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12. Do We Really Design Façades For The Life Cycle?

12.1 Introduction: The evolution of the building skin

The industrial revolution both induced changes in the earth's climate as the prosperity of the western world: in retrospect a conflicting development. The increasing prosperity and technical knowledge over the last two centuries, is clearly reflected in the success of façade engineering. Various requirements ask for specific material properties, in addition the performance of the facade becomes more complex every day. The building skin functions as a buffer between interior and exterior. Undesirable effects by the ever changing exterior, are blocked, filtered or transmitted to provide the user with a comfortable interior climate. The effects are grouped by their relating comfort criterion, amongst it are the thermal, hygienic, acoustic and visual comfort. The difficulty for these criteria is that each user has a different definition of comfort. Therefore, the legislation that strives for maximum overall user satisfaction offers band widths for the designer to strive for. The attention lately, is on the importance of the building's energy performance and sustainable materialization. Both criteria must not be seen as separate requirements, they cover all conditions. In general, façade engineers, strive for a minimum of energy consumption during the façade's operation to minimize costs. This aspect is recently viewed from another perspective, namely sustainability. A good energy performance can contribute to smaller emissions. This criterion is not so much one that stands on itself, but needs to be seen in combination of the other criteria. The same applies to the efficient materialization, in order to avoid a high environmental impact. Thermal criteria Surrounding surfaces influence a room temperature by convection and radiation. The thermal insulation value (U-value) of the façade is a major factor within the process of convection and radiation of the inner surface of the façade. A low U-value attends to small thermal transmittance through the façade, resulting in small fluctuations of the inner surface temperature. Façade parameters or components that regulate the thermal comfort are insulation, active heating and cooling, sun shading devices and so on.

12.2. Façade parameters

1. Visual criteria: Although a maximum inlet of light to the exterior is preferred, blocking unpleasant light effects is needed as well, e.g. direct sunlight, glare and overheating. The g-value should be as low as possible in summer to reduce heat load, however a high value can offer pleasant additional warmth in winter. The daylight factor defines the amount of natural light that enters the interior via the façade. The parameters that regulation the façade´s parameters are transparency, sun shading devices (fixed and flexible), light directing systems.

2. Hygienic criteria: High CO_2 levels increase discomfort. Good circulation of air increases the comfort and can be achieved by mechanical or natural means.
   This is a fact to consider at the base of the design phase. Façade parameters or components that regulate the hygienic comfort are natural ventilation (gap and window ventilation) and mechanical ventilation (by centralized systems or de-centralized units).

3. Acoustic criteria: Noise from the exterior can be an annoying factor within the interior. The source can be traffic related, from a building site, however sound from the interior is sometimes experienced as unpleasant as well. Exterior noise can be reflected on the façade or absorbed by a high mass or sound insulating material. Internal noise can be absorbed or reflected by the inner surface of the façade.

4. Safety criteria: Amongst the safety criteria are the structural requirements and the fire safety requirements. The load bearing function in curtain walls is reduced to bearing the façade’s dead weight and the wind load. Conventional construction materials are timber, steel, aluminium and plastics in curtain walls (light weight facades) and brickwork, concrete and lime stone for solid, load bearing facades.

12.3 Now and the future

Conventional definitions of the building skin do not always suffice to describe the use of contemporary facades. Lang explains in The Building skin, that the façade is a system through which prevailing external conditions can be influenced and regulated to meet the comfort requirements of the user inside the building. External conditions might differ more in the future than they do now on a day to day basis. However, this does not imply that the comfort requirements set today should not be sufficient by then. A contemporary phenomenon is seen, that the emphasis is not so much on a building to suit the material used, but on the impact a particular building material creates, its material and visual qualities. Therefore the building skin mainly turns into a medium for the architect to express. By means of the current techniques, any material can be applied as an effective skin. Can this, however, still be approved upon when resources are scarce? **Perhaps it is time to return to a more functionalistic approach**, where materials are used more carefully without compromising on user comfort and transparency. A second trend, induced by the attention on sustainability, is energy performance. The main objective is often to decrease the use of (expensive) non-renewable energy sources, both in a passive way (e.g. thermal insulation) as an active way. The changes in technology, user requirements and fashion tend to come and go faster every day. This implies a need for a large degree of flexibility in order for the building skin to adapt.

