# Sustainable construction

"Less bad is not good enough"

(McDonough & Braungart, 2003)

Ivan Baartmans

P5 report

2013

Delft University of Technology

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# Preface

This is the result of the final research conducted within the Master Real Estate & Housing, specializing in Design & Construction Management, at the Faculty of Architecture of the Technical University of Delft.

In light of the construction management theory at the university and the many diverse pieces of literature and the rather low impact of all the measures in practice, has made me think about the construction process in depth. A building is unique, no argument made however construction includes various processes that are the same. I have always wanted to know why a construction process can only improve due to construction management and not in a different manner. In light of the crisis and the impact the construction industry has on the environment, together with the growing importance of sustainability made me think about a new way of viewing the construction process.

This has made me look at the construction process in depth and also look at a manner to define sustainable construction and the current construction process. The fact that sustainable construction is possible but not achieved has formed the bases to investigate the obstacles for sustainable construction but also how to achieve sustainable construction. Together with an analysis tool these models designed for this research are usable for the industry to achieve sustainable construction and be a front-runner in the world.

This past year I worked with a lot of enthusiasm, ambition and joy towards the result of this research work. The result would be impossible to have come about without the help of a few people, whom I particularly would like to warmly thank.

First of all, my thanks to my immediate supervisors from University: Alijd Doorn and Aad van der Horst. Alijd, thanks for your confidence in this research, your enthusiasm about the subject and the results, critical eye were necessary, and professional knowledge. Aad, thanks for your time, confidence in the research, teaching me so much about interview analysis, the professional and critical eye on the research. You both have encouraged me to raise the level every time. I have always considered is as a very valuable experience. I would also like my colleagues from BAM Utiliteitsbouw. Special thanks for ir J. (Joep) Radermacher and R. (Renee) Sterken for their genuine interest in the subject and facilitating the research at BAM and for the time, energy, confrontational and instructive conversations. The organization has inspired me to look at the research in a somewhat different perspective improving it every time.

I would also like to thank all the experts, which took the time to meet for an interview and provide their perspective and opinion on the subject. Knowing the tight schedules these experts have, the value of you opinion and perspective are of great value for this research. I hope this research contributes towards all you work and that together we can achieve sustainable construction.

Furthermore, my thanks to Chloë Baartmans and Richard Verschuren. They gave me some linguistic advice, despite their busy work schedules.

Special thanks to Stephanie Duijverman and my family for their support during this research!

**Ivan Baartmans**
Leiden, 04-12-2012

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# Management Summary

This summary will provide a brief overview of the research design and the motivation for this research project. Together with the description of the results the conclusions are formulated, followed by the research recommendations.

**Motivation and problem analysis**

The construction styles all over the world have fascinated me. Having lived twelve years of my life in third world countries has taught me that these people live in housing that we (in western countries) would not want to live in. The interesting aspect is that these countries still construct their homes in a manner which is uninfluenced by the industrial revolution. During my recent vacation to Kenya, I noticed that most homes there were built from clay bricks reinforced by wood. What is striking about this is that the building materials come from the nearby environment so that there is barely any need for transportation. The construction of these houses has almost no impact on the environment; there is no transportation and industry needed to produce materials. Together with the fact that the materials can be reabsorbed by the earth shows us that this is a very sustainable manner of constructing. One could argue that before the industrial revolution people constructed houses in exactly the same manner. This poses various questions to why we construct in the manner we do now.

With currently a large number of phases in the construction process and a diverse investigation of previous graduates of the sustainability of these phases and researchers, we can conclude that there is still a lot to be investigated and researched on how we can construct in a sustainable manner while keeping the quality of living we currently have. There are problems in the construction phase with the realization of the ambitions for sustainable products. It can be said that sustainability is of importance. People are using it as marketing tool or as an ideology, but achievement of true sustainability is not yet taking place. Sustainability is older than various people think. Since the publications of the club of Rome and Brundtland we know it is of importance. Many tools for helping to achieve sustainability have not yet provided the result necessary because they only assess the final product and do not help achieve the process. The achievement of sustainability lies within the process of construction and will need to be researched.

Thereby the construction process is a well known process but not yet visualized in the form of a flow model to assess how sustainability can fit into this process. The sustainability know mainly focuses on the assessment of the products delivered from this process: buildings. The construction industry, on the contrary, has not yet expressed the need to visualize this process (Koskela, 2000). There are various methods that explain how to deal with the construction process, however, only in project management perspectives (G. M. Winch, 2011).

The impact of the construction activities is a portion of the total impact we as humans have on the environment. This total impact on the environment is incorporated in the term sustainable development. Construction can be of great importance to contribute to the overall sustainable development. The corporate social responsibility is becoming increasingly important in the industry and for a start for sustainable construction. This is not enough. Sustainability is often lost in a project environment where money and time play a more prominent role. This means that sustainable construction which does not cost more than the traditional construction will have the future. This is due to the fact that it is not depending on other factors which involve value creation and that EMVI criteria, which value sustainability, still incorporate extra costs. We have been talking about sustainable construction since the club of rome and are still not doing so. We are not achieving sustainable construction. We know what needs to be done but cannot achieve this. The sustainable construction process is often not defined clearly and is dependent on the commercial incentives.

**Goals and results**

The goal of this research is to find out what sustainable construction is and why we are not constructing our buildings in a sustainable manner. This will provide insights on what strengths and weaknesses the current construction process incorporates together with the external threats and opportunities it reacts upon. The next step is defining a sustainable construction process that possesses the strength to overcome threats and utilize the potential of opportunities provided by external factors. An example is that the defined sustainable construction is always the best option and not dependable on external factors like EMVI criteria that virtually reduces the tendered costs in order to be awarded a project.

The result of this research will be a method or tool which contractors can use to analyze their main current process of construction in order achieve sustainable construction. This model, together with a manual, will be a result of this research, allowing actors to optimize their processes towards sustainable construction and knowing the obstacles of the current construction process.

**Research questions & Methodology**

The problem analysis has lead to the following main research question: 'How can a sustainable construction process be defined and how can the sustainable construction process be achieved?' This question contains various sub-research questions which consists of different parts, namely:

1. Defining a relationship between elements in a sustainable construction process
2. Assessing obstacles sustainable construction
3. Achieving sustainable construction

The research goal is to define sustainable construction and conduct research on how to achieve this goal. The goal of an engineer (Dym & Little, 2004), who wants to design a solution for a problem and the solution is defining sustainable construction, in this case the problem is that sustainable construction is not defined.

For the first part, the first step will be to take a look at the full pallet of elements in the construction industry and technology. The next step is to design a system that visualizes the relations between elements of construction and the sustainable construction. This design will be tested in practice by interviewing particle experts in the field of construction to see whether the theoretical model is applicable in practice. In order to test the design's applicability in the real world process model will be tested by taking a certain element of the construction process and testing if it is applicable in the real world through case study analysis. This will provide the current and desirable situation in the research design below.

The second part will look at the answers provided by the experts on what they believe are the strengths and weaknesses of the current construction process and what threats and opportunities influence this process in order to assess what obstacles (weaknesses influencing threats or weaknesses preventing opportunities) are there for achieving sustainable construction.

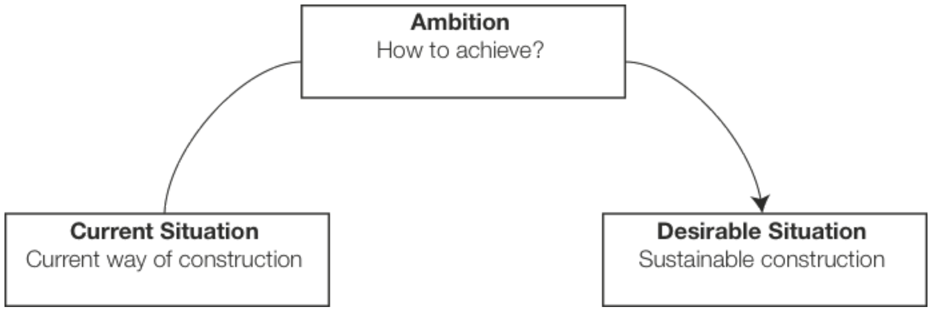



**Figure 0 - 1**: Research design

The research design shown above, has been used to structure the research done in this report. It is often used in the change management theory of Cameron & Green (2012). The first step in this theory is to define the current and future situation and then to assess how to achieve this. The same has been done in this research, but complimentary to this an analysis tool will be provided to work towards the desirable situation because achievement takes time. In the meantime, optimizing the process with a tool will help in in providing the solution that is sought in this research.

Through use of literature studies combined with expert interviews and case study analysis, the answers must be obtained. The defining of the current and future situation will be done through process design and conduction of literature studies. The assessment on obstacles on achieving sustainable construction will be done through expert interviews. The last part of optimizing towards sustainable construction will make use of a case study analysis to go in-depth on the subject.

**The construction process**

The construction process as we know it has existed for a large period of time. There is a rich history on the construction process that dates back to the large structures built before Christ, like the pyramids. The construction process has evolved from the building of huts with wood, stone and clay, towards the housing you are in while reading this report. History shows us that since the industrial revolution the processing needed to make materials and transport al over the world, impacted the world with the carbon emissions and pollutions from factories and power plants. The energy and oil demand increased tremendously. This shows us that the process stayed the same and is about the assembly of materials on-site.

There are also various definitions of the construction process. Various books often describe the manner of working during this process or relate their definition towards the end product (often a building). The definition of Sarkar & Saraswati (2008) was the one that really looked at the process:

> *"Construction technology is the application of applied sciences in order to enhance productivity and quality of its products, The nature of the **construction activities** (performed by **labor**) involves, the **place** where construction work is to be carried out and the **time** available for construction work are the four factors that determine the effective construction process"*
>
> *(Sarkar & Saraswati, 2008)*

This formed the basis for the design for the construction process flow model. By designing the model based on the literature read during the literature study, the design came to being. This means that it changed a lot and also needed styling in order to be communicated. Together with the expert interviews and other conversations in the field of construction management, the following became the result of this work. The figure on the right shows the construction process in a manner that is representable for the 2013 construction process with all the supplier industries and aspects related to the process. The model is built up from five main layers. These will be discussed briefly and substantiated by some literature in order to make the design of the model insightful:

1. The first layer in the model is the arrow in the middle. This represents the main **construction activities** with the different phases of construction. This takes place on-site indicating the aspect of **place.** The **time** taken is visible in the sequential order of the activities.
2. The second aspect is the actors (**labor**) that are involved in the process. These actors are often in relation to one another and the form of this relation is dependent on the contracting form. In this example the design and construct contracting form is illustrated.
3. The third aspect is the resources that are needed to construct. During construction the labor force assembles the materials in the form of the design. These materials have come from being mined from the earth towards a material useful in current construction. This raw materials is transformed to the material in different phases of manufacturing and processing.
4. The fourth section is the process input that helps the labor force in assembly and also involve the transportation aspect. The energy and water usage during the material and construction process is also included for the whole process, including supply chain.
5. The last aspect is the product of construction and the wastage of materials, energy, carbon emissions and pollution, summarized as process output.

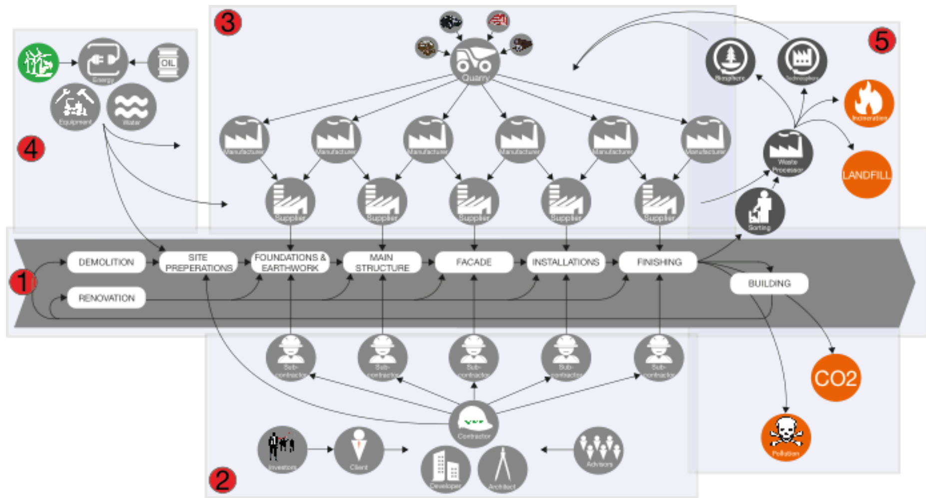



**Figure 0 - 2**: Construction process

**The sustainable construction process**

The design of the sustainable construction process is derived from a specific scope on sustainability. For this research the philosophy of Cradle-2-cradle and industrial ecology are used as basis for this thinking. The basis of these philosophies is that they look at the processes in a cycle nature. Together with a clear definition defined by the expert interviews this definition will also form the basis for the design of the sustainable construction process:

> *'Sustainable construction is construction that does not impact the environment (**planet**) and **people**, while making a **profit**'*

This research will focus on the planet aspect of sustainable construction and will define this in the model. Profitability and people will be looked at if this is essential in the achievement of sustainable construction. Together with several tools and other methods this will be made practical in the model. The basis of thinking in a circular economy is the Ladder of Lansink (1979). This forms the basis for the three main steps that need to be taken in the ladder in order to achieve sustainable construction; recycling, reuse and reduce. The last steps of the ladder are not part of sustainable construction because materials are lost forever and in the Cradle-2-cradle philosophy waste equals food.

