mixture of aspen and black pine (Pine Banks). Some manufacturers began to produce strand boards from a mixture of balsam poplar and white birch.  

In the mid 1980’s, when the first factories were opened in Europe - in Scotland and France, they started using the Scottish seaside and pine trees for the manufacture of
OSB. One of the last OSB plants, built in Chile, uses pine Radiata. OSB plants in Asia and Australia are working on the raw materials from the rubber tree and eucalyptus.

3.3.1 OSB classification

There are four kinds of oriented strand boards depending from bending strength and moisture resistance: 5

**OSB-1:**
- The bending strength on the main axis < 20 N/mm²;
- Moisture resistance (swelling in thickness within 24 hours) > 20%;
- Plates are intended for use under conditions of low humidity (furniture, paneling, packaging).

**OSB-2:**
- The bending strength on the main axis 22 N/mm²;
- Moisture resistance (swelling in thickness within 24 hours) is about 20%;
- Plates can be used in the manufacture of load-bearing structures in the dry areas: intended for use in dry conditions.

**OSB 3:**
- The bending strength on the main axis 22 N/mm²;
- Moisture resistance (swelling in thickness within 24 hours) is 15%;
- Plates are to withstand more severe operating modes: the manufacture of load-bearing structures in high humidity.

**OSB 4:**
- The bending strength on the main axis 30 N/mm²;
- Moisture resistance (swelling in thickness within 24 hours) is 12%.
3.3.2 Measurements

Table 1.  Oriented strand board measurements

<table>
<thead>
<tr>
<th>Name</th>
<th>Length x width, mm</th>
<th>Thickness, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSB, Standard</td>
<td>2440 x 1220</td>
<td>6, 35; 9,5; 11; 12; 15; 18; 22</td>
</tr>
<tr>
<td>OSB, Superfinish ECO</td>
<td>2500 x 1250</td>
<td>6; 8; 10; 12; 15; 18; 22</td>
</tr>
</tbody>
</table>

3.4 Use of oriented strand boards in construction nowadays and sustainability

Each year timber-frame construction technology, using OSB, gains popularity for several reasons:
- No shrinkage allows to work over interior design immediately after construction;
- Construction features do not make any restrictions on the design of the house;
- The use of modern insulating materials lowers the price in comparison with traditionally built houses;
- The speed of timber-frame house construction makes it possible to build all year-round.

According to experts opinion, OSB is not produced in Finland, it’s all imported. The reason is not only economical. The production process leads to formaldehyde and xylitol emissions into the environment. Ecology became the main factor that stopped the construction of many OSB production factories in the design stage in Russia. Following all ecological standards makes domestic production more expensive than import. On the other side, new technologies make it possible to use polyurethane resin for the chip bonding, which means an absence of harmful to health formaldehyde and an opportunity to use OSB not only for construction, but also for finishing.

The main sustainable feature of the material, as it was mentioned before, is that it uses inapplicable chips, left after clear-cutting tree trunks.

3.5 Future aspects
Experts predict a great future for OSB. In New Zealand there is a research institute for development of new wood composites. Oriented strand composites are assigned to be one of the most promising areas. Currently being developed, in the nearest future there will be an increase in use of OSB for the furniture industry, the door industry, particularly stressed building structures, etc. So-called on-line quality control systems are developed. They will allow to test all the volume of production in real time. And finally, in matters of production and resinification chips, the accuracy of its orientation when forming a mat, and pressing the mat there is still enough room for the research work.

Very soon new oriented strand materials will be able to compete with all known structural and non-structural board wooden materials.

4 Plywood Materials

4.1 Plywood

Plywood is a wood-based panel, which has at the same time a very good mechanical strength, and a light weight. It is a type of manufactured timber made from thin sheets of wood veneer and one of the most widely used wood products. It is flexible, inexpensive, workable, re-usable, and can usually be locally manufactured. Plywood is used instead of plain wood because of its resistance to cracking, shrinkage, and twisting/warping, and its general high degree of strength.