It is hard to foresee what the future will bring; therefore it is impossible and arrogant to make decisions now that will narrow down the possibilities for future world citizens. In my opinion the most important guidelines can be abstracted in the fig. 1. It all starts with an intention to not harm the environment and the future creating any build object. This is the base of the pyramid to build on and it is continued along the entire design and building process. Approaching the pyramid's top, the design is becoming more and more detailed. After displaying the problem, there should be no discussion that changing our ways is a must to guarantee a future. However we should become conscious of the fact that this does not stand for a compromise in today's luxury.
After all, in principle a building can never be sustainable when there is actually no need for. Therefore this question always has to be posed up front: "Do we really need to build this at all? Do we really design for the Life Cycle?"

12.4 Minimize environmental impact

The top of the pyramid represents the design phase with the highest detail and focuses on minimizing the environmental impact of the façade. Environmental impact being primary energy and primary emissions, especially caused by the materialisation of the façade, is preferably relatively low or beneficial to the environment. An example of the latter is the carbon dioxide storing capacity of timber. It is actually the main topic of this thesis and can be achieved by two means: either minimizing the amount of materials or using materials with low environmental impact. Usually the correct method lies in the middle. As the environmental impact has a linear relation to the amount of mass used, it is best to keep the amount of materials used as small as possible. Therefore small components out of low density materials are preferred. But also smart engineered shapes instead of standard sizes or over dimensioning can initially bring down the environmental load. Using customized components has to be seen in perspective with the use of standard components. Although it has become fairly easy to produce customized components due to CAD and computer aided production, the benefit of the overall availability of standard components, must always be kept in mind. Finally substitution of high impact materials with low impact materials is an option to minimize the environmental load. However not all materials are suitable for all applications, and using a low impact material can have an adverse effect on the weight of the construction and the total environmental impact. Especially in facade engineering the line between good and bad materials is extremely blurry as the state-of-the-art facade's (energy) performance is often dependent on the materialisation.

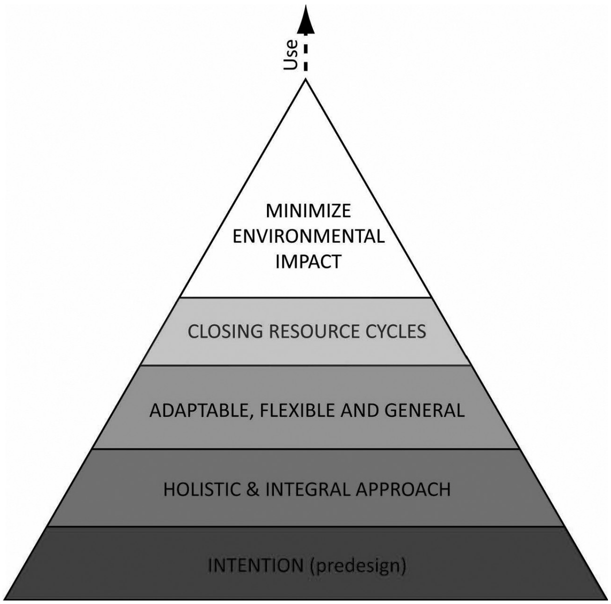

Figure 12-1: Design phase pyramid

12.5 Façade Materials in general

The materials discussed here are the most used façade construction and cladding materials, therefore materials like rammed earth and bamboo are not included. Sustainable materials must be drawn from a source that is renewable, either because it grows as fast as we use it or because it reverts to its original state on natural decay and does so in an acceptable time span. For this to be true, the resource and the material must form part of a cycle of the natural world: closed loops that run at steady state, recycling the elements N and C and the compound H_2O such that the resource remains constant. The above applies to the part of the pyramid on closing resource cycles, however in this chapter I want to discuss the ability to minimize environmental impact by choosing materials that benefit it, especially by the influence of the absolute environmental impact of materials.