1. Recycling is currently already being done; the financial incentive is there because recycled materials are in some cases more profitable than new materials. The products of the recycling process are secondary raw materials that in time should replace new materials quarried, thereby keeping the materials once used (as input) in a construction process. Urban mining involves the mining of vacant buildings that possess various secondary raw materials that will replace the new mined primary materials.
2. The step or reuse can occur in different levels, at the level of systems, sub-systems, elements and components. The last is also referred to as down cycling (recycling) because it degrades a system to a component and then upgrades it to a system again, thereby needing more energy while carbon emission is taking place. The next level is to reuse elements like floors, parts of a facade or a sub-system of the whole facade. The reuse of energy in this diagram has been visualized by the using the buildings and viewing them as small energy plants that have a over supply of energy, thereby solving the energy shortages (Rifkin, 2011).
3. Reduction involves all actors in the supply chain to reduce the demand for process inputs and to reduce the output impact they have on the environment. The construction industry itself can then reduce the materials needed and thereby reduce the impact of the project. The impact on the world will also be reduced because less materials means less assembly, manufacturing and mining. This is the most effective way of reducing impacts but the fact that there is a limit to reduction because a building needs to be made up of materials in order to perform a function. Therefore the lean methodology, focussing on reducing the wastage in processes, can prove to work effectively in the process model by stating that all actors need to look at their process and reduce wastage. This methodology impacts the process in an effective manner that should also make it more efficient and cost-worthy.

These steps have been visualized in the colors of the ladder of Lansink steps. This model also shows the cyclic nature and that it is self-sustaining. The definition and methodologies are all represented in the model.

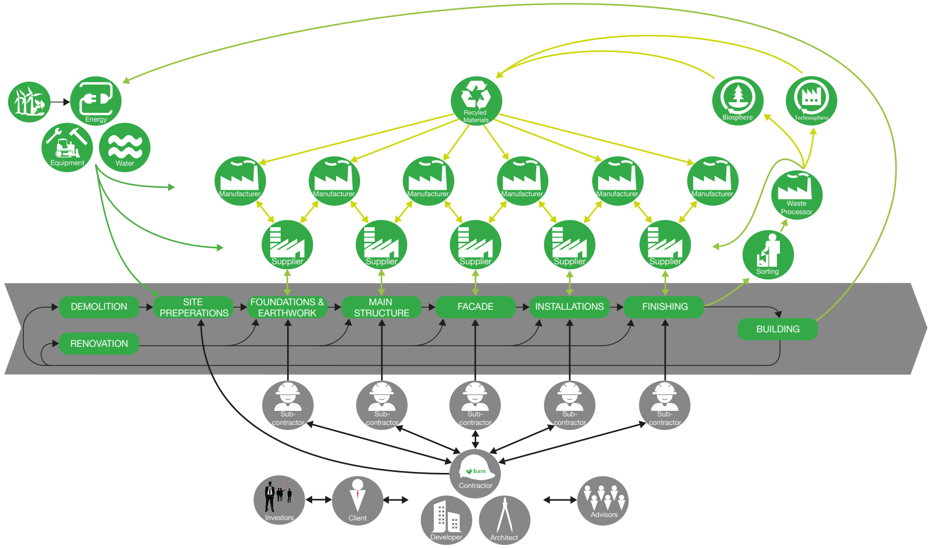



**Figure 0 - 3**: Sustainable construction process

**Results interviews**

The goal of the interviews is to assess the obstacles for achieving sustainable construction. Interviewing twelve experts in the field of construction and sustainability does this. The experts are asked about the positive and negative aspects of the current construction process (referred to as a system in the following text). Together with the question on what the obstacles are for achieving sustainable construction.

The experts that have been selected represent the main actors in the construction process model: construction managers, site managers, project developers, supplier industries, academics and government specialists. The reason no architects was involved was due to the fact that this actor is mainly focused on the product and not enough on the realization process.

Underlying, the answers mentioned by multiple experts, are the strengths and weaknesses of the in current construction process (system). Together with the threats and opportunities (as external factor) influencing the system, also mentioned in the answers, will provide the basis for the SWOT analysis at the end. Important to note is that strengths and weaknesses refer to the system, in this case, the construction process. The opportunities and threats are aspects that influence the system but can only be controlled by the strengths and weaknesses of the system.

The answers must have been mentioned by a minimum of three experts from different perspectives in order to be useable for this analysis.

The result is that the answers are put forward in a diagram like the one below. This will allow to assess whether the internal factors (strengths & weaknesses) interact with the external factors (opportunities & threats). the following example is used to explain this:

| | Strength | Weakness |
|---|---|---|
| Opportunity | Do the strengths influence the opportunities? | Do the opportunities have a relation to the weaknesses of the system? |
| Threat | Do the strengths to minimize the impact of threats | Do the weaknesses influence the threats? |

**Figure 0 - 4**: Sustainable construction process

The following was said in the interviews with the experts (quotes): “We sort up to 94% of our waste”, “Waste separation is improving”, by Thomas Heye and Jeroen Troost and “Waste separation creates awareness”, by Jan van der Hoeven. These quotations are clustered into the code *waste separation*, which is a strength of the current system.

“We are sorting waste because the processors charge less for unsorted waste” and “Energy has a return on investment that is attractive for a investor” mentioned by Hans Korbee and Jan van der Hoeven. These quotes indicate a weakness of the system: *sustainability is dependent on profitability*.

“Changing legislation means we have to change all the time” and “Legislation on energy is changing all the time” mentioned by Hans Korbee and Jan van der Hoeven. Together with other quotes these can be clustered in the code: *changing legislation threat on the system*. An external matter for the system and one that has a negative influence: threat

When a strength interacts with an opportunity you have a win-win situation, however the interaction between a threat and a weakness provides an obstacle that will need to be dealt with in order to overcome this problem (obstacle). Filtering the answers with the SWOT and sorting them into a diagram (based on figure 0-4) in the categories allowed for the assessment of interactions between strengths & weakness and threats & opportunities. In this manner the following four main findings have been provided by the expert interviews:

1. *The current **linear** way of thinking opposed to the **cyclical** (desirable) way of thinking.*
2. *The **profit** that is needed for sustainable construction (reduced impact on **planet**), which not all initiatives currently have.*
3. *The **commitment** needed during the process.*
4. *Using labels as **unjustifiable definition** for sustainable construction.*

This analysis method will help in achieving sustainable construction and thereby overcoming the main obstacles mentioned. Finding sustainable construction as defined in the sustainable construction model as the economical best option.

## Implementing sustainable construction

The achievement of sustainable construction in total is far more complex than this graduation research. In the quest for achieving sustainable construction and assessing the obstacles has, however, provided insights on how to actually achieve the desirable situation. The following step can be visualized in figure 0-5, showing that the obstacles has been looked at and that achievement is about a step-by-step plan.

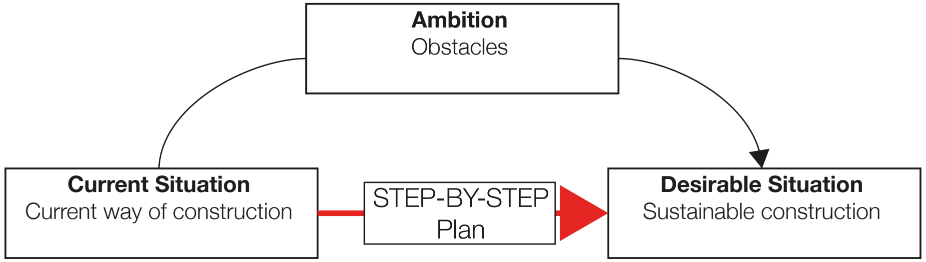



**Figure 0 - 5**: Placement in research design

Investigating the whole impact of a system (all parts of the building during the process) would be non realistic because of the complexity of the construction process. The first step is to choose an element of interest (scoping). This element can involve a specific process (dry heating) or material (aluminum facades) or method of working (Smart Building Logistics). The fact that all elements mentioned can be analyzed, shows the exclusiveness and possibilities of the model and step-by-step plan. For the analysis the aluminum facade is used as example, insights in this mapping will be used to develop the step-by-step plan.

The model used in figure 0-2 is useful to scope the elements processes and transportation routes. It is far to abstract to properly investigate the different sub-processes that take place within the processes. Therefore a new model is developed that allows for the visualization of these sub-processes and places them in the context of the main (abstract) processes, by showing the symbols in the background of the new model figure 0-5. This directly shows the cyclic nature of the process, with two streams that lead towards a building (on the right). The reason that the building has been visualized outside the circle is because of the scope definition of a process, therefor excluding the product that is a result of this process.

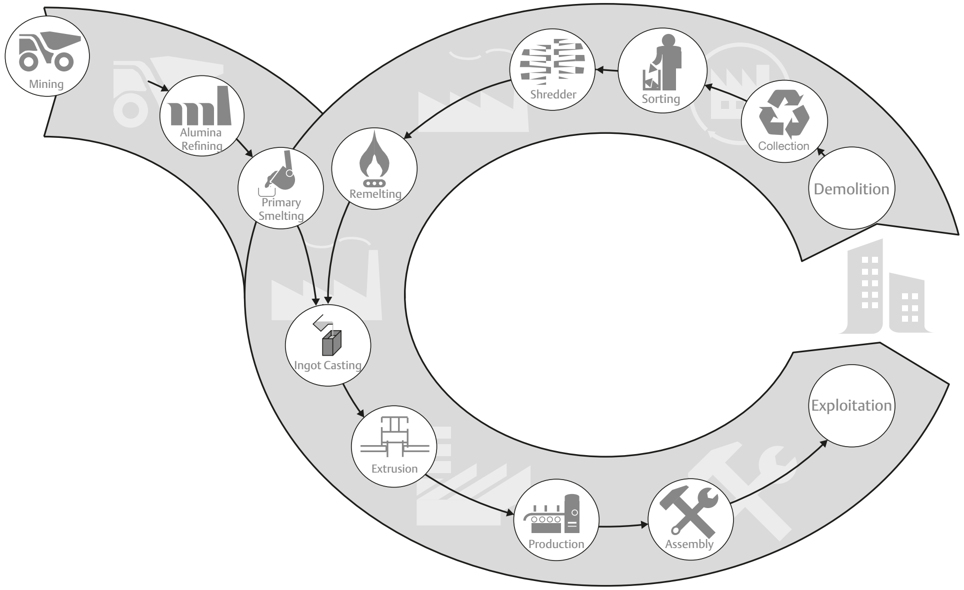



**Figure 0 - 6**: Aluminum facade in detailed model

You then assess the impact on the environment for the individual sub-processes. The figure above can then visualize the processes that need to be looked at and assess in which manner it has an impact on the environment (energy, carbon emission, materials wastage or pollution). Pie charts can visualize the difference of the impact on the environment per process. This is the third part of the step-by-step plan. This is done by gathering all data provided by all the actors in the supply chain and will involve a high level of transparency in the supply chain. For this research the report by the European Aluminum Association (EAA) was used. This is done because this step involves a long process of data collection. The organization like the aluminum institute can help in providing the necessary data needed.

The model incorporates processes that have an impact on the profitability (profit) and the environment (planet). The sustainable construction process involves the three steps of the ladder of Lansink: recycle, reuse and recycle. These are then designed in the following diagrams; together they form the sustainable construction process (desirable situation). These must be designed using the two abstract models, this is the forth step.

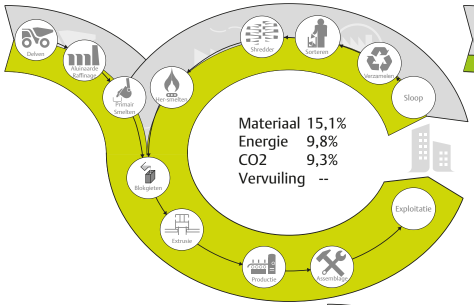



**Figure 0 - 7**: Recycle

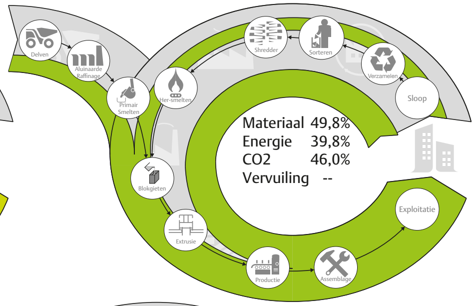



**Figure 0 - 8**: Reuse

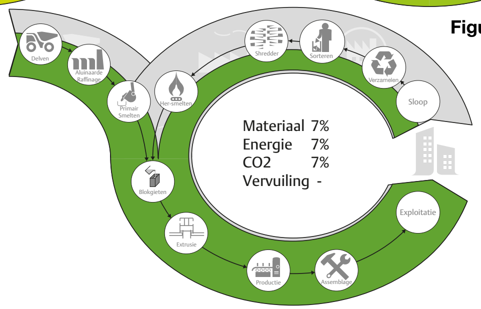



**Figure 0 - 9:** Reduce

These scenarios form the bases for the fifth step in the plan to discuss them with all the actors in the supply chain, in this case in the form of an expert meeting with all the actors in the supply chain. The scenarios are designed based on the sustainable construction process. Thereby, different processes have a reduced impact every time and the optimization can take place during the design of the scenarios.

The sixth step is the assembly of the whole supply chain in order to solve economical and technical feasibility of the scenarios made above. This is part of supply chain integration and the transparency of the actors involved is crucial for the total feasibility of the plan.

The last part is analyzing the meeting and making conclusions on how to achieve sustainable construction and make agreements on the steps that need to be taken in order to achieve sustainable construction and make a profit. The step-by-step plan is not a linear process but a circular process that evolves every time it is used. Furthermore, the steps do not have to be sequential, you can go from step six to step five in order to change the scenarios. This step-by-step plan is made in the spirit of sustainable construction and cradle-2-cradle.

## Conclusions

The research done is based on the following main research question: '*How can a sustainable construction process be defined and how can the sustainable construction process be achieved?*' This research has provided us with the answer to the question and thereby the different parts of this question; defining sustainable construction, assessing obstacles and achieving sustainable construction. These are discussed separately before the main conclusion can be made.

This research started with the history and the relationship between the industrialization and the sustainability movement. Together with the manner in which a sustainable construction process is initiated, different from other industries like production and manufacturing. In this research, a sustainable construction process is defined based on the analysis of a current construction process, which was defined first. This involved defining different elements and their relationship to one another in a process flow diagram. The definition used in this research is: "Construction technology is the application of applied sciences in order to enhance productivity and quality of its products, the nature of the construction **activities** (performed by **labor**) involved, the **place** where construction work is to be carried out and the **time** available for construction work. These are the four factors that determine the effective construction process". This definition lead to the flow diagram in figure 0-1. The understanding of the mechanisms and elements in this process helped designing the process.