The earliest occurrence of plywood was in ancient Egypt around 3500 BC, when wooden goods were produced from sawn veneers glued together in a crosswise pattern. Today, plywood is manufactured by peeling logs on a rotary lathe, the inventor of which was Immanuel Nobel, a 19th Century Swedish inventor, engineer, architect, investor and industrialist, whose brother Alfred, founded the Nobel Prizes. Nobel realized that several thinner layers of wood bonded together would be stronger than one single thick layer of wood In commercial terms, plywood came into its own from the 1930’s onwards, following advances in adhesive technology.
4.2 Advantages of Plywood

- Saving of wood: waste is confined to the small core and bark that remain after peeling away the strips.
- Strength: Generally speaking, wood is more strong (about 24-25 times stronger) along the grains than across the grain. In plywood, the alternate layers are at 90° to each other. This ensures that the weight per weight, plywood is stronger than wood.
- Reduced shrinkage, swelling and warping: The balanced construction of plywood (with the grain direction of adjacent plies at 90° to each other) equalizes cross layer stress. This in turn reduces shrinkage, swelling and warping.
- Compared to solid wood, the chief advantages of plywood are that the properties along the length of the panel are more nearly equal to properties along the width.
- Plywood offers greater resistance to splitting.
- Plywood can be molded into different shapes and sizes.
- Improved utilization of wood - plywood can cover large areas with a minimum amount of wood fiber.
- Plywood has high strength-to-weight and strength-to-thickness ratios.
- The stiffness and strength of plywood is more equal in length and width than that of solid wood.
• Plywood makes an excellent choice for users that call for fasteners to be placed very near the edges of a panel because of its alternating grain direction that significantly reduces splitting.
• Plywood comes in convenient sizes.²

Picture 5. There could be any material added between the layers or the Plywood could be coated with any other preserving material. (by Deniz Löktas 2012)

4.3 Cross Laminated Timber

If we are talking about Plywood, we have to talk about Cross Laminated Timber, so called X-Lam, too. The idea they are produced are the same, layers of wood panels glued on and on each other.

X-Lam is made by gluing wooden boards in a 90 degrees crossed way (like a plywood panel but with plies thick as much as 2 cm). It has been invented 12 years ago in Germany and soon developed in Austria. Compensating the physical-mechanical behavior of wood on two cross dimensions, it is possible to obtain wooden panels almost indestructible, with an excellent and suitable mechanical behavior. Simply genial.¹⁰

In fact, X-Lam panels are extremely strong and stiff, considering their low density; they are also quite easy to process and to assembly with ordinary tools; the quick erection of solid and durable structures – even in seismic areas – is possible even for non-highly-
skilled manpower. The good thermal insulation and a fairly good behavior in case of fire are added benefits deriving from the massive wood structure.

4.4 The Carbon Footprint of Plywood

The Finnish company UPM’s plywood brand WISA, has published the carbon footprint of their product in 2010.

"WISA plywood’s carbon footprint from forest to finished product has now been established. One cubic metre of softwood plywood generates 80–150 kg and, correspondingly, one cubic metre of birch plywood 130–400 kg of fossil carbon dioxide emissions depending on the mill in question. On the other hand, plywood acts as a carbon reservoir which sequesters more carbon than is incurred in its production. One cubic metre of softwood plywood sequesters on average 800 kg of carbon and one cubic metre of birch plywood 1,070 kg.

The model of the Confederation of European Paper Industries (CEPI) – the same as that used to calculate the carbon footprint of UPM’s paper grades – has been applied in calculating the carbon footprint of plywood. Only the mill-specific carbon footprint of uncoated standard plywood has been calculated so far. The footprint has been calcu-
lated from forest to mill gate, and therefore emissions arising from transportation to customers are not included.

The carbon profile of plywood has been calculated according to the amount of carbon sequestered in the product itself. Fossil CO2 emissions arising from plywood production and from the manufacture and transportation of raw materials, and from raw materials other than wood-based ones, for example, adhesives are included. The energy consumed in production is included as well.

The carbon footprint of plywood arises mainly from fossil CO2 emissions from energy used in the manufacturing process. Another significant addition is caused by emissions other than those from wood-based raw material production.¹¹

4.5 The Sustainability of Forests

The most important raw material for plywood is a renewable natural resource - wood.¹² So, the sustainability of the world forests must be taken care very seriously. Greenpeace Organisation has a very serious report on illegal plywood and forest destruction products sold in UK. There could be found:

“Demand for tropical hardwood plywood in the UK and internationally is one of the main causes of illegal and destructive logging in the rainforests of countries such as Brazil and Indonesia. This deforestation is causing the loss of biodiversity, displacing local communities and contributing to climate change.