12.6 Façade components: glass Curtain Wall

Design of glass curtain wall (CW) systems has long been under the influence of structural, thermal and daylighting performance requirements as well as cost and aesthetic concerns. However, environmental life-cycle impacts of the systems are usually ignored when selecting the suitable materials for mullions and glazing units. This paper intends to examine the effect of mullion material change on the environmental impacts of a typical CW system over its life-cycle. The mullion materials studied in this paper include extruded aluminum, carbon steel and glulam timber.

The environmental impact categories of interest include global warming, acidification, eutrophication and human toxicity. In addition, the paper applies a process-based Attritional Life Cycle Assessment (LCA) technique to achieve its objectives. According to the results of this study, an extruded aluminum CW system contributes most to the environmental impact categories of interest in this research while a glulam timber CW makes the least contribution. Contribution of steel CW systems falls in-between.

12.7 Facades in contemporary building

Construction industry needs to evaluate its environmental impacts and take actions in order to reduce them through the development and implementation of green practices. Glass curtain wall (CW) systems occupy huge areas of the facades in contemporary commercial buildings. Their mullions are made of a variety of materials including extruded aluminum, carbon steel and glued laminated timber (glulam). While aluminum is used for most CWs and in buildings of various heights, glulam timber can be used in CWs of low-rise buildings. Steel is preferred in high-rise buildings, even though it can be used in low and middle-rise buildings too. The key objective of this lecture is to outline a life cycle inventory model for a typical CW system, under different scenarios of mullion materials (aluminum, steel and glulam timber), and study how change in mullion material can impact the environmental performance of the entire CW system. To do this, the inventory model is outlined based on the goal and scope of the LCA study. Subsequently, the contributions of each scenario to the environmental impact categories are assessed. The impact categories studied in this paper are global warming, acidification, eutrophication and human toxicity. Finally, the LCA results are interpreted and discussed.

1. Timber: The application of timber in buildings has been known for a long time, both in the western world as other civilizations thanks to its remarkable combination of properties: it is light (compared to its weight, timber is 50 % stronger than steel), cheap and strong and easy to work with. Knowledge on using the material and its restrictions is therefore widely available. These restrictions include for example different strength and shrink parallel to the grain and transverse to it. In this project the most important properties are embodied energy and CO_2 emission. These properties are amongst the lowest of all available construction materials: the embodied energy by means of harvest and production are often outweighed by the energy it contains when timber is combusted.

2. Brick and fired clay products: The energy consumption for producing these products is very high and consequently, when using fossil fuels, the emission of GHGs is evident. Especially a lot of oil-based energy is used to dry the unfired brick before firing. The required temperature is very low, which means that solar energy and recovered waste heat form the kilns could be used as well. Perforated hollow products require relatively low amounts of energy, as do products with biomass. Remarkably, bricks for inferior use, like inner leaf brick walls, could do with medium fired components, therefore energy saving is simple to achieve. Energy consumption is also related to transportation and the weight of the products. However, this type of products is overall found to be very durable. Most clay building waste is inert, except for brick and ceramics that are coloured with pigments containing heavy metals. Treating bricks to improve durability must therefore always be related to the environmental impact. To be able to recycle a clay product Portland cement

mortar must be avoided in advance, since it causes that the components cannot be separated. The same accounts for strong glue binders.