The term 'sustainable construction' was defined using the definition provided by the experts interviewed. This definition is based on the well-known definitions of Elkington and Brundtland: 'Sustainable construction is construction that does not impact the environment (**planet**) and **people**, while making a **profit**'. This definition does not provide the insight needed for a new flow diagram, which is why the tool of Lansink (the ladder) was used to structure the process diagram incrementally. The basis of the whole diagram and definition can be found in the cradle-2-cradle philosophy and industrial ecology. These philosophies are based on a cyclic nature of elements related together, like in natural processes. The sustainable construction process model (figure 0-2) is the translation of the definition provided by the expert, tools and philosophies into one model.

The first part of the main research question was answered by defining what sustainable construction encompasses. This definition proved to be a definition for the construction process and not for the product; the building that is a result of the process. The second part of the research focused on the achievement of sustainable construction. This achievement included the assessment of the obstacles and the implementation of a step-by-step plan.

The obstacles for achieving the desirable situation have been provided by assessing the answers by the experts with the SWOT analysis. This put forwards four main obstacles. The first obstacle is that the current (linear) way of thinking is so different in comparison with the desirable (cyclical) way of thinking that it would make achieving sustainable construction hard. This means that a new mindset and a new manner of thinking is needed. The second obstacle is that profit is needed for sustainable construction (reduced impact on planet). Various examples, like the waste separation initiatives, are all successful due to the economical incentive found in each of the initiatives. The achievement of sustainable construction involves a step-by-step plan where the current situation changes into the desirable situation. For this plan, the commitment of management of employees is needed during the process of change. Commitment is needed because the proof for profitability is not there. If the profit aspect is proven, commitment would most likely become superfluous. The last obstacle is that labels are used as an unjustifiable definition for sustainable construction. The definition provided in this research is far more broad and flexible, which makes room for new interpretations and possibilities.

The implementation, using the step-by-step plan, provides insights on how to achieve sustainable construction, how to deal with this change, and on how to help overcome the aforementioned obstacles. The steps mentioned form the basis for the change that is needed to achieve the desirable situation. These steps involve a lot of methods that are known, however, they are put together in such a manner that particle situations can be solved. The steps form the basis of the knowledge retrieved during the entire research. To achieve sustainable construction the main obstacles must be dealt with, by using the designed step-by-step plan and solving the technical and financial feasibility within the supply chain together.

**Recommendations**

This research has put forward a definition of a sustainable construction process and a tool to help achieve this process. However, conducting this research has also brought to light, the imperfections, as well as limitations of the scope of the research. These aspects are discussed below, together with recommendations for new research.

First off, my recommendation would be to relate the defined sustainable construction process to the product produced by this process. Various experts have mentioned that scenarios - like the *reduce scenario* - within processes have a strong connection to the design and the product made from the design. This means that optimizing the process will affect the product and the other way around. Research into these effects could compliment this research.

Secondly, the research scope did not involve the product and the result of the new process on the product. This lack of involvement caused the question to arise what effect the sustainable construction process has on the sustainability of the product. This question is of interest because this would create a certain value for the new process. In conclusion, new research into sustainable construction could involve the exploitation phase and therefore the product.

The third element of recommendation is about the step-by-step tool developed in this research. Time limitations in the graduation project have confided the ability to test all the steps in this tool. The tool, includes a new expert meeting were the concrete plan of approach is designed by the supply chain actors and translated to a plan of approach and CPI's. Therefore, this is a recommendation to the people wanting to use the tool; test the last step first, in order to see the results it might deliver.

The achievement of sustainable construction deals with a series of obstacles, four of which have been addressed in this report. One of these obstacles is commitment, the obstacle that is not needed once people believe its added value (profitability). However, convincing these people will involve determination. In the most ideal situation, it will involve a pilot project which is used to prove the step-by-step plans value in practice. The last recommendation would be to use the tool in practice in the form of a pilot, then monitor the process and gather information to prove its worth to the rest of the world.

# Reading Guide

**1. Research design**

In this chapter, the research design is discussed, which includes the motivation, relevance, problem analysis, problem statement, research questions, goal of the research, the intended goal and method.

**2. The construction process**

This chapter is about the evolution of the construction process, followed by a flow diagram that visualizes the construction process in its current form. The design of this flow diagram will be illustrated in this chapter together with the aspects of the process impacting the environment. The reflection of twelve experts on the model are also discussed and put forward.

**3. Sustainable construction**

This chapter formulates the sustainable construction through the different definitions provided by the market. This will form the basis for the design of a sustainable construction process, together with a full analysis of the sustainable construction process including the decomposition of the model into parts.

**4. Obstacles sustainable construction**

This chapter explores the interview with the experts on the obstacles of achieving sustainable construction in order to find out how to achieve sustainable construction. This will involve a thorough analysis of the interview together with the analysis on the answers in a SWOT, providing insights on aspects preventing sustainable construction to take place.

**5. Implementing sustainable construction**

This chapter will look at the sustainable construction model and go into depth on the possibilities of the model. This will provide a new tool for analysis and furthermore a method to optimize the model by running through an interesting element of research. The goal is to find the strengths of the model that will help to achieve sustainable construction by using the right chances and getting ride of some threats.

**6. Conclusions & Recommendations**

This chapter will first answer the main- and sub-questions. Then, based on the results of this study some conclusions are drawn. Finally, recommendations are suggested for practice and further research.

# 01 Research Design

This chapter describes the reasoning, motivation, relevance and choice for the specific research topic. The relationship with related and/or overlapping research, are substantiated with sources (literature, proceedings, own experiences and conversations). This will explicitly address the added value of this research. Together with a clear problem analysis and statement the research questions are presented. These research questions will form the scope of this research and answering them will be done in a transparent, retraceable and critical manner.

## 1.1 Motivation

Living in third world countries for the first twelve years of my life has given me perspective on the differences in housing situations within western countries and third world countries. The differences in housing styles all over the world is partially due to the manner in which buildings are constructed. During a recent vacation to Kenia, the difference in construction processes were big in comparison to, the traditional construction of homes in Kenia is done by using tressed wood with stones in-between, covered by clay from the ground combined with water to form a sort brick. The materials used for housing are from the direct environment. The difference with western construction is enormous. Western building organizations get steel from china, concrete from belgium, aluminum from Australia and brick from the Netherlands for a shelter. This delivers a more luxurious living environment but with the transport differences alone, the shelter in Kenia is constructed, with less $CO_2$ emissions and resource depletions. The fascination for construction methods motivated me to do the architecture program at Delft University of Technology and study my masters at the department for real estate and housing, design and construction management.

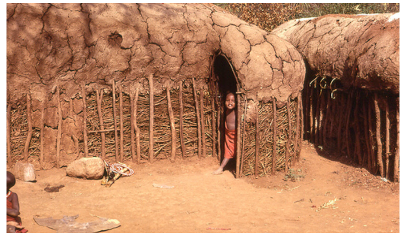


**Figure 1 - 1**: Traditional construction in Kenya

This research will incorporate the subject of ‘sustainable construction’ and ‘process innovation’, which lie in the domain of the Design and Construction Management laboratory. Sustainability is an issue that has been emphasized at this faculty and has brought something extra to the construction industry. For instance, the GreenCalc Top ten shows buildings that are $CO_2$ neutral or energy neutral and some of these buildings even generate electricity. This indicates the possibilities in the realization of sustainable buildings. However, it does not indicate indicate how or in what way the product has been constructed and assembled. The BREEAM label incorporates a part of the construction process but this is no more than 13% of the points available (Dutch Green Building Council, 2012). The construction phase has been looked at in-depth only and not in respect to sustainability, while the potential of this phase can be of great importance to the whole industry (DTIE, 2009), due to its strategic position within the supply chain (in the middle).

The construction industry and its related materials, services, and supply feeder industries are jointly considered to be both the world’s largest industrial employer and the largest natural resources consumer (UNEP, 2006). Therefore, construction processes and sustainability seem to be interconnected. Practice shows that the process of getting from the design to the actual product in a sustainable matter can be problematic. For instance, lighting at a construction site runs on diesel motors and not on the electrical grid. At night they light up the construction sites with halogen lamps for safety issues (Van der Horst, 2012), something that is unthinkable now, due to the price for this and the sustainable awareness. The construction sites use dry heating for certain processes, which uses almost half of all the energy needed on site (Radermacher, 2012). Various processes in construction involve of high energy usage and $CO_2$ production, these can be incorporated in sustainable construction.

## 1.2 Problem analysis

The problem analysis will look at the problems with sustainability and specify this towards the construction industry and construction process. Sustainability is part of the greater movement called sustainable development

#### *1.2.1 Sustainable development*

The need for sustainable development has been shown in the various reports of the United Nations Environmental Program (UNEP, 2003). The UNEP have published different figures that indicate that the construction industry is a key player in the waste generation over the world. Also, the use of hazardous substances and excessive concentration of harmful substances in the air, water and soil contribute towards impact on the environment. This pollution has a negative impact on the health of people and the biodiversity of animals and plants. The carbon emissions, like $CO_2$ and other harmful gasses (indicated as $CO_2$ equivalents) in the air, also contribute to the first main aspect of sustainability: global warming. The second major aspect is resource depletion. Nowadays we realize that the resources used are limited which means we have to overcome the resource scarcity by substitution reuse and recycling in order to contribute to the next generation of problems which are associated with global environmental problems. This realization provides an enormous challenge and is encapsulated in the term sustainable development (Redclift & Voodgate, 2010).

**Environmental impact construction industry**

The construction industry has a large share in the current environmental issues and is therefore a focus sector sustainable development (UNEP, 2006). The built environment is also responsible for almost 40% (world wide) of the total waste production of the industry

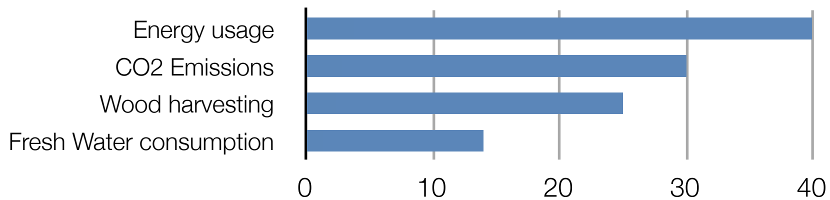



**Figure 1 - 2**: Share building environment on resource usage and pollution (UNEP, 2006)

(DTIE, 2009). Figure 1-2 illustrates the impact of the built environment and its share in the four different waste sectors. Taken into account that these are general figures for the whole built environment, the transformation of raw materials used in the construction industry generally have high energy demands in the production process.

Books on the construction technologies indicate that construction and its products (buildings) use 40% of all energy (with 8% used in construction). This has an enormous impact on the global environment (Riley & Cotgrave, 2009). The world is facing two major problems at this moment; global warming (causes the climate change) and mineral depletion (this has reached a point where many of the world's resources are simply running out).

**Dutch Initiatives**

In order to address these environmental problems, goals are set within the European Union. These goals are also known as the 20-20-20 goals to minimize the emissions of greenhouse gasses in the EU by 20% the use of sustainable energy by 20% and reduce the energy use by 20% (European Union, 2012) compared to 1990 levels. The Dutch government has made initiatives to reduce the greenhouse gasses and use more renewable energy sources. Their main goal is to become totally reliant on sustainable energy sources before 2050 (Senternovem, 2008). Not only are renewable energy resources of importance, the buildings must become more sustainable and the way these buildings are constructed must become  more sustainable as well. Currently. the Dutch government. together with 'Bouwend Nederland', NEPROM, NVB and the ministry of VROM, has constructed a new energy savings agreement written in the Spring Agreements. This is an initiative that will ensure that the country is built up of high energy efficiency, where the climate, fossil fuels and environment will be spared. The goal is that housing initiatives in 2011 will save 25% and in 2015 will save 50% in comparison to 2007 measurements (Nederland, 2011).

In the Netherlands, the construction sector contributes largely to the environmental problems; mainly in the activities of maintenance, demolition and construction of buildings (Milieuloket, 2011). The problems occurring during the construction of a building are first of all the Volatile Organic Compounds (VOC) that contributes to smog. Secondly, during the construction phase a lot of energy is used that contributes to the $CO_2$ emissions and greenhouse gasses, by using power from non-sustainable resources. Thirdly, water is used to clean dirty building materials, which results in dirty water that runs into the ground (pollution). Last but not least is waste production. In 2008, sixty-three million tonnes of waste was produced, and the construction industry contributed twenty-five million tonnes (Agentschap, 2012).

**Problems with sustainable development**

Even with the goals set at this time by the government, there is a lack of sustainable development all over the world. One of the reasons according to people in this industry is the circle of blame; a vicious circle where all actors in the construction industry blame each other for creating unfavorable circumstances for the realization of sustainable buildings. This led to a low number of sustainable building realizations in recent years (Hulshoff, 2009).

Leaders within the construction industry have made initiatives to break this vicious circle. They each have their own specific position and have taken responsibility and started working towards the realization of sustainable buildings (Agentschap NL, 2010). The construction sector is becoming increasingly aware of their responsibilities in this area. Thus, the so-called circle of blame is more frequently broken, and this results in construction buildings like the ‘The Hague College’ in Delft. This is an example of a breakthrough of the vicious circle of blame, but not a solution to the problem. There are only a handful of people that are able to realize a sustainable buildings in a sustainable manner and this is also due to missing ambitions, technical knowhow or financial possibilities. A good example is the current integrated contracts also called PPS projects.

Sustainable ambition brings along a certain extra load on the participating actors and this will create friction when executing the project (Dansen, 2009). It is important that all people in the organization of the real estate development process are willing to put in the extra effort for the realization of sustainable projects; commitment is needed. There is also a need for an independent party to assess the sustainability in products and processes. There are various methods that assess sustainability and there are a lot of people that have wanted to assess the real sustainability. However, this definition is still not clear. This is illustrated by looking at the different assessment methods. These methods can be compared as was done in the research of Jerry Niemann (2012).

### *1.2.2 Assessing sustainability*

Since 1989, many methods have been conducted on how to determine sustainability and how this assessment can be made insightful and transparent. There is not one clear method to build or design sustainable buildings and construction processes. The lack of uniformity in which sustainability is assessed, is illustrated in the number of different instruments for assessing sustainable quality.