There are no laws yet in place to prevent illegal timber from entering Europe. As a result, large quantities of illegally logged timber still make their way into the UK. The construction industry is the biggest consumer of timber in the country which is why it is vital for contractors, architects and builders to source timber from environmentally and socially responsible sources such as those certified by the Forest Stewardship Council (FSC).¹³
P-5: A Greenpeace campaigner watches as plywood is loaded on to a Maltese bulk carrier, The Greveno, anchored near the mouth of Lamandau River, on the west side of Tanjung Puting National Park, Kalimantan. (http://www.greenpeace.org/international/Global/international/planet-2/image/2004/2/a-greenpeace-campaigner-watch.jpg)

4.6 Fire Performance and Today’s Uses of Plywood

Although plywood burns it can have better fire resistance than many materials which do not burn. Plywood has an optimal dimensional stability under heat and a low rate of combustion, better than solid wood.

The temperature at which plywood will ignite when exposed to a naked flame is about 270°C whilst a temperature of over 400°C is needed to cause spontaneous combustion. When exposed to a fully developed fire, plywood chars at a slow and predictable linear rate (about 0.6 mm per minute), which enables it to be used in certain fire resisting constructions. This property can be improved by impregnation or coating the plywood with proprietary formulations or by facing with non-combustible foils.14

Plywood can be used in a lot of purposes for construction but also for some other uses.
Examples of end uses:

- kitchen cabinets, door mirrors
- partition walls, sight screens
- furniture parts
- sound insulation latticework
- toys, souvenirs, cards
- models
- musical instruments
- interiors
- saddles
- icehockey sticks

In some structures, plywood is used for sound insulation. Sound is transmitted through air and through structures. Airborne sound insulation is dependent on the density of the insulating material. Plywood is a good insulating material in relation to its weight. For these reasons plywood is a good material for acoustic improvement solutions.

4.7 Emission of formaldehyde

Formaldehyde emission from phenol formaldehyde resin adhesive bonded plywood is very low and measured values are below even the tightest national requirements in Finland. When determined according to EN 717-2, the formaldehyde emission from unsurfaced exterior birch plywood is 0.4 mg HCHO/(m²·h), significantly lower than the requirements of class E1 (the best class). Also Finnish plywood meets requirements of the formaldehyde emission limits of EN 1084, release class A (the best class).

4.8 The Most Innovative Ways of Using Plywood

Today, out of the typical uses like walls and floors, plywood is mostly used for making noise barriers nearby the highways, with special claddings against moisture. But there is a very interesting experiment conducted by Professor Ario Ceccotti, Civil Engineer, Prof. of Structural Engineering, from University of Venice. He designed an X-Lam 7 storey building for seismic safety and tested it in Japan in 2007.

Test results have confirmed that X-Lam building is a self-centering construction system that can be safely and easily designed against earthquakes to avoid not only loss of
lives but also loss of property, according to the rules anticipated by CNR-IVALSA (National Research Council of Italy).12

Some similar researches are made in USA by National Science Foundation, under the name of NEESWood.

4.9 Conclusions

Plywood is definitely a good material when it is produced with good requirement elements up to where it will be used. It has advantages and disadvantages compared to concrete but for low-storey construction and some special parts of the building, it is a very good material. But the construction sector is in the beginning of everything, the wood has been started to be considered as a strong contrition material for the last decades in today’s modern construction sector, except the low-storey family housing. The most important point in this concept is to show people how wood is a good material and it has a long life period. This technology will continue to improve as it has been and will be a very popular material in future.

4.10 Interviews

JO UNI KALLIOMÄKI: Head of Structural Engineering, MSc Metropolia University of Applied Sciences, Degree Programme in Civil Engineering
ERIC POLLOCK: Lecturer and Coordinator, Sustainable Building Engineering, Lecturer Metropolia University of Applied Sciences
LARS OSTENFELD RIEMANN: Group Market Director, Buildings at Ramboll

*How can you use plywood to make more sustainable buildings?
JO UNI KALLIOMÄKI: Plywood is not the best for structure. For manufacturing, it needs more heat and that requires more energy.
ERIC POLLOCK: More than plywood, first I have to say that wood is used because the production requires less energy and wood is a carbon sink. Less energy to erect, to use and it is nontoxic except if it is not glued. There are some problems, as 2 mains, Moisture and fire. Moisture is solved with using a covering material. Fire is solved with gypsum board cover.
LARS OSTENFELD RIEMANN: Plywood should be used everywhere in a building where it suits the purpose better than other materials. This could be as structural components where plywood is feasible as shear plates, facades structures, roof structures and internal walls.