3. Metals: The energy consumption for the extraction and refining of metals from ore is very high. Once used metals cause relatively few environmental problems except for particles that are washed off when exposed to water. As waste products metals release quantities of particles into the soil and surface water, which is irreversible as metals do not decompose. Metals can be divided into benign (little polluting), polluting and very polluting metals, concerning being exposed to these metals. This does not concern the pollution by extraction or refining. Amongst the benign metals are iron, aluminium, magnesium and titanium. The polluting metals are chrome, nickel, copper and zinc. The very polluting metals include cadmium and lead. As for all building materials surface treatment makes it more difficult to recycle, for instance stainless steel. But mechanically fixed steel and aluminium building components can easily be disassembled and reused when the surface is treated as well. Steel in concrete is hard to recover. It is considered easier to recover pure metals in the raw material cycle than alloys. Steel and aluminium alloys can only be used for similar alloy products, whereas copper, nickel and tin can be completely reclaimed from alloys in which they are the main component. Iron ore can be found equally spread over the world and extraction often causes deforestation, erosion, affects the groundwater and ecosystem. One ton of ore produces 5 to 6 tons of waste materials. Stainless steel must be used efficiently to justify its higher environmental costs, exploiting its high strength and corrosion resistance. Aluminium ore can mainly be found in Brazil, Surinam and Venezuela. This means, using it in Europe the share of transportation energy is fairly large in the total energy consumption. Recycling aluminium by melting it in order to make new products only uses up to 7 % of the energy used making the aluminium form ore. Although the waste it is made from has to be pure. The ratio bauxite to aluminium is 4 to 1. Copper is very toxic to water and soil. Copper ores are mainly found in the Congo, Zimbabwe, Canada, the US and Chile, however the reserves are limited. Still, it is a popular building material for its corrosion resistance and corresponding green patina.

4. Glass: The reserves of the raw materials for glass are rich: soda, limestone and silicon. Glass can be recycled by re-melting without high costs, clear glass can use up to 50 % recycled glass. Coloured glass can be difficult to recycle and it must be cleaned of all impurities first. Laminated glass and glass with metal films cannot be recycled as window glass at all. All types can be ground to use for instance as aggregates in concrete. The most important environmental factors are the high energy consumption in production and the related energy pollution. Glass does not produce pollution in use.
   In general the more actions needed to produce a building component, the higher the environmental impact will be. This is true for laminated and low-e glass that originates from ordinary float glass. Especially glass is a building material that deserves thorough consideration when designing a façade.
   It is considered to be essential to design a façade that has a high degree of transparency.
   Unfortunately, glass is known to be an inefficient cladding material concerning its thermal resistivity. In summer the interior enclosed by glass tends to warm up very fast and in winter it cools down very quickly.

Several glass producers continuously try to reinvent glass, in order to get the optimum ratio between transparency and thermal control. An example is the low-emission glass that prevents sunlight from heating up the interior and heat form the interior from radiating to the exterior, however the embodied energy is consequently higher and the ability to recycle lower. This is a great example that shows the importance of a holistic design attitude.

5. Plastics: The plastics used in the construction industry are generally low-density non-load-bearing materials. Unlike metals, they are not subject to corrosion, but they may be degraded by direct sunlight, with a corresponding reduction in mechanical strength. Processing of oil to plastics requires a great deal of energy, with intensity similar to that of the metal industries.
   When used in buildings they release volatile organic compounds either as direct emissions or through chemical reactions during use. Let's observe several plastics that are frequently used in building skins: Silicone elastomers, used int.al. for sealing in structural glazing facades, PE, used as vapour barrier, ETFE, used in pneumatic constructions as air cushions, and polycarbonate, commonly used in safety glazing.

12.8 Goal and Scope Definition

The functional unit (FU) of a CW is to safely support the loads imposed on a typical glass CW system, with thermal break. A CW system is to enclose part of a building (low & high rise). Since it is assumed that CW systems are designed with thermal break, the energy gains or losses through curtain wall mullions would be ideally zero. Figure 12-2, 12-3 and 12-4 illustrate the system boundaries for each CW system scenario.