DHV is a leading international consultancy and engineering firm known for its world-class expertise and leadership in innovation and sustainability. They conducted research into a large amount of different assessment methods for sustainability that had existed till 2008. The research searched for a certain measure of sustainability for sustainable buildings: when can a building be called sustainable? The study included 50 different sustainability tools/methods from the tool palette of Senternovem. From these instruments, there are six methods to a greater or lesser extent, which have found their way into the building practice. In this research, it is presumed that when a building meets one of these six methods, it can be called sustainable. These methods are:

1. The Energy Performance Coefficient (EPC). This is an index that indicates the energy efficiency of buildings, and is determined by calculations defined by the NPR 2916 (commercial buildings) and NPR 5128 (housing). The EPC calculation is obliged to be submitted during the planning application. Since 2011, It is expected that from 2015 the standard is set at 0.4 (Bouwkennis, 2012).
2. The GreenCalc + method looks at the impact of buildings on the environment and expresses this in a building environmental index (MIG). This is the sustainability of a building, which is independently measured from the behavior of its users. The focus is on the materials in the design and construction.

**Figure 1 - 3**: GreenCalc Logo (Stichting Sureac, 2010)

3. GPR building is an instrument that evaluates buildings in five themes and assigns grades to these themes. A building that meets a 6 score out of the 10-state for the

maximum possible sustainability of a building, is labelled as a building that complies with the building regulations in the Netherlands.

**Figure 1 - 4**: GPR Gebouw (Stichting Sureac, 2010)

4. Cradle-2-cradle is "more a philosophy than a labeling method" and calls for 'good' action rather than 'less bad' action regarding sustainability. According to this philosophy, waste is considered as food for new products. This idea of sustainability is difficult to measure and can not be expressed in a number.

**Figure 1 - 5**: BREEAM Logo (DGBC, 2012)

5. BREEAM label came shortly after the investigation of DHV, in 2008. Since, the large growth during the past five years this one is worth mentioning. The BREEAM methodology was introduced in the Netherlands as a tool that evaluates the sustainability of a building on the basis of nine themes. Buildings can score points in these nine themes, which ultimately leads to the granting of a particular label. On the topics of energy, materials and the other nine themas, points are awarded (Dutch Green Building Council, 2012). The labels can vary from pass, good, very good, excellent and outstanding depending on how many points are awarded in the assessment. The highest label possible, outstanding, has rarely been achieved.

6. LEED is a similar method to BREEAM. Where BREEAM originated in Great Britain and BREEAM NL mainly focuses on Dutch buildings, LEED has its origins in United States of America and is applicable to buildings all over the world (USBGC, 2012)

This variety of assessment methods shows that sustainable buildings can score differently in one assessment method compared to another while still be named sustainable, Therefore, it is important to define the assessment method beforehand, in order to define what sustainable buildings signify for the client. The labels also assess differently in different manners and incorporate different phases of the process.

### *1.2.3 Different phases in construction process to assess*

The assessment methods mainly refer to the product produced and its sustainability. The piece of real estate (product) passes through various phases in its lifetime. There are several pieces of research on the various phases of the real estate development process and the sustainability in these different phases. Research done at the faculty of Real Estate and Housing by Lameris, (2007), Dansen (2009), Van der Woerdt (2010), Rietdijk (2010) on the constraints of realization of sustainable buildings are discussed in the following phases.

**Initiation**

The first phase of a project is the initiation phase. It is during this phase that the project goal is established and the initiative is made to develop a building. During this phase, a project manager is assigned, who works with the main project stakeholders (these are the people with a vested interest in the project, and often hinders who make it happen), to fully determine what the demand is and how to measure the success of the project once all work is completed. The project scope will include project goals, budget, timelines and any other variables that can be used for success measurement once you reach the final phase (Ausgabe, 2004). Research has shown, that a clear vision on sustainability formed by the client, can become hard to steer in future processes (Rogaar, 2011). Clear formulation is the foundation towards a sustainable project (Manfron & Mallgrave, 2009).

**Definition**

In the definition phase, clients are aware of the formulated sustainability ambition, in order to have control during the process. Research has shown that clients do not have the expertise to formulate sustainable goals and lifespans accurately and control the process. They are often reliant on their advisors (Navabifard, 2011). Saskia de Nie (2011) has developed a manual for client advisors that can be followed, in order to controle the ambition of the client and therefore steer on a better result.

**Design**

The design process is a search for the optimal design solution with an iterative phase tracking (Doorn, 2004). A first problem that presents itself, lies in the fact that the available information is usually inversely proportional to the information during the design process, while the influence of judgments in particular in the early stages, is the greatest. The design phase itself can be divided into as many phases steps as necessary in order to resolve all design problems and to integrate the concepts into a functional plan. It is generally recommended that at least two stages are used. These are: preliminary design, and final design. The end products of the design phase are written reports, architectural and engineering drawings, construction costs, projected operational costs, and schedules of construction. From the principle of the project, the design is considered to be a straightforward process with a sequential phase follow-up (Mehta, Scarborough, & Diane, 2009a).

Research has proven that the form of corporation can form problems in realizing the sustainable ambitions (Rietdijk, 2010). Rietdijk also describes that it is important to incorporate the right actors that have expertise in the sustainability sector. The design phase is closely interconnected with the construction phase of a project (Wamelink, 2009). It is the design that provides the form in which the materials will be assembled in the construction phase. Therefore, sustainability, with respect to the construction phase, is influenced by the design phase (Graham M. Winch, 2010).

**Preparation**

This phase involves the specifications and cost estimations that are made. It includes signing the budget, purchasing budget and the work preparation, which includes the site preparation, engineering and translation of design into documents a contractor needs to start building (Wamelink, 2009). Research by Dansen (2009) shows that in the specifications and ambitions, people find out what the costs for sustainability are. He also implies that the higher costs for sustainable solutions are often lost due to financial incentives (Dansen, 2009). This is contradicted by publications that mention that sustainable initiatives do not have to cost more than other solutions (Doorn, 2012). The extra expenses for sustainability is an area that is in need of extensive research.

**Construction**

Higgin & Jessop (1965) have made a connection between to the process and product of construction and building. “looking at the building process, we can distinguish three main functions. Two are obvious: design and construction; the third is coordination”. This third function is the construction phase, also referred to as the assembly of materials in the form of the design (Carpenter, 2001a). Even if the previous phase has been followed successfully, this is no guarantee for success in the construction phase. The sustainable ambitions can disappear during the construction phase due to incorrect implementation by the contractor (Dansen, 2009). A good example of this is the Town Hall of Leiderdorp. Heat storage does not work because of the wrong time of implementation of the installations. In order to optimally use the heat storage, the engineering and work preparation must be done in a manner that heat storage facility can be used during the construction, this could even solve problems with dry heating in construction (Burgstede 2012). Sustainability is often used as a marketing tool for an organization, public imaging though the corporate social responsibly (CSR) is becoming increasingly important. This often does not include the actual sustainability but looks at the green imaging or marketing goals. The research in this area (SASBE and CIB proceedings) only looks at the realization of sustainable goals in the construction phase and rarely incorporates any research on the sustainability in the construction process.

**Demolition**

Demolition is of growing importance due to the increase in redevelopments of areas opposed to traditional development (where everything is demolished and the area developed). Demolition processes are seen as reversed processes compared to construction. The demolition industry is motivated by a budget for activities and not to reuse unless budget is there for reuse. A recent personal encounter with demolition was at the old faculty of architecture at Delft.

### *1.2.4 Reaction by the market*

The market is able to use these tools and labels for their products and for parts of their processes. However, they have also done something extra. The reaction of the market on the environmental problems is making a contribution to the environment by implementing a tool: Corporate Social Responsibility (CSR). Social Responsible Netherlands explains that a company takes responsibility for the effects of their activities, products and services on men and environment. The company makes conscious choices in order to reach a balance between People, Planet and Profit. This will be the standard for contractors in the 21$^{st}$ century, and it contains three starting points. The first point is that CSR will be integrated in the vision of construction companies, where a company creates value in an economical, ecological and social way. The second aspect of CSR is that with every decision the balance is made between different stakeholder interests. The third aspect is that CSP is a process improvement and not an end goal. The goals can change over time with every decision made.

Contractors like BAM, Heijmans, Dura Vermeer, Ballast Nedam and different smaller contractors contribute to this process by making CSR policies. Yearly, a sustainability report is published. This includes aspects like the use of FSC certified wood and whether they use sustainability as a selling argument along with various other aspects. Research from 'Bouwkennis' shows that 78% of the material suppliers use sustainability as selling argument towards the client. 70% of the advise/construction management offices and developers use sustainability as argument while 55% of the construction companies do so.

Klaas van den Berg, head of sustainability at PricewaterhouseCoopers (PwC), concludes that mainly the construction and supply industry are too little concerned with the consequences of the impending scarcity of raw materials (Mullink, 2011). However, contractors such as BAM, Heijmans and Dura Vermeer indicate in their sustainability report 2011 that they have the ambition to reduce $CO_2$ emissions, to reduce waste and to apply sustainable materials. A study by Friends of the Earth shows that sustainable wood with the FSC label is not always used in construction projects of the government. Of the researched cases, 70% does not use sustainable materials, while it is included in the specifications (Kuit, 2011). Some examples include the Royal Palace, the National Museum, the new office of DUO and the tax authorities in Groningen. Construction companies like BAM state that it is difficult for suppliers to generate information on the volume of non-FSC certified wood products. This complicates the measurement of the proportion of FSC-certified wood for suppliers (BAM, 2011).

BAM indicates that rising up to the objectives in practice is difficult (BAM, 2011). This is confirmed by Heijmans, indicating that construction companies are facing a number of dilemmas as well. Construction companies explain that their own activities of providing sustainable solutions is not enough, they depend on sub-contractors who are hired. This is why sustainable purchasing can prove to be a valuable contribution to sustainable construction (Heijmans, 2011).

#### *1.2.5 Findings*

With a large number of construction process phases and a diverse investigation of previous graduates into the sustainability we can conclude that the construction phase is in need of research. There are problems in the construction phase with the realization of the ambitions for sustainable products. It can be said that sustainability is of importance: people are using it as marketing tool or as ideology. Achievement of true sustainability is not yet taking place. Sustainability is older than various people think. Since, the publications of the club of Rome and Brundtland we know it is of importance. The achievement of sustainable development proves to be a problem that can often not be explained. Many tools for helping to achieve sustainability have not yet provided the result necessary because they only assess the final product and not the process. The achievement of sustainability lies within the process of construction and will need to be looked at.

The construction process is a well known process, but, not yet visualized in the form of a flow model in order to assess how sustainability can fit into this process. The current sustainability research now many focusses on the assessment of the products delivered from this process: buildings. There are various pieces of research that explain the process, but all miss essential parts in the explanation towards sustainability. The construction industry, however, has not yet expressed the need to visualize this process (Koskela, 2000). There are various methods that explain how to deal with the construction process only in project management perspectives (G. M. Winch, 2011). This gives a indication on how to deal with the process. A model that explains the flows in the construction will allow for a better flow analysis to see where the construction sector can increase efficiency and help elaborate on the subject of sustainability.

## 1.3 Problem statement

The impact of the construction activities seemingly plays a small role in sustainable development of the sustainable development but, can be of great importance in a contribution to the overall sustainable development. The aspects mentioned above state that the construction sector needs to improve with respect to sustainability and in a manner that can impact the industry in an important way. The corporate social responsibility is becoming increasingly important in the industry and a start for sustainable construction. This contribution is, however, not enough. Sustainability is often lost in a project environment where money and time play a more prominent role. This means that sustainable construction that does not cost more than the traditional construction will have the future because it is not depending on other external factors. The achievement of sustainability lies within the process of construction of the products and the sustainability of this process itself. People have been talking about sustainable construction since the club of rome and are still not doing so. We are not achieving sustainable construction we know what needs to be done but cannot achieve. The sustainable construction process is often not defined clearly and dependent on the commercial incentives. This is in need of a visualization that can help in the achievement of the desirable situation.

## 1.4 Research questions

The problem statement above has lead to the following main research question together with the more specific sub-questions:

*How can a sustainable construction process be **defined** and how can the sustainable construction process be **achieved**?*

The following research questions are drawn together in order to give an answer to the main question. These consist of three parts:

1. Defining a relationship between elements in a sustainable construction process
2. Assessing obstacles sustainable construction
3. Achieving sustainable construction

Part 1

- What are the elements of the construction process, and how are these elements related?
- What are the elements of a sustainable construction process, and how are these elements related?
- What, in practice, is meant by sustainable construction and how can this be visualized in the theoretical sustainable construction model?

Part 2

- What are the strengths and weaknesses of the current construction process (system) that interact with the external threats and opportunities for the system?
- What are the obstacles for the construction industry to move towards sustainable construction and what are the causes of these obstacles?

Part 3

- How can you implement the construction process model as a tool, in order to achieve sustainable construction?
- What are the elements of the analysis tool and how are these elements related?
- What does this insight on implementing the analysis tool provide that is useful in answering the main research question?
- How can we achieve sustainable construction?

## 1.5 Research Goal

The goal of this research is to find out what sustainable construction is, why we are not constructing our buildings in a sustainable manner and to provide insights on what strengths and weaknesses the current construction process incorporates together with the external threats and opportunities it reacts upon. The research aims to define a sustainable construction process that possess the strengths to overcome threats which utilizes the potential of opportunities provided by external factors.

The result of this research will be a method/tool that contractors can use to analyze their main current process of construction in order to move towards sustainable construction (achieve). This model together with a manual, will be a result of this research which allows actors to optimize their processes towards sustainable construction, knowing the obstacles of the current construction process.

## 1.6 Relevance

In various pieces of literature, the word ‘sustainable construction’ (C. F. Hendriks, 2001) is used as a word for the product of construction (the building) and less for the process. When examing the process of construction, one can see that various pieces of literature describe this, but only few relate this to sustainability. There is a need to define ‘sustainable construction’ as a process and a need to improve the sustainability in the construction activities. There have been some improvements in the construction industry with respect to waste management and other scattered initiatives. This is, however, symptom treatment and not a treatment for the diagnosed illness. Currently, the ISO 14001 norm is being implemented at different construction companies, this norm helps contractors with the environmental management of waste products (materials, $CO_2$, energy and pollution). This norm mainly focusses on the output part of the process and is not linked to the input of the process. Further scientific and social relevance for a research are discussed below.