*If you compare plywood to concrete?*
JK: Easier to apply, cut, manufacture. Concrete is a very heavy material.
EP: A benefit of concrete is fireproof. Also it is possible to use the viscosity to give shapes. The quality of it is high. Acoustic and light is good. ABOUT wood, the compression is good. Also it is light in weight. But tension is not good. In the direction of grain, it is very weak. Wood has a direction, concrete not.
LOR: Concrete structures have advantages to timber in terms of fire resistance, acoustic damping and strength. However timber structures can be designed to fulfill all such requirements so at the end of the day it is a question of choosing the option that has the lowest costs taking into account a number of other factors such as architecture, weather conditions, environment, deflection limits, skills of the contractors etc.

*What about the CO2 footprints?*
EP: For wood, it is much much less. Concrete requires 1600 degrees used producing cement. Wood is a perfect carbon sink.
LOR: Unless you choose to emit a lot of CO2 in fabrication, transportation and installation the Carbon Footprint of Plywood would normally be positive as you help removing CO2 from the atmosphere by using and thereby storing plywood in building structures.

*What about their lifecycle?*
JK: Under the maintenance, it might be even 100 years too.
EP: WE do not know so well. IT is up to the maintenance program. In Finland, it is guaranteed by law that you should present your maintenance program when you have a building project.

*What kind of maintenance does it need?*
JK: The most important thing is to keep them dry. It also should be used in the right places. It is also a very good material for wind barriers.
EP: The maintenance starts already in the beginning. Changes in moisture, deflection, rusting in the steel, all the structural maintenance are needed concerning these. Wood structures are good to renew several times easily. In future we will have more knowledge because the wood buildings are made now and in use.

LOR: Depending on very you use it. Any maintenance is dictated by the environment especially the water and humidity. Outside usage limits any maintenance lifetime to very few years, which is not the most feasible way to use plywood. For such environment other materials should be considered. For inside usage plywood requires almost no maintenance and has unlimited lifetime.

*In the final of the lifelong period, what is done with plywood? Is it burnt or recycled into some other material?
JK: It is reusable material and sometimes even more stronger than the newer material.
EP: After the demolition, the beams could be used low storey contruction or pedestrian bridges. They should be used again because if it is burnt, the carbon will be released. Availability of the source is important also.


What can you say about the most innovative ways of using plywood?
JK: First of all the most traditional ways are floors and walls, furnitures, building truck backs, boats if waterproof etc. The most innovative I saw is an earthquake research made by an Italian professor Ario Ceccotti, they made a 7 storey wood building and tested in Japan.
EP: Outer facades using is very new for wood materials.

5 CO₂ Absorbing Concrete

5.1 Introduction

Concrete is the most widely used building material in the world because of its beauty, strength and durability, among other benefits. Concrete is used in nearly every type of
construction, including homes, buildings, roads, bridges, airports and subways, just to name a few. And in an era of increased attention on the environmental impact of construction, concrete performs well when compared to other building materials. As with any building product, production of concrete and its ingredients does require energy that in turn results in the generation of carbon dioxide, or CO2. The amount of CO2 produced during manufacturing and the net impact of using concrete as a building material is relatively small. The following features of concrete construction help minimize its carbon footprint:

- Concrete is resource efficient and the ingredients require little processing.
- Most materials for concrete are acquired and manufactured locally which minimizes transportation energy.
- Concrete building systems combine insulation with high thermal mass and low air infiltration to make homes and buildings more energy efficient.
- Concrete has a long service life for buildings and transportation infrastructure, thereby increasing the period between reconstruction, repair and maintenance and the associated environmental impact.
- Concrete, when used as pavement or exterior cladding, helps minimize the urban heat island effect thus reducing the energy required to heat and cool our homes and buildings.
- Concrete incorporates recycled industrial byproducts such as fly ash, slag and silica fume which helps reduce embodied energy, carbon footprint and quantity of land filled materials.
- Concrete absorbs CO2 throughout its lifetime through a process called carbonation, helping reduce its carbon footprint.