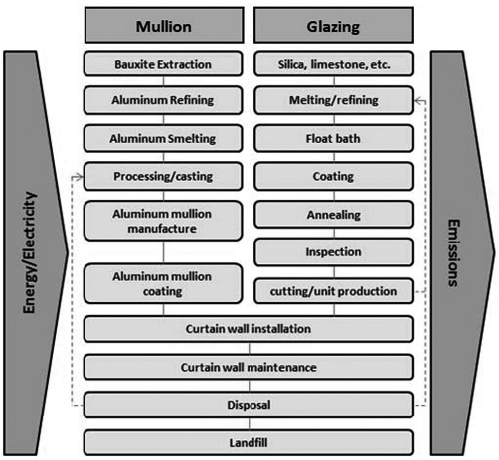

Figure 12-2: System boundaries for CW with aluminum mullions

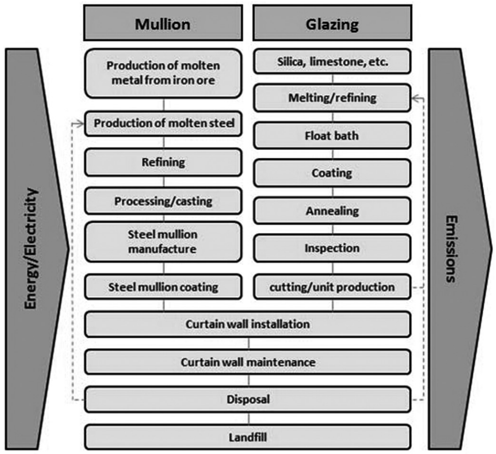

Figure 12-3: System boundaries for CW with steel mullions

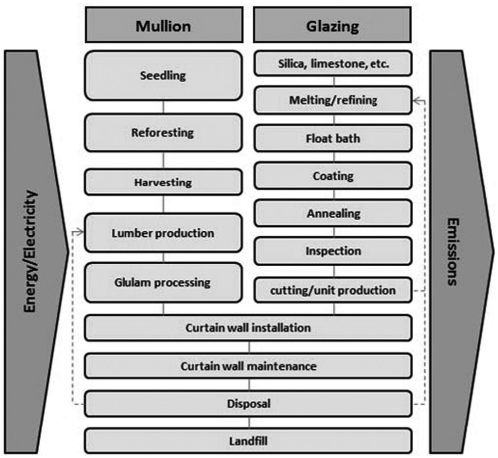

Figure 12-4: System boundaries for CW with timber (glulam) mullions

12.9 Thermal insulation

The thermal performance of facades is highly dependent upon the insulation materials used. Most of them can be considered as plastics, as they are oil-based, however there are variants that are bio-based. The embodied energy is very much dependent on the production of these materials, as they are much lighter compared to other building products. However the production is centralized and therefore the transportation does have significant input in the total energy consumption and related pollution.

12.10 Assumptions

The assumptions regarding transportation and electricity are two other important assumption categories in an LCA study. Transportation from raw material extraction phase through manufacturing process to installation at the site location was assumed be diesel-powered combination truck. The distances were estimated based on the closest manufacturer to the site location and return of the truck from the site to landfill. Also, the type (based on the fuel used in electricity generation) and quantity of electricity used at various phases in system boundaries were assumed to represent the EU average data for steel and aluminum and EU data for glulam timber. This assumption was made based on the location where materials are produced and based on the availability of data.

12.11 Interpretation of the LCA Results

Contribution to Global Warming

Contribution of greenhouse gasses to global warming is measured by Global Warming Potential (GWP). GWP is measured in carbon dioxide equivalents. The impact assessment results for CW scenarios and their comparison show that the CW system with aluminum mullion makes the largest contribution to global warming, among the three CW systems (Figure 12-5). This has to do with high levels of energy consumption and thus, emissions in the process of aluminum manufacturing. The results (Figure 12-5) also show that glulam timber CW makes the least contribution to global warming among the three systems. However, this contribution is just slightly lower than that of a steel CW. One might expect GWP of glulam timber mullions to be much lower than that of steel mullions. However, considering the fact that the mass of glulam timber mullions is 9 % greater than that of steel mullions in order to do the same functional unit in the CW system of this study, the results would make sense. According to the results, a glulam CW system, even with 9 % higher mass of timber mullions, still contributes about 0.5 % less to global warming than a steel CW system. The results also depict that global warming potential in all CW systems is mainly caused by carbon dioxide emissions followed by methane (Figure 12-5).