**Scientific relevance**
This research combines different scientific areas of process innovation, construction management, construction technology, sustainability and industrial ecology into an area focused on ‘sustainable construction’. Various pieces of research and books like that those of Sarkar & Sarawati (2008), George Ofori (2012), Riley & Cotgrave (2009) and Madan Mehta (2009b) illustrate how construction as a process functions and how it can be managed. This is illustrated in a descriptive manner of a transformation process with input, process and output, while other pieces of research indicate that it should be approached in a flow approach, as is described in the books of Koskela (2000). He states that a rapid glance at the content of textbooks on construction management shows the descriptive account of a construction project and Koskela then proceed to specific techniques of management and control. No major conceptual or theoretical in-depth analysis of construction is provided by outset.

The construction process has been looked at with respect to sustainability but in a scattered and non-integrated way. There are various reasons for this. One is that construction is fragmented and therefore dependent on different sub-contractors and also different industries. Supply chain integration research looks at this problem and states this as a problem for sustainability (Vrijhoef, 2010). Secondly, limited attention is given to the on-site construction impacts due to its perceived relative lower significance of construction impacts compared to the lifecycle impacts associated with building design and management (Gangolelis, 2009). Although environmental issues associated with the current construction and demolition processes are included in environmental assessment methods, their coverage is neither consistent nor comprehensive. Most construction impacts are assessed by the presence or absence of environmental protocols (Cole, 2000). On the contrary, Riley & Cotgrave (2009) describe that the impact of the construction industry in the climate change and resource depletion is enormous and that initiatives need to be taken.

The fact that the sustainability in construction processes is occasionally assessed is motivated by the latest proceedings of SASBE (2009) and CIB (2011). These indicate that sustainability is still an important subject, but not with respect to the construction process. The CIB proceedings incorporate the latest research on sustainability within the building sector and reveal that there is a lot of research on sustainable buildings and its relation with design and sustainability (CIB, 2011).

**Social relevance**
The construction sector accounts for around 10 % of Gross Domestic Product in Europe, with some three million enterprises operating across the sector. The sector also provides around 7.6 % of the total number of jobs across Europe, employing approximately 14.8 million people (CEN, 2011). Any impact on this economy is of great social relevance.

The construction industry is a large natural resources consumer. More than 50% of the raw materials extracted from the earth are transformed into construction materials and products (Environmental Protection Agency U.S., 2004). Building activities account for as much as 40% of all energy used; 12-16% of the fresh water consumption, 25% of the wood harvested and 30% of the green house emissions (Mocozoma, 2002). The transformation/conversion of these materials in the construction sector does not seem to be efficient, dealing with high energy consumption and waste production. The waste that is produced by the industry in the Netherlands alone is 26% (Bossink & Brouwers, 1996). Dealing with these problems is incorporated in corporate social responsibility.

The Corporate Social Responsibility (CSR) is becoming increasingly important for various industries (incl. construction). Due to an increasing interest in society and responsible behavior, many companies nowadays are concerned about values such as integrity and develop ethical codes to foster responsible behavior of their employees. They feel that they must meet the 'Triple P' (People, Planet, Prosperity) bottom line (Elkington, 1994), expressing the expectations of stakeholders with respect to the company's contribution to people, planet and profit in order to get a license to operate. Firms who do not meet these expectations may see their reputation go down with a negative impact on market shares and profitability (McIntosh, Leipziger, Jones, & Coleman, 1998). People come to expect corporations to take a social role, in which they develop a social identity that is as important for their branding identity (Pot, 2012).

Various reports of construction companies state that they monitor the waste production and the $CO_2$ production of their activities. BAM states for instance that they recognize sustainability and the value it creates for their business; it improves the efficiency of their operations, it helps them to develop client and supply chain relationships, to attract and retain talent, to drive innovation and to build their reputation in their sector and beyond (BAM, 2011). Constructions are into lean management and have their own vision on sustainability and the opportunities to improve. This indicates that there is a social necessity for research in the field of construction linked to sustainability in order to improve the aspects of the sustainable construction. It also indicates that there are still a lot of thresholds that need to be dealt with. This research will contribute to the market demand of CSR and sustainability in the construction sector by providing a sustainable construction process.

## 1.7 Research design

There are numerous solutions for the problem statement made in the previous section and there are different manners in how to define the solution. This research is in need of a research framework to take an approach in solving the problem statement. There are various philosophies and different approaches in these philosophies on the question of how to solve sustainability in construction. The change management theory can been used to structure this research (Cameron & Green, 2012).

The diagram illustrates that in order to define sustainable construction you must need to know what the current state of construction is. This will be referred to as traditional construction. From this point one is able to formulate the desirable situation, in this case sustainable construction. However, this is not enough for the research, in order to make it worthwhile , the question of how to achieve the desirable situation must be investigated. This is directly related to the 3 parts of this research. In addition to this conceptual framework, the last part will look at an analysis model that will help to optimize the sustainable construction process towards the desirable situation.

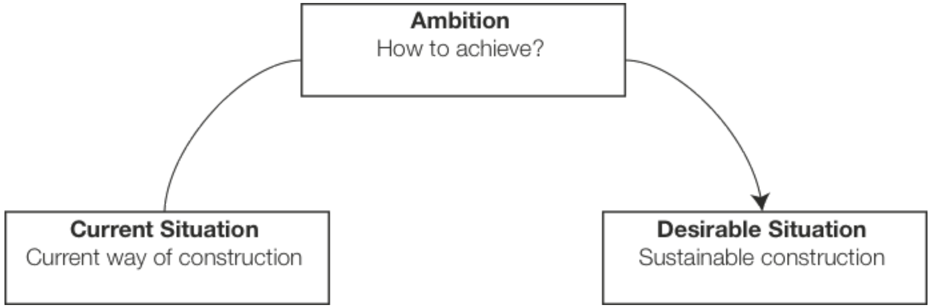



**Figure 1 - 6**: Research design

This theory is often used when making radical changes in an organization or at a personal level. However, this model will not be used at an organization level, but at an industry wide level, in order to incorporate change within the industry. The goal is to create and optimize a new sustainable construction process as opposed to the current construction process, while it also investigates obstacles on achieving the future (desirable) situation. In order to make a successful change, the theory states that answering the following questions are essential:

1. *The actual change necessity* is essential for successful change in an organization (Cameron & Green, 2012). This question is applicable for this research too. The relevance and problem statement indicate the necessity to change with global warming and resource depletion as main problems.

2. The *willingness to change.* The construction industry is seen as a traditional industry (also named as current situation), this is absolutely not the case. The fact that the

construction industry is able to produce the Burj Khalifa with a length of 810 meters, implies that the construction industry is very innovative. She might be conservative, and holding to traditional attitudes and values and might be cautious about change or innovation. The increasing importance of sustainable development through government and clients shows that the industry must be willing to change in order to survive. This is shown by the fact that construction companies have been publishing sustainably reports since 2008 which indicates the willingness.

3. The change capability of the construction industry and the questions on whether this industry is able to change and how this change will need to take place. This is closely related to the ambition illustrated in the figure on the previous page, and the question on how to achieve the desired situation.

**Research methods**

In this section, a description will be given on the applicable research methods and phases and they are coupled with the research questions in section 1.5. To display the research design in an arranged manner, the research steps relative to one another are positioned and visualized in a following figure. This scheme is a single and clear visualization on how the structure of the research is put together, which steps are parallel

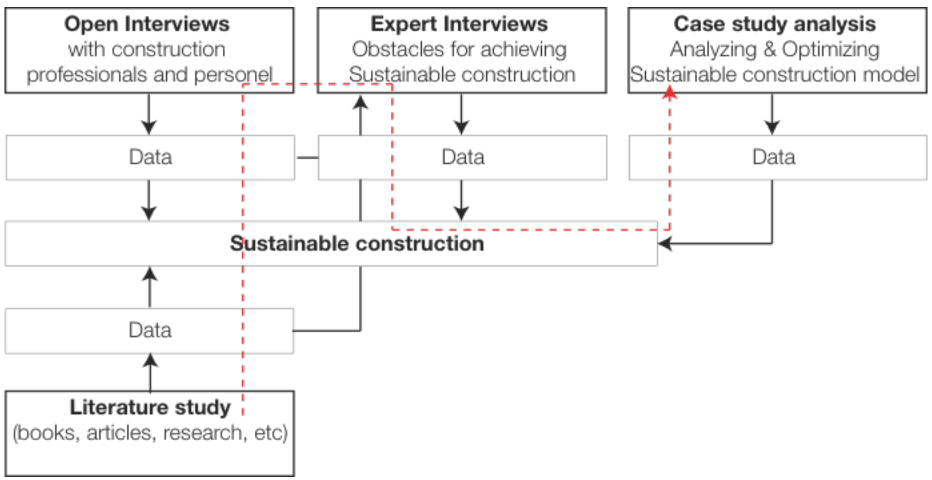



**Figure 1 - 7**: Data collection model

and sequential, and to what extent the output from one stage or activity contributes towards the research.

In order to preform the research in a correct manner different research methods will be used. The study will consist of three research areas:

1. An exploratory and in-depth *literature study* on the concepts, construction technology, construction process, process theory, sustainable development and sustainable construction. This will then be combined in the sustainable construction process model by using a method called *system theory*.

2. In addition or complimentary to the findings in the literature, a series of interviews will be held in order to verify the results. This will consist of *open expert interviews* with a selected number of construction professionals.

3. A specific element is selected, in a specific case. In order to optimize the sustainable construction model within a *case study analysis*.

**Literature study**

A literature study attempts to gain as much information and knowledge through publications, articles and existing literature on the subject and to ascertain what others have done in a similar studies (Baarda, De Goede, & Teunissen, 2001). The literature is applied to the first phase of the research. These results are the background information on construction technology and processes, together with sustainability and process design. In order to organize the information, into a design that is insightful for actors in the construction industry and shows what sustainable construction incorporates and implicates, the model is made. In this manner, this model will be used as a tool for communication but also as a tool to make sustainable construction insightful for others. In order to design a model for the sustainable construction, the system theory is used.

**Expert interviews**

The interviews provide a meaningful opportunity to study and to theorize about the social world. Narrative accounts produced through in-depth interviews provide us with access to realities. Specifically, interviews reveal evidence of the nature of the phenomena/theory under investigation, including the contexts and situations in which it emerges, as well as insights into the cultural frames people use to make sense of these experiences and their social world (Emmison, 2011).

The first interviews will be used for two purposes in the research. The first purpose is to find the obstacles for sustainability in construction activities, to define sustainable construction and also to investigate obstacles and causes of the unsustainable construction industry. The second goal of the interview is to reflect the theoretical model to the social and practical world. The experts have insights from practice that could prove valuable as addition to the theory.

The interviewees that have been selected are all part of the main actors in the construction process model. The six types of experts that were interviewed are: construction management, site management, developers, supplier industries, academics and government. The reason that no architect was involved was due to the fact that this type of actor is mainly focussed on the product and not enough on the process. The following table shows the list of interviewees and their role in the construction process. The list shows 12 experts that have been interviewed:

| INTERVIEWEE | FUNCTION | PERSPECTIVE | ABBREVIATION |
|---|---|---|---|
| Jeroen Troost | Commercial director BAM Utiliteitsbouw | Contractor (Management) | CM1 |
| Robert Koolen | Strategic management Heijmans BV | Contractor (Management) | CM2 |
| Thomas Heye | Manager Sustainability Boele en van Eesteren | Contractor (Management) | CM3 |
| Jan van der Hoeven | Main site manager BAM Utiliteitsbouw | Contractor (Site manager) | SM1 |
| Ron van der Horst | Production director BAM Utiliteitsbouw-Utrecht | Contractor (Site manager) | SM2 |
| Danny Burgstede | Site manager BAM Utiliteitsbouw | Contractor (Site manager) | SM3 |
| Onno Dwars | Developer VolkerWessels Vastgoed | Developer | D1 |
| Marit van Rheenen | Manager sustainability OVG | Developer | D2 |
| Peter Fraanje | Director NVTB | Supplier Industries | SI |
| Michel Haas | Director NIBE / Professor Sustainable materials | Material Expert / Academic | AC1 |
| Hans Korbee | Agentschap NL | Government | GO |
| Andy van den Dobbelsteen | Professor climate design | Academic | AC2 |

This diverse selection has been done to find similarities and differences between the different experts but also to look at the similarities and differences between the same types of experts. The abbreviations for the perspective have been mentioned in this table, in order to identify the perspective in the answers. This will allow for some discussion in the analysis and form a basis for the final conclusions.

**Case Study**

In order to answer the last part of the research questions, a case study will be used. Therefore one case is chosen that incorporates one element of construction which will be investigated. This case will be mapped in the current situation of construction and in a desirable (sustainable) way of construction (sustainability). This element can be chosen at will because it is meant to visualize the steps that need to be taken in order to achieve optimized sustainable construction. The model is so abstract that any element chosen is possible to investigates. By analyzing this specific element in this specific case insights on how to analyze the construction process and steps to optimize the process towards a sustainable construction process.

# 02 The construction process

In order to define the sustainable construction process, the elements of the current construction process will need to be defined. This is related to the first question on defining the elements of the construction process. These elements of a process have evolved over time and problems in this process have been dealt with in different manners. In order to understand the elements, the evolution and history of this process will need to be understood and will provide insight on why the process has evolved into the way it is now. This process involves various elements that have been found in the literature; these elements are described and sorted into a process design. This design has been tested by experts and their insights on the process as we know it will provide the defined construction process used for the further research. The goal in the next chapter will be to look towards a sustainable construction process. The impact of the process on the environment will be examined in order to design a solution in the next chapters.

This will be done by an in-depth literature research in the construction process. A description of the end results and aspects investigated will provide insights on the process. Starting with the history, evolution and definition of construction and moving towards the elements of construction, these processes will be discussed through the various pieces of international literature used to answer the sub-research question: *What are the elements of the construction process, and how are these elements related?*

## 2.1 History

Specific steps made during history have influenced the industry greatly in order to understand the problems that occurred over time, one needs to take these aspects into consideration. In similar steps, sustainability and its history will also provide new insights.