5.2 Concrete manufacturing

Cement is made by heating limestone and other raw materials to 1400 – 1450 °C in a rotary kiln. Fossil fuels such as coal and oil have usually been used to provide heat for the burning process. In the process, limestone (CaCO3) first breaks down to calcium oxide (CaO) and carbon dioxide (CO2). CaO then further reacts to form the “portland clinker.” The clinker is ground with a small amount of gypsum into a product (i.e., cement). Some types of cement also include other constituents in addition to clinker and gypsum, such as limestone filler, ground granulated blast furnace slag, fly ash, or other
mineral by-products from industrial processes. The most important environmental effects of cement production are the use of energy (fossil fuel and electricity), emission of carbon dioxide, and the use of natural raw materials (mainly limestone). The manufacture of cement requires about 4 GJ of energy per ton of finished produce and the about 1 ton of CO2 emissions per ton of cement. The worldwide production of cement accounts for almost 7 percent of the total world CO2 emissions\textsuperscript{18}. Since the early 90’s, the cement industry has made major strides in reducing energy consumption by some 20\%\textsuperscript{19}. This has been achieved primarily by placing wet production facilities with modern dry-processing plants. Modernization of cement plants and machinery has decreased the electricity consumption during milling of cement, with consequent reduction of CO2 emission from power plants. Using certain wastes as alternative fuels in the cement kiln eliminate wastes that would otherwise be incinerated or land filled. Waste materials that the cement industry has used as alternative fuels include petroleum coke, used tires, rubber, paper waste, waste oils, sewage sludge, plastics, and spent solvent. Apart from recovering the thermal energy of the waste, this leads to significant reductions in the emissions of CO2. As an example, up to 20\% of the total thermal energy requirement at a New Zealand’s cement factory has been routinely replaced by the used oil, making possible a very significant reduction in the consumption of non-renewable coal\textsuperscript{20}. Supplementary cementing material (SCM) including waste products from other industries, such as fly ash and ground granulated blast furnace slag, can be ground with clinker to produce blended cement. Increasing the use of SCM, and thus reducing the cement content, represents a technically-proven approach to reducing greenhouse gas and air pollutant emission. Limestone filler is being increasingly used in Europe in the clinkering and grinding phases of Portland cement production\textsuperscript{21}. These materials also have the added advantages of reducing energy consumption, using materials otherwise destined for landfill, and increasing plant capacity without installing new kilns, and improved concrete performance.

5.3 Use of supplementary cementing materials

Supplementary cementing material (SCM), such as fly ash, ground-granulated blast-furnace (GGBF) slag, or silica fume, is one of the most sustainable construction materials because it
• Recovers an industrial byproduct through beneficial use when incorporated into concrete,
• Avoids disposal of industrial byproducts,
• Reduces Portland cement content in concrete, resulting in decreased emission of greenhouse gas and decreased use of natural raw materials, and
• Increases structure service life by improving the durability of concrete.

The current annual production of fly ash is on the order of 900 million tons worldwide, with major production occurring in China, India, and the U. S.$^{21}$. The use rate and the way fly ash is batched in concrete vary from country to country. One of the major developments in the area of fly ash utilization in concrete has been the technology of high performance, high-volume fly ash concrete$^{22,23}$. Studies have shown that, when the water-cementitious materials ratio (w/cm) is maintained at 0.30 or less in the superplasticized concrete mixtures, up to 60 percent of portland cement can be replaced by ASTM Class F or Class C fly ash to obtain excellent long-term mechanical and durability properties$^{23}$. Table 1 shows an example mixture proportion for a high-volume fly ash (HVFA) concrete.