Contribution to Acidification and Eutrophication

Contribution to acidification, Acidification Potential (AP), is measured in sulfur dioxide equivalents In addition, Eutrophication Potential (EP) is measured in phosphate-equivalents The comparison of the results show that, similar to the pattern of differences in global warming potentials among the CW systems, acidification and eutrophication potentials of CW system with aluminum mullions are the highest among the three CW systems (Figures 12-6 and 12-7). The glulam timber CW causes the lowest acidification and eutrophication potentials, closely followed by the steel CW. Also, the impact assessment results show that sulfur oxides are the largest contributors to acidification potentials in all CW systems, followed by nitrogen oxides (Figure 12-6). Eutrophication potential in all three CW systems is resulted from nitrogen oxides (Figure 12-7).

Contribution to Human Toxicity

Human toxicity, which is caused by environmental and occupational exposure of humans to poisonous substances , is quantified by human toxicity potential which is a dimensionless measure of the contribution of a substance to human toxicity . The impact assessment results show that aluminum CW contributes the most to human toxicity, followed by the steel and glulam timber CW systems (Figure 12-8). Nitrogen oxides are the main drivers of human toxicity in an aluminum CW while barium emissions are the largest contributor to human toxicity potential in steel and glulam timber CW systems.

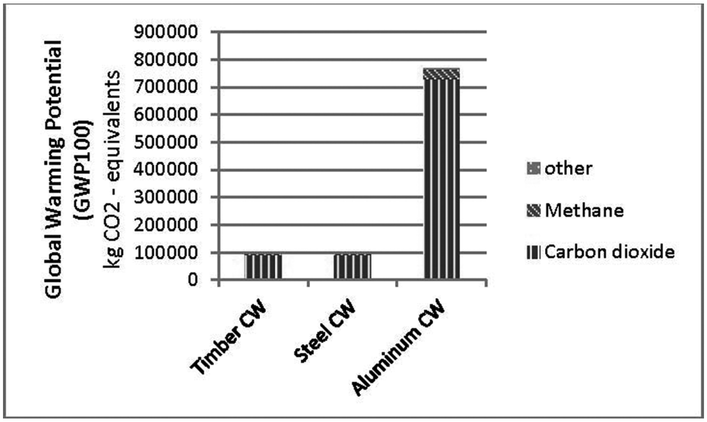

Figure 12-5: Contribution to global warming

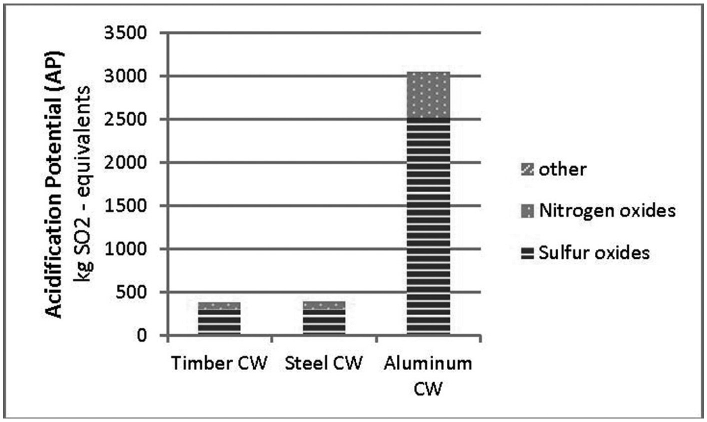

Figure 12-6: Contribution to acidification

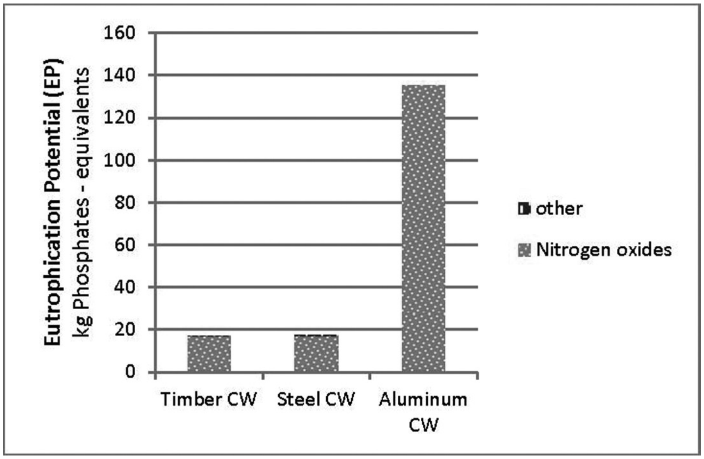

Figure 12-7: Contribution to eutrophication

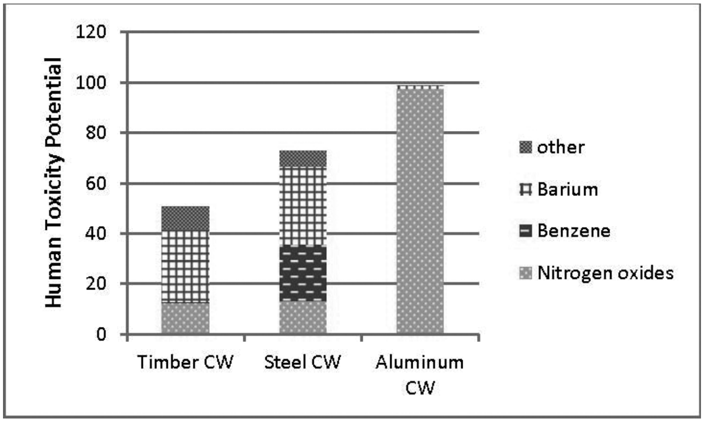

Figure 12-8: Contribution to human toxicity potential

12.12 Results and discussion on the influence of the construction

Load bearing facades with 50 % transparency

Using glass in a concrete and brickwork wall as opposed to not using glass, must be considered as a good thing to do when minimizing the GWP. The scores of both constructions radically change from not using glass to using glass. For all the other construction this effect is considerably smaller, although one would think using glass in an all timber construction would make a difference. I think there are two lessons to be learned from this: concrete and brickwork walls have an extremely high carbon emission and the scores of the frame constructions with glass infill are not valid.

Non-load bearing facades
The scores of this group, curtain walls without glass, differs 7,5 kg CO_2 eq. in absolute sense with the group with glass. In my opinion the assessment without glass gives a clearer image of the impact of the construction types, therefore the transparent group is not shown. The relatively lowest score is found using a fir frame, in this case a low score benefits the environmental impact.