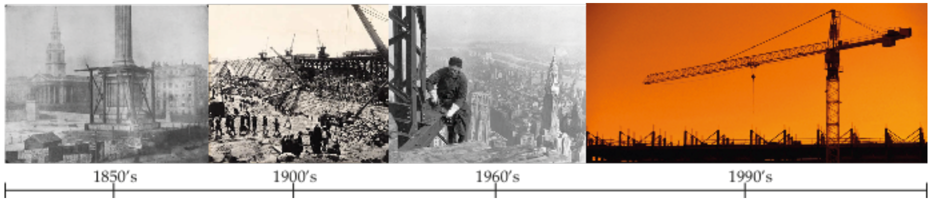



**Figure 2 -1** : Construction history. Images from retrieved from (Google, 2012)

**Construction**

Construction is as old as the pyramids in Egypt, the Colosseum in Rome and the Edinburgh Castles. People have been building ever since realizing they could provide for better shelter than caves. It still remains a mystery how some of these structures/ buildings were assembled and constructed in these early times. The buildings and structures in over different times in history have a big relation to the worshipping of gods or are connected to the afterlife. However, most construction during the whole history deals with housing.

Before the 16th century, the building form and method was mainly dictated by the availability of materials, the local climate and the cultural lifestyle of the people living in that area. There are some main structures like castles and churches that have been built by craftsmen for the church or wealthy people. Most people led a Nomadic lifestyle where they moved around all the time. This is motivated by the search for food (Riley & Cotgrave, 2009). Construction in this time was often done by making the materials on site and also assembling them in the same location. It is not until after the 16th century that there was a great increase in the demand for a more static lifestyle. Agriculture played an important role in these developments because food could be harvested and the need for people to move became smaller. The construction of buildings was done in a similar manner to the construction of castles and other structures; in a traditional labor-intensive building craft manner. The building manner was not organized by construction companies but by wealthy people, or families. It was at this time that bricks were made off-site and transported on site, although often not more than a couple of kilometers away. The prefabrication of stone and import of materials also took place through rich families and only small portions of the materials were imported. The assembly of the materials was done in hostile weather conditions with lots of rain and strong winds (Sebestyen, 1998).

During the 18th and 19th century, master builders were responsible for the design and construction of the major construction projects: they had all the necessary knowledge. In the 19th century, the role of the architect was to be an agent for the client and to be responsible for the design of a project. Over time, the number of specialists grew exponentially (Higgin & Jessop, 1965). It is in this time that not only construction became a business. This was the cause of the disadvantages of high costs for labor and materials. Together with uniformity of quality standards and acquiring skilled labor force, the construction of buildings was made vulnerable to faults.

The transportation of materials also grew exponentially due to the possibilities of the industrial revolution and shipping possibilities. The construction companies were increasing in size and unable to handle the demand for housing in this period. This led to the 1850-1900 revolutions and the transformation of traditional construction towards post traditional construction. The introduction of Portland cement is an important aspect for the $CO_2$ impact of concrete on the environment, energy requirements for steal also also have a drastic impact on the environment (due to coal and oil needed to heat the steal). Advances in transportation mechanisms and technology made it possible to import materials from further away and also allowed for exclusive materials to be used in foreign countries. Transportation methods introduced the first logistics management aspect and the need to coordinate (during) construction (G. M. Winch, 2011).

Furthermore, the transportation of materials on-site had an impulse due to the development of a mechanical plant site with cranes and bulldozers that made five craftsmen replaceable to one machine. This allowed the necessary production improvement of construction. However, the large part of the construction, like masonry, was still done by skilled craftsmen. On the other hand, the materials are largely being prefabricated in industrialized buildings where the quality of the products has gone up through this development (Kibert, 2008). This allowed for better quality materials and less impact on the environment. Since the Second World War, building construction changed considerably from a technological and market demand point of view (Sebestyen, 1998). The driving factor for this was the development of new materials, prefabrication and equipment. Construction projects have become larger and time pressure more urgent.

From the 1950s onwards, rationalized building took place, meaning that organizational and planning aspects used in the production and manufacturing industries are then implemented in the construction industry. An important aspect of rationalized building is that the production - assembly of materials - is ensured during all stages, not waiting for materials and not wasting time. This has a close relation to logistics. The aim of this was to ensure cost-effective construction, within time parameters, while maintaining quality. This would imply that continuous, effective provision of all resources (labor, plant, materials and information) is done by different measures.

An important component of rationalized building is the Modern Methods of Construction (MMC), also referred to as modular building, industrialized building, system building etc. This term is generally accepted and refers to construction methods that seek to introduce benefits in terms of production efficiency, quality and sustainability. This MMC had to deal with a number of important aspects, the first of which is the skill shortages in labor. These shortages were solved by training labor and reducing the work that needed to be done by the labor forces. Quality was also an issue in 1950-1960. There was a high demand for quantity and not a real quality demand. The introduction of building regulations allowed for some performance assessment but not in a substantial way. The sustainability was not seen as important as quality at this time.

It is from 1980 till now that technology evolved into the idea that we can build anything. Just take a look at Las Vegas, where in the desert a city flourishes, or the new Burj Khalifa in Dubai (eight-hundred meters high). It is in this time that the quality assessment of buildings has evolved in a manner that ISO 9000 has separate assessment methods for quality. Furthermore, the safety of construction has improved drastically, where before 1980 lots of construction workers died due to activities, now there is zero tolerance when it concerns safety. This is also included in the ISO standards. This process does, however, provide a building but also additional impacts on the environment.

## 2.2 Evolution of management in construction process

There have been several different initiatives to improve construction efficiency and to develop corresponding solutions for the industry's problems. We recognize strategic initiatives like industrialization, mechanization, contractual and organizational relations and computer-integrated construction. There are three developments towards modernizing construction and one corrections to mainstream construction (Koskela, 2000). The development towards modernization includes the following concepts:

**Scientific management**
The studies on centralized and formal production control have been adopted widely with the development of the critical path method and its related software. However, in practice, the integration of ideas of formal and centralized control have been slow: "many small and medium-sized contractors do not readily accept the notion that their profitability can be substantially improved through better management of the materials" (Thomas, Randolph, E., & Steve, 1989).

**Industrialization**
Under the influence of the widely reported success of mass production the idea of industrialized construction caught the attention of the public and construction industry. It was not until after the Second World War that industrialized construction received attention in the form of attempts to implement industrial construction in the industrialized building methods. Nowadays, the usage of pre-fabricated elements has increased together with the pre-constructed materials. Japanese house producers have developed an industrialization of construction (Gann, 1996), which can almost be seen as a production line of houses. However, Japan is the only country that uses this method and therefore can be an inspiration to others.

**Mechanization**
There have been developments in which machines like tower cranes and mobile concrete mixers are used more widely since 1950. Computers also have automated certain tasks in construction and supported information flows, although no real computer-integrated construction has yet been created. The impact of technological initiatives has been disappointingly modest according to some. The building information model (BIM) model is being assessed at this moment and can be seen as the first real leap in the development of mechanization of the construction industry for a long time (Eastman, Teicholz, & Sacks, 2008).

**Mainstream construction**
This is a mixture of transformation concept principles and legacy of the crafts period. The main reason for this is the separation of design and construction, procurement through bidding and institutionalized roles and division of labor (Koskela, 2000). This is seen as the fragmentation of construction as opposed to the master builder that knows everything. Now more people with specific knowledge, of whom cooperation is a necessity, are involved, allowing for communication to become an important issue in the quality of the group.

**Findings**
The developments above illustrate the struggle of the construction industry with the developments throughout the 20$^{th}$ century. Koskela (1992) finds that there are analogies with the production industry, and that construction practice has been influenced by approaches of the transformation concept. This while more recently, the flow concepts and value generation concepts are widely used in the production industry but not in the construction industry (new production strategy).

The fact that mainstream construction and other strategic initiatives are not yet worked out in the construction industry and have the desired effect could be because of the limited literature is from around the 1980's. It is striking that the first scientific journal on construction management was founded in 1983. The Construction Management and Economics journal (CME) was first published in the spring of 1983. The rise of construction management and economics as separated academic and scientific subjects seems to have evolved after the second world war. This was observed by various researchers such as Laufer and Tucker (1987).

The discipline of construction management has to a small extent, been directly occupied with problems of construction as experienced in practice (Koskela, 2000). This posses the question that construction has a problem to make a step in efficiency. Something the production industry has already made.

## 2.3 Production vs. Construction

The new production process of Koskela and also in the research in Higgin & Jessop, the development of the production and construction industry have looked at. In these studies, the development of the production industry has shown a lot of comparison with that of the construction industry but where the development of the construction industry, stagnated, the development of the production industry made a big step in waste reduction and efficiency compared to that of the construction sector (Koskela, 2000).

This is not the only reason that the production industry made a step. The production industry also started by integrating their supply chain and using the supply chain to create extra value. This could be done due to the manner in which products were made. This can be explained by using figure 2-2.

This figure illustrates the manner in which a product is made. This always starts with a need from the market. Lets take for instance the need to communicate in a flexible manner. This need is then embraced by the production industry and within the limitations of the market this need is fulfilled with a mobile phone. The level of creativity within the limitations illustrates the level of innovation that is needed to fulfill the need. By involving the supply chain, the production industry was able to increase the boundaries and to increase the level of creativity.

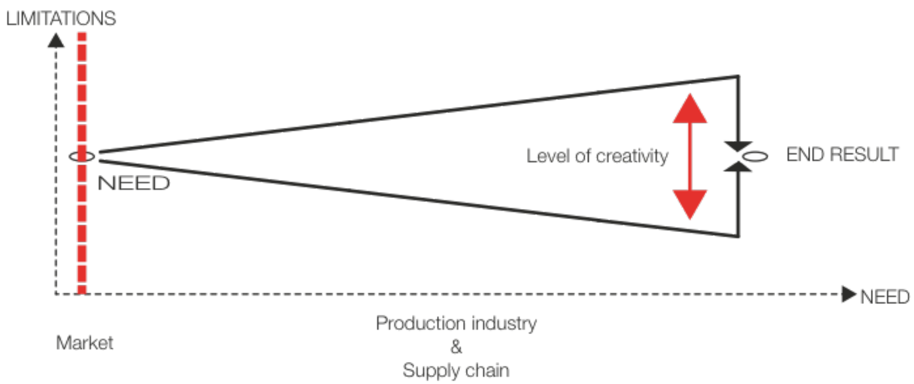



**Figure 2 -2** : 'From need towards product' Production industry

For the construction industry, the manner in which the need is formulated is far more complex than it is for the production industry. This process involves more than simply a need and the industry to provide the end product.

For most of the developed real estate, the manner of working is such, that a need for housing (from the market) is often derived from the municipality (through the aldermen). This is then put forwards in a program of requirements that is then interpreted by the urban planners/designers and the building regulations. After that, the plan that incorporates the need is put forward to the market where they have little room left for creativity because the previous parties have used this creativity to formulate a need for the industry.

The red line symbolizes the point from which the industries are involved. It also shows also the amount of creativity that can take place in the different industries and indicates that the level of creativity in construction cannot be improved as much by involving the industry. This will provide the necessary improvements, but the three steps before the need comes to the market will need to be sorted in order to increase the level of creativity. This research will focus on the moment the need comes to the market and how this process is visualized. In order to improve the process, while involving the supply chain to increase the level of creativity. Thereby, the research will limit itself towards the need and the development of the end product from the moment the need comes to the market. The previous phases are the domain of other studies. They do. however, explain the reason why construction lags behind on the production industry.

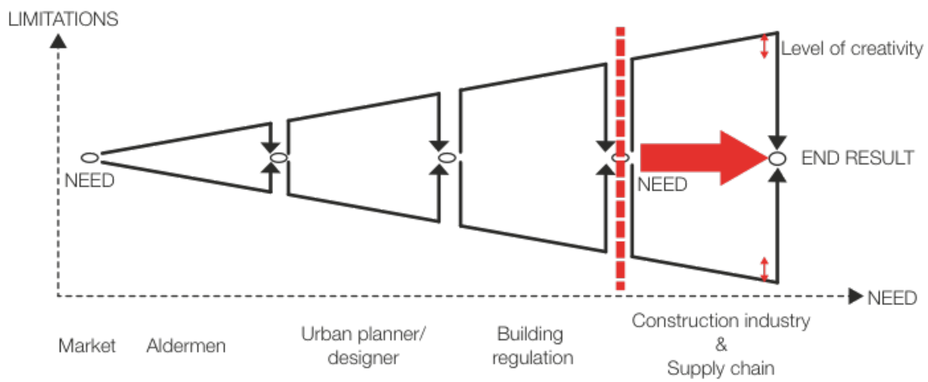



**Figure 2 -3** : 'From need towards product' Construction industry

## 2.4 Defining the construction process

In this part, the design process of the construction process model will be described. The manner in which this is done can be found in the book of Clive Dym & Patrick Little (2004). They have described the engineering design in their book ‘Engineering Design’. This book describes the design process in a way that is insightful and meaningful in order to understand what steps need to be taken. They have many descriptive and prescriptive models for the design process from which one will be used in this research because it was also prescribed by the authors of the book. The model of the design process shows three active stages. The starting point (not part of the stages) is the statement, which is often identified as the need for a design. The end point is the final design or set of fabrication specifications. The stages in between are as follows (Dym & Little, 2004):

- The first stage is the conceptual design, in which the designer looks for different concepts that can be used to achieve the objectives. A concept is an outline solution to a design problem.
- The second stage of the model is the preliminary design. In this stage the designer embodies or endows design concepts with their most important attributes and then starts to select and size the major sub-systems, based on lower-level concerns that take into account the performance specifications and operating requirements.
- The detailed design is the final stage in which the designer refines the choices made in the preliminary design and articulating early choices in much greater detail.

These stages are of importance in the design of the process model. This process is an engineer seeking a solution for a problem that has been defined, in this case, the problem of defining a construction process in a flow model. Furthermore, the design of this process will be done through the assessment of literature and conducting interviews in order to scientifically map the steps taken in the design process.