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Cement</td>
<td>150 kg/m$^3$</td>
</tr>
<tr>
<td>Fly Ash (ASTM Type F)</td>
<td>200 kg/m$^3$</td>
</tr>
<tr>
<td>Water</td>
<td>102 kg/m$^3$</td>
</tr>
<tr>
<td>Coarse Aggregates</td>
<td>1220 kg/m$^3$</td>
</tr>
<tr>
<td>Fine Aggregates</td>
<td>810 kg/m$^3$</td>
</tr>
<tr>
<td>Super-plasticizer</td>
<td>7 L/m$^3$</td>
</tr>
<tr>
<td>W/CM</td>
<td>0.29</td>
</tr>
</tbody>
</table>

Table 2. Mixture proportion for a high volume fly ash concrete$^{24}$

The compressive strengths of this HVFA mixture were 8, 55, and 80 MPa at 1, 28, and 182 days, respectively. Extensive laboratory tests$^{23}$ concluded that the Young’s modulus of elasticity, creep, drying shrinkage, and freezing and thawing characteristics of HVFA concrete are comparable to normal portland cement concrete. The HVFA concrete also has high resistance to water permeation and chloride-ion penetration. An-
other by-product that is useful for cement substitution is ground-granulated blast-furnace (GGBF) slag. Although the world production of this slag is approximately 100 million tons per year, only approximately 25 million tons of slag are processed into the granulated form that has the cementitious properties\textsuperscript{25}. Because GGBF slag is derived as a by-product from the blast-furnaces manufacturing iron, its use has environmental benefits. The use of GGBF slag in concrete significantly reduces the risk of damages caused by alkali-silica reaction, provides higher resistance to chloride ingress, reduces the risk of reinforcement corrosion, and provides high resistance to attacks by sulfate and other chemicals. The use of GGBF slag in concrete has increased in recent years and this trend is expected to continue. Laboratory work by Lang and Geiseler\textsuperscript{26} on a German blast furnace slag cement (405 m\textsuperscript{2}/kg specific surface area) containing 77.8 percent slag showed that excellent mechanical and durability characteristics were achieved in super-plasticized concrete mixtures with 455 kg/m\textsuperscript{3} cement content and 0.28 w/cm. The compressive strengths at ages 1, 2, 7, and 28 days were 13, 37, 58, and 91 MPa, respectively. The concrete also showed good resistance to carbonation, penetration of organic liquids, freezing and thawing cycles (without air entrainment), and salt scaling. Approximately 5 million tons of GGBF slag were used in concrete mixtures annually in Taiwan. Up to 55\% of the portland cement (ASTM Type V) had been replaced by GGBF slag in concrete mixtures where high sulfate resistance is required. In the moderate sulfate resistance applications, 45\% of portland cement (ASTM Type II) can be replaced by GGBF slag with excellent performance. Concrete containing 45-50\% of GGBF slag was commonly used for concrete slurry wall constructions in Taiwan. Silica fume is a by-product resulting from the reduction of high-purity quartz with coal or coke and wood chips in an electric arc furnace during the production of silicon metal or ferrosilicon alloys. The condensed silica fume contains between 85 and 98 percent silicon dioxide and consists of extremely fine spherical glassy particles (the average particle size is less than 0.1\textmu m). Because of its extreme fineness and high silicon dioxide content, condensed silica fume is a very efficient pozzolanic material. The worldwide production of silica fume is estimated to be about 2 million tons\textsuperscript{21}. Because of limited availability and the current high price relative to portland cement and other pozzolans or slag, silica fume is being used primarily as a property enhancing material\textsuperscript{22}. In this role, silica fume has been used to provide concrete with very high compressive strength or with very high level of durability or both. It has been used to
produce concretes with reduced permeability for applications such as parking structures and bridge decks and for repair of abrasion damaged hydraulic structures. One of the major barriers against the use of large quantities of fly ash and other supplementary cementing materials in concrete is the current prescriptive-type of specifications and codes. The prescriptive-type of specifications generally place limits on the maximum percentage of the cement that can be replaced by the supplementary cementing materials. For example, in U.S. ACI 318 Building Code limits the maximum percentage of fly ash or other pozzolans to not exceed 25% of the total cementitious materials by mass for concrete exposed to deicing chemicals. High performance concrete mixtures being produced with HVFA concrete prove that prescriptive specifications hinder the widespread use of fly ash and other supplementary cementing materials. Replacing the prescriptive-type of specifications and codes with performance-based specifications and codes will accelerate the rate of utilization of fly ash and other supplementary cementing materials and can provide economic and environmental benefits.