The average of the GWP is 205 kg CO_2 eq./m^2, several façade constructions score better than that, that is they have a smaller GWP. For the opaque frame constructions, the timber frame is preferred over the steel frame.
The timber curtain wall system complies with the energy regulations. Again, the use of timber is the reason for the high score that is a low GWP. Timber is extremely useful in a P&B construction, as it has a low environmental impact, the right thermal properties and strength when used properly. Pneumatic constructions with ETFE cushions: The low environmental impact of the materials of these constructions related to the relatively high impact of glass, offers options to replace one with the other. A similarity between all facades that score good, is the use of a frame work (either visible or not) and a light weight cladding or transparent area. The double facades all score worse than the average of 205 kg CO_2 eq./m^2. It is striking to see that the double facades account for more than the GWP of the single curtain walls. This means that a double facade has more environmental load than two curtain walls and an energy performance calculation can offer insight to assess whether the high burden is justified compared to the energy performance and materialization of a single wall solution. Compared to the other double facades; the construction with an ETFE skin scores good. This fact opens perspectives: it might be an efficient solution, both for energy performance as materialization, in other situations too. The material with a bad score every time is aluminium. All facades with high mass of aluminium have a high environmental impact.

An important characteristic of aluminium is its durability: an aluminium window frame can do without extra maintenance over a minimum of 50 years. This is different from using a timber window frame, especially one from European timber that needs paintjobs every five years. What we can do is designing low impact façade components that are adaptable to future needs in a basic framework that is fixed and durable lasting up to 80 or more years. Consequently, such a basic framework will have a high, and in this research referred to as adverse, environmental impact. But this is justified by the extensive use of these components.

12.13 Conclusion: Curtain wall, cladding, windows

Curtain Wall
Using aluminum in CW systems provides a lighter structure compared to steel and glulam timber CW systems but, at the same time, causes the largest damages to the environment (global warming, acidification and eutrophication) and human health (human toxicity). On the other hand, glulam timbers create a heavier structure compared to aluminum and steel CWs of the same functional unit, but impact the environment and human health the least. The only drawback in the application of glulam timbers as CW mullion is their unsuitableness to be used in middle and high-rise buildings.