Having made the construction process model based on the literature that often dated back to 2008 or 2006, therefore, wondering if this model was a representation of the current construction process. The expert interviews were used for a reflection on the model of the current construction process and thereby dating it for 2013.

The interviews conducted with twelve experts in the field of construction, were used for various reasons. The first part of the interview was about finding the right flow model for the current construction process in order to communicate initiatives mentioned by the experts in the first part of the interview.

The interview was set up for three different reasons, the first discussed above, together with the defining sustainable construction and assessing obstacles to achieve sustainable construction.

The following questions were used to derive information about sustainable construction. The first questions were to see if the model reflected the personal vision of the expert in the construction model.

*The design of the ‘sustainable construction process’ before you includes a number of elements; do these elements represent the full scope of a sustainable construction process?*

*What would be missing and why?*
*Should elements be left out and why?*
*Do you have anything to add and why?*

The reflections of the interviewees will be divided among the different types of experts interviewed, because the answers by the same type of interviewees were very similar.

#### *2.4.1 Construction as part of the property life cycle*

Construction is part of the property life cycle. Therefore, construction is part of a larger context. The literature from the Delft University of Technology visualizes the elements that belong to the property life-cycle according to the Netherlands Normalization Institute. The execution phase (‘Uitvoering’ in Dutch) of the cycles is the construction part. The term ‘construction’ is used as opposed to execution in the rest of the text due to the better visualization it gives when talking about this aspect. The property lifecycle includes 4 main phases; initiation, preparation, execution (construction) and use (exploitation). All the actors involved must appreciate that to greater or lesser degree. Because of the very cyclical nature of the life cycle, their decisions and actions will have consequences in all other stages of the cycle.

Another cycle, called the real estate development process, uses different phases in its process; initiation, definition, design, preparation, construction, maintenance. The goal of this process is to make a physical object that is needed at a certain point in time. The process follows the different steps in sequential order and a building is always in one part of the life time cycle (Wijnen, Renes, & Storm, 1999). However clear this may be, the model does not incorporate an important aspect of the cycle which is demolition and renovation. The book of Wijnen (1999) explains that this aspect takes place in the construction process. Decision-making about this aspect is done in the maintenance phase of the project, relating it to the different motivations for a new building. The absence of demolition in the real estate development process allows to add demolition to

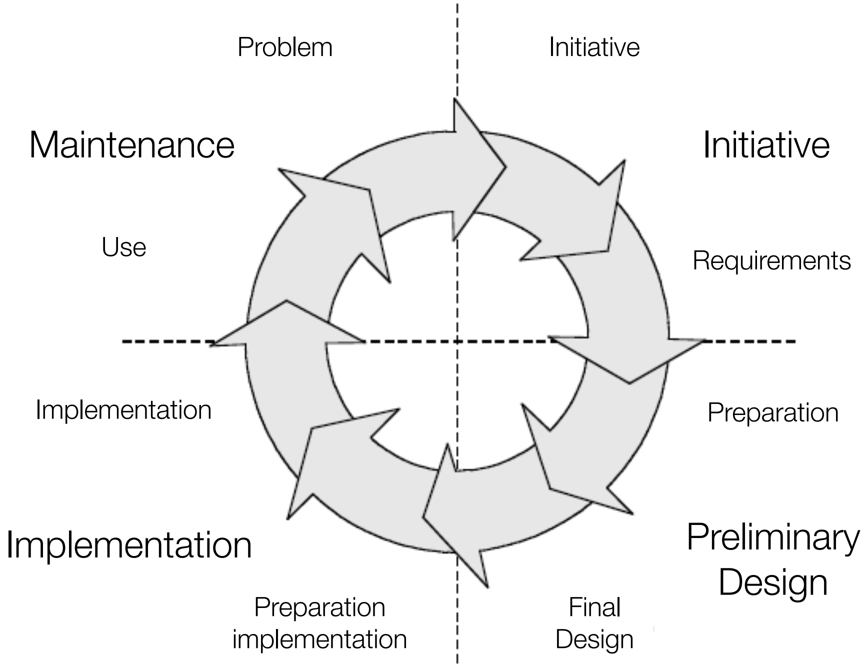



**Figure 2-4**: Property life cycle (Wamelink, 2009)

the book of Hendriks (1999), that illustrates how this phase fits in the real estate development phases. Before the building is built or loses its function, there are various ways on how to decide upon demolition. The model in this book illustrates that all the phases influence the demolition process, including construction (F. Hendriks, 1999).

Knowing the full property life cycle and real estate development process we can focus on the construction phase and the phases before and after. A definition of construction has to be sought. There are various books on construction and its technology. Madan Mehta (2009b) describes the subject in a manner that is representative for a various amount of construction technology books. He describes that: “Construction is a complex, significant and rewarding process. It begins with an idea and culminates in a structure that may serve its occupants for several decades, even centuries”. Like the manufacturing of products, building construction requires an ordered and planned assembly of materials. Buildings are assembled outside by a large number of diverse sub-constructors and artisans on all types of sites and are subject to all kinds of weather (Mehta, et al., 2009a). This indicates the number of different phases on a different scale level meaning these are sub-phases are for the process.

The Dutch book of Jellema from Flapper (1998) looks at the Dutch NEN 2574 norm. They use four main phases in the building process including a number of sub phases. The construction process is defined as the process of getting from the program of requirements of the client, to the realization of the actual product that is desired by that same client. This gives us a larger variety of frameworks but no definition.

### *2.4.2 Definition*

Opposite to the phases of the building and construction being one of the phases, the judicial definition must be mentioned because this is of great importance in the construction industry. Most contractors use this definition in all projects, due to its perceived value as a judicial definition. Judicially, the input and output of the construction process is defined in the uniform administrative conditions (UAV‘2012). This document states that the construction phase is bounded by three reference dates. The building instruction (1), the start of the construction activities (2) and the delivery of the final product (3). In a legal sense these reference dates play an important role in construction because of contractual agreements. There are, however, more specified definitions for the construction process.

Madan Mehta's (2009b) definition proclaims: "Construction work comprises many activities, including the assembly of materials, performed by construction workers'. This definition is strongly related to the actual work done on-site and the activity 'construction'. Sarkar & Sarawati (2008) have defined the construction processes in a more scientific manner. They have related it to the more generic activities of civil engineering. They start with the definition of technology and civil engineering that have made the impossible possible: "Engineering is the application of laws of science, mathematics and economics for production of things, and civil engineering is the principle branch of engineering concerned with things constructed as opposed to things manufactured, mined, grown or generated" (Sarkar & Saraswati, 2008). Because of this, construction is the implementation of most civil engineering work. "Construction technology is the application of applied sciences in order to enhance productivity and quality of its products" (Sarkar & Saraswati, 2008). The nature of the construction activities involved, the place where construction work is to be carried out and the time available for construction work are the three factors (mobilization of men, material and timely implementation of works) that determine the effective construction process.

In the next phase, the following definition will be used to define construction. The activities, actors involved in the activities, place and time define the elements of a construction process.

> *"Construction technology is the application of applied sciences in order to enhance productivity and quality of its products. The nature of the* ***construction activities*** *(performed by* ***labor****) involves, the* ***place*** *where construction work is to be carried out and the* ***time*** *available for construction work are the four factors that determine the effective construction process"*
>
> *(Sarkar & Saraswati, 2008)*

### *2.4.2 Construction activities*

The most general conception is to see construction as a set of conversion activities (*process*) aimed at a certain output, a building, with the input of materials, labor, equipment and process energy (Koskela, 2000). This activity view of construction is shared both in traditional and modern methods in the industry. The concept creates a link with the production process of Koskela (2000).

The phases illustrated in figure 2-4 show the full scope of the building cycle. Examining various pieces of research, we can see that there are various sub-phases in the construction phase. One of which is the preparation phase. A potential important phase, because the decisions taken there, (Riley & Cotgrave, 2009) influence the construction a great deal. This is also called the engineering of the building, often done by construction companies themselves.

The property life cycle forms the basis for the new construction cycle. This is in a more detailed manner. This has to do with the scale levels in which we are operating. A system has its inputs and outputs at different levels and has its own internal processes.This means that, depending on the scale level, you can look at a process in a transformational manner, but internally you can close the input and output through cycles, which is more similar to a flow principle (Koskela, 2000). In order to converge the subject of this research, a larger scale level is analyzed (property life cycle) while moving towards a smaller one, in order to understand this process (construction phases) (van den Dobbelsteen, 2012). This indicates that we will zoom in on a part of the property life cycle

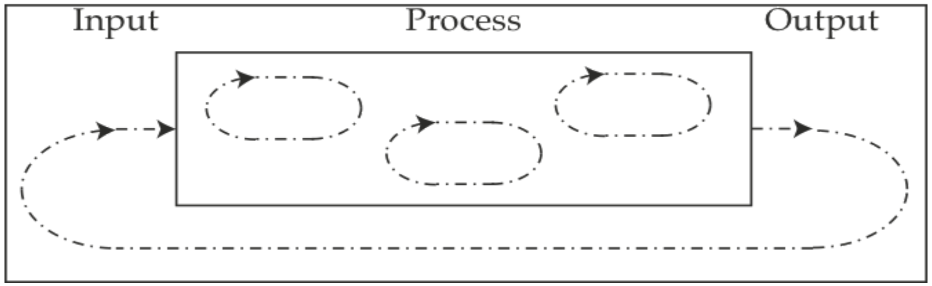



**Figure 2 -5** : Scale levels processes and thereby will disregard the others, in order to focus and delineate the process.

In the traditional construction process, the construction entrepreneur gets his job through tendering (this is why it is often called a contractor). The client mainly chooses the economically most advantageous tender. The contractors in turn always do the same towards their supplier industries and sub-contractors. This price competition, combined with the most unique and complex nature of a construction project, means that every project starts with a large number of different companies with separate contracts (Voordijk, 1995). Companies are always changing partnerships in order to continue with other projects. After completion, the project team of contractors and subcontractors part again. This temporary nature of relationships, and the existing project-based mode of production, has led to a culture with strong short-term thinking (Korbee, 2012).

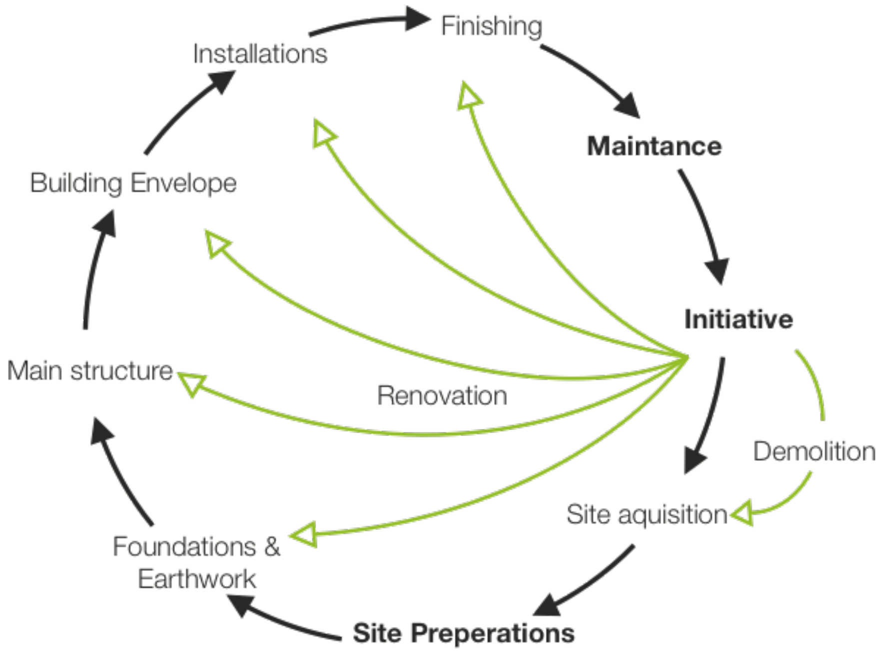


**Figure 2 -6**: Phases of construction used

**Initiative**

The start of the construction phases always include the initiative to build something for a client. This forms the basis for the first choice; renovation or demolition and indicates the start of the process of preparations. The choice for the demolition of renovation determines the site preparations that need to be taken. Figure 2-6 shows the different phases including the main phases on the property life cycle. Construction has been divided into 5 main phases and will be discussed later.

**Demolition & Renovation**

The literature often shows the demolition process as a process before the construction process. This is due to the fact that another specialized contractor performs the demolition. If in the same location a new building is built, it should be seen as part of the construction process (Diven & Shaurette, 2010). Nowadays, most developments are redevelopments due to the dense areas we live in. For this reason, the client could consider renovation of his/her current building. This often excludes the foundation and main structure, but this is not always the case and can still be part of the renovation. The construction industry is about integrating and assembling materials, while the demolition industry is about disintegration and deconstruction of materials. Specialized demolition companies are involved due to their expertise in the demolition and deconstruction of buildings on-site. Demolition is a waste producing activity. Therefore, waste is in the intended output of this transformation process, instead of at the building in the construction process. Energy waste has to deal with the energy used for the activity that was not needed to complete the task. The largest part of demolition is about material

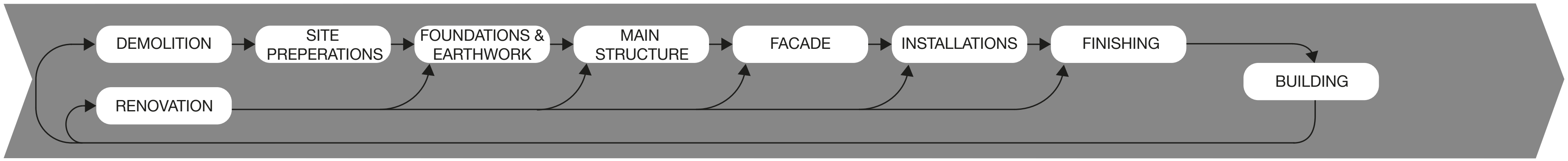


**Figure 2 - 7**: Phases of construction put into the construction model

waste (Winkler, 2010). This waste can be dealt with in many manners and is currently often sorted on-site or off-site and then recycled in order to make secondary raw materials (C. F. Hendriks & Jansen, 2009).