5.4 Utilization of concrete wastes

It is estimated that 1 billion tons of construction and demolition (C&D) waste are generated annually worldwide. Whether C&D waste originates from clearing operations after natural disasters (e.g., major earthquakes) or from human-controlled activities, the utilization of such waste by recycling can provide economic and environmental benefits. In recent years, utilizing C&D waste for new construction through recycling and reuse has received increased attention throughout the world, especially in the European countries, Japan, U. S., and Taiwan. Practical and economic experiences from Japan and Denmark suggest that road base and sub-base materials are expected to be the most important area of use of C&D waste. When used for such purposes, C&D waste (primarily of broken concrete, bricks, and stone) can substitute for up to 20% of the consumption of natural sand, gravel, and crushed stone, thereby saving natural resources. At present, more than 95% of C&D waste is being recycled and used mainly as road base material in Japan. Recycled concrete has also been used as partial replacement of coarse aggregate for the concrete structures and concrete pavements. For example, 35% of the coarse aggregate was replaced with recycled concrete aggregate for the cast in-place concrete for all foundations and 50% of the basement walls and columns in a new high school outside Oslo. Extensive testing of hardened
concrete properties indicated that they were comparable to all natural aggregate concrete. The use of recycled concrete aggregate did not cause any noticeable increase in cracking and other durability problems\textsuperscript{19}. Since the 1990s, other by-products have been successfully used in concrete. These materials include used foundry sand and cupola slag from metal-casting industries, post-consumer glass, wood ash from pulp mills, sawmills, and wood-product manufacturing industries, sludge from primary clarifiers at pulp and paper mills, and de-inking solids from paper-recycling companies\textsuperscript{30,31}. Although recycled concrete aggregate has been successfully used as road base and fill material and as aggregate in new concrete, a significant amount of C&D waste is still disposed of in landfills. However, the future outlook for recycling concrete is favorable because the local natural aggregate sources and the suitable landfill sites for industrial waste are becoming scarce. Furthermore, improvements in demolition, processing, and handling technologies will improve the quality and decrease the cost of recycled concrete aggregates.

6 Reactive Powder Concrete

6.1 What is Reactive Powder Concrete?

Reactive Powder Concrete (RPC), also known as Ultra High Performance Concrete is one of a number of cement based building materials that have emerged in the last two decades. Its creation is credited to the French Bouygues laboratory in the early 1990’s and has since been used in an increasing number of applications around the globe.

Picture 7. Electron micrograph of silica fume.
RPC is defined as a concrete mixture whose density is maximized through the utilization of a precise gradation of all particles in the mix. It differs however from standard concrete in the size of the particles used. RPC contains sand with a diameter between 100 to 600 µm (.1 - .6 mm) in place of the larger aggregates used in standard concrete, these standardly being between 10-20mm in diameter, and where standard concrete mixtures use sand, RPC goes even finer still, using silica fume with an average diameter of only .5µm (5 x 10^{-4} mm) as illustrated in Picture 7. The result of this is a concrete that is far denser than can be achieved otherwise.

This higher density results in a product which can easily achieve compressive strengths of 200 MPa and in certain cases have tested as high as 800 MPa. This high compressive strength, in comparison with the standard 50-100 MPa of high-performance concrete, enables RPC to carry loads equal to those required of today’s high performance and standard concrete mixtures with a much smaller profile, meaning less product used. Reinforcing material is also used in RPC; however it also is orders of magnitude smaller than that used in traditional concrete structures. Steel fibers with a diameter of only 200 µm (.2 mm) and a maximum length between 11-15 mm are placed within the concrete at the time of mixing. These reinforcing fibers allow the material to not only achieve a tensile strength between 6 – 13 MPa, but to maintain this after its first cracking. This in comparison to the strength of 2-4 MPa found in standard concretes which is lost after first cracking occurs.

Such incredible strengths can be increased even farther though when this concrete is being used in pre-cast modular construction. The addition of silica fume to the concrete mixture already has added curing benefits as it means the concrete is less prone to creep as it is setting. This concrete actually begins to set before all before bleed water from the mixture even begins to evaporate though, this not only gives you a quick setting mixture, but one which cures much faster, in some applications it can even be opened to light traffic the very next day. However when being used as a pre-cast construction material there is far more control over the curing process allowing far better and faster results. (See Picture 8)
It has been claimed that when pre-stressed (cured under high temperature steam in a pressurized environment) this material can reach compressive strengths of up to 800 MPa. However tests have been performed which have proven the effects this curing process has and its ability to reach strengths in excess of 200 MPa (See Figure 9). Such pre-stressed modular components can be made smaller than standard concrete structures, reducing the amount of material used and increasing the structural and architectural possibilities as well as the amount of useable space within building built of such modular components.
None of this comes without an increase in cost though; after all standard concrete prices have doubled in the last decade and not will continue to do so with the rising costs of fuel and energy used to produce this product. RPC is created with a variety of highly specific and exactly sized materials so it is not a large surprise that its per yard cost comes in at an average of 5 to 10 times the cost of a yard of standard concrete. So with such a disparity of cost why are we interested in this material? What makes this a truly sustainable material and not simply a novelty item?