Steel as a CW mullion material falls in-between which makes it a good choice to be used at middle and high-rise buildings. There were several limitations in this study which future research is recommended to focus on. Firstly, a comprehensive life-cycle analysis should be based on the triple-bottom approach which considers not only the environmental impacts but also economic and social ones.

A GWP benchmark for the various façade types:

Opaque facades	10 kg CO_2 eq/m^2
Curtain walls	160 kg CO_2 eq/m^2
Double facades	400 (second skin glass) or 200 kg CO_2 eq/m^2
Pneumatic skins	40 kg CO_2 eq/m^2

Cladding

In general, the **timber based claddings** score the best. The highest scoring timber based cladding does not exceed the GWP of the lowest scoring of the metal based claddings and only one type of the mineral and polymer based claddings. The reason for this high score of timber based claddings is the GWP per kg. Timber actively stores carbon dioxide during its' growth phase and does not release it until the timber is combusted. The cladding with the lowest, i.e. best, score is the fir plywood cladding. Compared to the metal, mineral based and polymer claddings, no cladding in the timber based group needs discouragement for use. **The second best claddings** are found amongst the mineral and polymer based claddings. The average GWP within this group is 29 kg CO_2 eq./m^2 more than 4 times the GWP of the average timber based cladding. The average in the mineral and polymer based claddings is influenced extremely by the granite cladding. The reason for the high GWP of this cladding compared to other materials in this group, is the high mass granite has. The transport emissions therefore have a large share in the total GWP of granite and other stone claddings, for instance slate, are preferred.

The third group represents the metal based claddings. As discussed metals generally have a high GWP per mass and this is reflected in these results.

The average GWP of this group is 60 kg CO_2 eq./m^2, twice the amount of the average mineral and polymer based cladding and 10 times the average of the timber claddings. For sustainability requirements it is therefore not advised to use metal based claddings. However the best score in this group is coated and profiled steel.

It is preferred to use profiled metal claddings over flat metal claddings because the profiles allow the claddings to be executed lighter. It is for the benefit of the environmental impact of the façade not advised to use a non profiled coated aluminium cladding. Timber based claddings have the best score for GWP. Metal based claddings score relatively bad overall. The timber in the claddings should be sustainably produced, i.e. in sustainably controlled forests close to the building site (for European building sites, these are forests in Europe). However metal claddings are not preferred for the environmental impact, if ever, profiled metal cladding should be used instead of non-profiled, as this decreases the need of thick metal sheets and therefore reduces the weight of the panel. The best metal option is profiled steel.

Windows

Several researches have been conducted on environmental impacts of window systems and their frame materials. Citherlet et al (2000) studied the environmental impacts of window systems with different frame materials including wood, plywood, aluminum, PVC, wood-aluminum, plywood-aluminum, and concluded that aluminum frames contribute most to global warming and acidification, due to high levels of energy consumption during their production. Salazar and Sowlati (2008) in another study examined PVC, aluminum-clad wood and fiberglass as window frames and found out that PVC frames consume most energy over their life cycle and cause the largest environmental damages to the respiratory inorganics, acidification and global warming, compared with other frame materials.

12.14 Recommendations

The main result is that the use of a durable frame construction must be encouraged. If any kind of thermal capacity is wanted in an office building for energy performance reasons, this must be achieved primarily by the main load bearing construction for the environmental impact of the facade is kept small using a light weight construction. The façade's base construction must be designed to be reusable or recyclable in the end of course. The best way to minimize environmental impact is always to minimize the use of materials and this accounts for timber based materials just as well. For the environmental impact of the materialization it is not preferred to use aluminium at all, however in some cases the use aluminium is justified by other requirements. Transparent facades benefit from timber constructions and a light weight transparent area like ETFE foils instead of glass. Generally the largest components contribute highly to the total façade's GWP. In the end, the impact can be influenced by using the right material in the right proportions and the importance of good detailing

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