6.2 Why is it a Sustainable Material?

To start with it is possible to produce RPC form simple poured concrete applications with existing manufacturing facilities; it requires no change to existing infrastructure or equipment. This means that with the same carbon footprint for transportation and implementation as standard concrete you are achieving a much better product. How a better product? The increased density of RPC makes it far more durable than standard concrete or eve High Performance concrete. Denser material is less susceptible to penetration by moisture, meaning that reinforcing fibers retain their strength over the course of the materials use. Less moisture in the material means that it is less susceptible freeze and thaw conditions, as well as being less prone to explosive spalling in

Picture 9. Chart showing the Performance of RPC products.
high heat or fire situations. With its greater strength and density RPC is able to perform the same jobs as standard concrete or even steel with a much smaller curing and processing time. (See Figure 10)

This product maintains a structural density that it has in some cases been tested to have an impact absorption rate comparable to its steel counterparts. It is even able to withstand the corrosive effects of acid, and penetration by radioactive particles. Finally RPC provides us a valuable service in that it allows us to dispose of a waste material that otherwise must be cared for and disposed of in a carefully controlled energy intensive manner. Silica Fume has been long a byproduct of the making of silicon metal and ferro-silicon alloys, originally this waste byproduct was simply vented into the atmosphere, however as awareness grew of the impact on the environment stricter and stricter controls were emplaced regarding its disposal. Using Silica Fume in the creation of RPC not only disposes of this waste but in fact turns it into a saleable product.

Picture 10. Photo showing RPC beams with beams of other materials and comparable strength.
6.3 What are its Projected Uses?

RPC has many possible uses in the Construction field, its incredible strength means that it can be used to shore up or patch existing structures with only thin layers of material being added to previous construction, this means that many structures can continue to be reused as they are without the expensive costs of demolition and disposal shortening their life cycles. As a structural support it has many advantages, pushing the boundaries of what Concrete as a building material can accomplish. Consider the photos below.

![Picture 11. Photos showing the Sherbrook footbridge](image)

These are photos of the Sherbrook, Canada pedestrian and cycle bridge, All supporting structures which are visible in these photos are made from pre-cast, pre-stressed concrete sections, the decking surface of the bridge is a traditional pre cast waffle structure, but measures only one inch thick. This concrete bridge is sturdy enough to resist not only the harsh weather climates of the Canadian winter but also the abrasions of salt and other deicers used upon it. Finally RPC is dense enough to be used in the disposal of hazardous wastes, including acids and nuclear power station waste, and unlike standard concrete, it can be formed into a single material container of small enough size to be easily transported, and modified to meet future environmental standards.

In short, Reactive Powder concrete is an innovative building material of the future, its high cost mean that it is not suitable for all applications, however when it is the correct material for the job, it can be trusted to still be doing that job, long after standard cement materials have reached the end of their life cycles.
7 Conclusions

In conclusion we would like to recommend that all four of these materials would be useful in advancing of the sustainability of the Finnish building environment. Each material possesses applications in which it outperforms traditional or standard building materials. It is our feeling that by encouraging usage of these materials in projects her in Finland it will be easier to not only meet the future requirements for buildings in Finland, but to surpass them. As we are looking forward to new projects and goals we must remember our definition of what is sustainability, fulfilling the requirements of the Finland of today, without hampering the ability of the Finland of Tomorrow.
8 References


2. Figure 1. Chart showing life cycle factors. (UK Centre for Materials Education[homepage on the Internet].[updated 7 May 2012, cited 7 May 2012]. Available from: http://www.materials.ac.uk/guides/environmental.asp

3. Figure 2. Hierarchy Chart showing how to judge a sustainable material (Created by Authors)


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