All three experts in management mentioned the aspect of demolition. In ideas about demolition and incorporating it in the construction process, they also mentioned renovation as an alternative. They indicated the inclusiveness of this activity in the construction process as well.

The developers that have been interviewed both mention that renovation is an aspect that would be missing in the main process, (this deals with the different stages of the design). They also stated that the developer's role in construction is often done by making agreements and involving construction specialists in an early stage in order to assess whether or not renovation is an option (Rheenen, 2012).

**Site acquisition**

The site acquisition is not necessarily part of the actual construction process. This phase could be part of the construction activities, but is not in the true nature of the contractor; therefore, it will not be part of the construction process model, but merely something to take into consideration. The contractor is sometimes involved in an early stadium of the process and is asked for advise about locations. Most often, the client asks advise from the developer, contractor or architect about the possibilities on-site, this is because the client is often only involved in this process once in his lifetime. The client bases his/her decisions on the priorities within the company and its main production focus. The building is often only a place where their main organization activity can take place. These aspects are often forgotten and because of this, external advisors are involved (Hanna & Menches, 2009). These actors play an important role in the beginning of a development and have therefore been visualized in figure 2-6. Within the site acquisition, the preparation documents that need to be prepared are included, the preparation documents, also known as construction documents. The purpose of these documents is to prepare all documents required by contractors to construct (and engineer) the building. In this stage, the architect intensively works out the building to the 'nuts and bolts' and develops the documentation often together with the contractor (Mehta, et al., 2009b).

**Site Preparation**

When the project is approved and the building contract is signed, the construction group is assigned to deliver the end product in time and within budget with the right specifications (quality). Then, the team is placed on-site and prepares the construction site for construction (Flapper, 1998). This phase of the construction process is often the start of the projects for contractors. The contractors work on projects that have a start and an end, unlike public private partnerships and special contracts where for instance the construction company is obliged to maintain the building . These activities that take place in these phases include a number of aspects that a contractor will need to take care of in order to start the construction (Carpenter, 2001d).

- The first category would be infrastructure, like the roads to the site and on the site that are needed to construct the building and which allows for temporary storage. This, together with the temporary offices that are needed and made accessible.
- In order for a modern construction site to function, electricity is needed for the site office, lighting, equipment and other aspects. This electricity is an important factor because the electricity is also needed when the construction phase is finished and the exploitation starts. If electricity is not available, diesel aggregates are used to provide electricity.
- Gas lines will also have to be made available for the site. This is also part of the design.
- The water on-site also has to be there after construction is finished just like electricity. Therefore, a design where the main lines can be integrated in the building design is necessary.
- Another aspect in the preparation is legislation which, includs building permits and construction permits that are needed in order to start the project. The insurances and safety protocols also have to be taken care of.

Once these aspects have been taken care of and the construction site is fully prepared, the construction may commence. The main contractor is often the person that is responsible for these aspects, which allow the sub-contractors to do their work. The various activities in construction discussed will also indicate the main scope of the research project, closely related to construction site management. The site management often starts with an inspection of the location that will provide the necessary input before the activities mentioned above will commence. The location also involves specific characteristics that influence the construction, for example:

- Temperature, rainfall statistics, drainage possibilities  and environment.
- The soil investigation reports are a crucial input for the next phases. These are are often the boundary conditions and could influence a client to build in an other location with more favorable boundary conditions. This is in relation to the risk of the projects (Beer & Higgens, 2000).
- Distance for transportation is an important aspect to take into consideration in relation to the costs of the project (Holroyd, 1999).
- Accommodation possibilities and services related to the construction site. In densely populated areas, this could be a problem and a solution will need to be made in order to proceed.

**Construction**

The activities involved in the actual work done by the main contractor and sub-contractors can be put into five main phases. Four of these five phases are also used in the sequential construction process by Jos Lichtenberg (2005). The foundation of the building, often constructed by a specific sub-contractor, is added to the four phases of Jos Lichtenberg (where it is part of the main structure) due to its special nature. The next part is the main structure and facade; this involves almost 60% of the materials used in the total construction process (Haas, 1992). The installation part of construction is becoming increasingly important in modern construction and can include up to 40% of the costs for materials that are used in construction (Harris & McCraffer, 2001). The finishing part, or interior, of the construction often involves a variety of sub-contractors specialized in plastering, inner walls masonry or carpentry.

The most interesting element of the construction site is that all the supply chains (materials, energy, design, engineering and construction) come together at this one place, which is managed by the contractor. The contractor is able to manage the five main phases which include a lot of logistics when working in a good time-schedule plan. This actor in the chain has a central and curtails position and has experience with the management on site and with different supply feeder industries (Carpenter, 2001b). A different specialized sub-contractor often manages all the phases, because they do their activities faster and better than construction companies themselves. They are part of the supply chain and are therefore needed to do the construction. The sub-contractors often closely work together with a supplier to optimize the products.

It is interesting that some people within the construction industry state that the contractor is just the manager of the process. Project management on-site is very different than project managing at other companies. In the construction industry of the early days there was the master builder (figure 2-8) that knew everything. This involved the skills in logistics, construction, design and finance. Skills that not all project managers possess.

Nowadays, the process has become even more complex and there are various fragmented experts about all aspects of construction available. It is now of great importance that project managers know the right aspects in the right time and have the knowledge about who knows what. The role of the contractor has now evolved into the role of master builder (figure 2-8), with the exception that the aesthetics are often still done by an architect. The contractor also often brings in a lot of experience and money

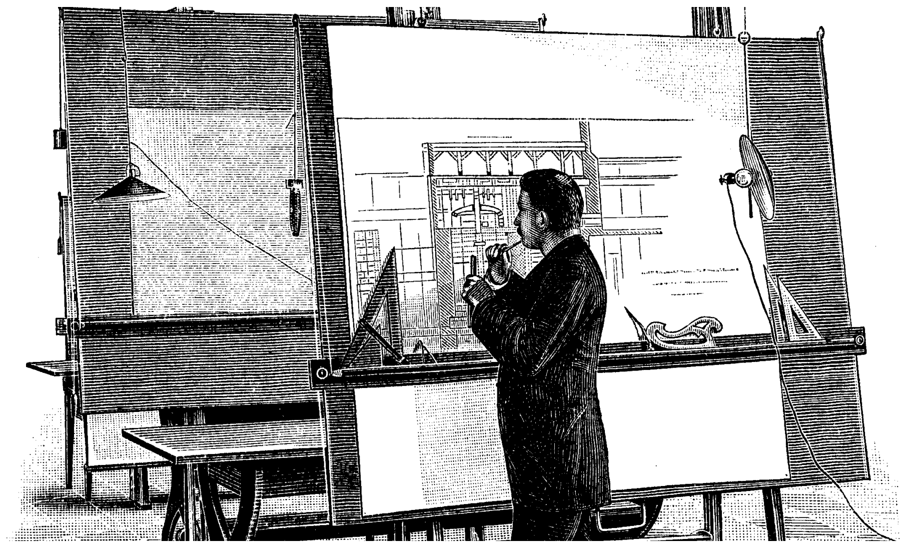


**Figure 2 -8**: Master Builder (Wikipedia, 2012) and is therefore a indispensable link in the chain. The client often still approaches architects due to their perceived role as master builder in the early days. This is wrongly imposed because architects often do not know enough about the process; they focus on the product. The role of the contractor as spider in the web between architect, client, suppliers, energy delivery services and logistics makes him a critical player (Mehta, et al., 2009b).

**Maintenance**

The use of the end product, the building, is the largest part of the building life cycle. If the quality of the building is according to certain regulations, the exploitation can be very long. This phase of the building life cycle and property life cycle is of great importance in the construction of buildings. The construction process is designed to produce the building.

Once a building is made, it will deteriorate over time due to the influences of weather and usage. The maintenance of a building includes maintaining the level of the quality of a building at a specified quality level. This involves various forms of maintenance, like cleaning, but also involves repairing specific parts of the building.

### *2.4.3 Labor*

The activities that take place in a process need to be conducted by people. These people involved are often organized in the form of an organization or a contract form that deals with the relations between different actors and teams. These construction teams form the basis for the cooperations in the teams.

The selection of a construction team: this team consists of a general contractor and a number of specialized sub-contractors, together with an architect or developer. In large construction projects, it is the trend, the trend to form a consortium with other construction companies in order to prevent the contractors to go bankrupt. The team organization is often closely related to the contracting form (Mehta, et al., 2009b). The contracting include the tender procedure of the contractors and the bid for the tender. The bids includes the different design-bid-build construction contracts in order to develop the project. Furthermore, when a contractor is awarded the construction project, the contract will also include specifications. The traditional form of contracting involves the 'classic triangle' that is used in a number of construction projects. Within the classic triangle, the employer first commissions a structural engineer or architect for the design of

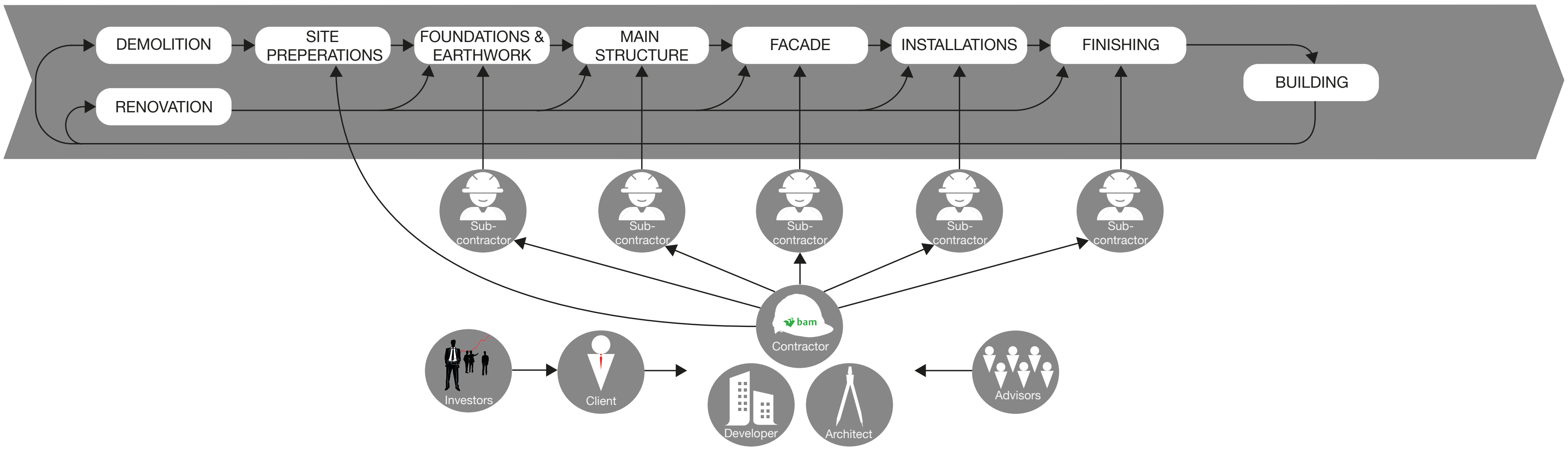



**Figure 2 - 9**: Actors in the construction model

a project on basis of the DNR 2011 regulations (Bruggeman, Chao-Duivis, & Koning, 2010). After this has been done the employer engages a contractor for the construction of the design on the basis of the UAV 2012 conditions. This will be referred to as the building contract in this paper.

The contracting form used in this figure is the design and build contract where the architect, developer and contractor work together in a team, using the expertise of external advisors, working on a need from a client that is often backed by an investor.

The investors have a lot of power in this process because they provide the money for the project or client. Contracts are of importance to these actors, but more important is making the cash-flow of the project insightful and together with the return on investment model and risk analysis in order for him to join the team. They are only involved when more money is needed or when major problems occur.

**Construction company**

A construction company consists of a headquarters where the marketing, acquisition and preparation of the construction is done. Construction takes place on a property location. For each building site, a temporary building Construction Company is founded (project team). On-site construction roads are constructed and storage is created so the distribution system can incorporate the large variety of materials and parts from the factory to carry and store temporarily until the materials can be processed. On the building site, there is a transportation system in the form of construction cranes and lifts, which are present for the transportation of building materials and prefabricated building elements. There are on-site machinery and tools for editing and assembling components (Flapper, 1998). On site accommodation is available for personnel (including a stand accommodation for the management). The planning of the deployment of all teams in the correct order, to perform their work, is also an aspect dealt with in the preparation. If the building is completed, the building construction business will be dismantled and all equipment will be removed.

The labor aspect in the construction process can be incorporated in the implementing construction company. They are responsible for the labor in the construction phase and on the construction site. The main task of the construction company is to take the job of construction, to construct the product and to deliver the building, with the goal to develop the building against lower costs than the available contracting sum. The construction company is a permanent organization with a policy focused on continuity and return on the longer term. For the continuity this means that the contractor will need to construct enough buildings in order to deliver the yearly turnover. For the return this means that the contractor will only construct buildings that deliver enough potential profit. From this point of view they can better outsource certain activities to specialized sub-contractors because the cost price is better for the main contractor.

A construction company has many employees and all of them deliver labor in the construction process in order to deliver a building as a product. This is done by taking the organization of BAM that has the following structure:

- The implementation (realization) group: the core of the construction company. It is a reservoir of people that are deployed to construct a building. This includes numerous functions, from project leader to executer and construction teams.
- The technical staff: this group of people is there to support the execution group with their technical knowhow and organizational qualities. Furthermore, this group calculates and assigns projects and takes on construction projects.
- Commercial staff: these persons promote the organization and make clients known with the organization in order to acquire projects.
- Technical management and maintenance: this group works on the maintenance of larger projects or public private partnerships and ensures that the building is maintained at a certain defined quality.
- The administrative group: these people are the accountants of the organization and are responsible for the administration and income of the employees.

**Sub-contracting**

The actual work is often not done by the contractor and his personnel but sub-contracted out towards sub-contractors that do specialized work. Another aspect of importance, according to construction management experts is the fragmentation; the possibility to influence sub-contractors by contracting is there, but is not used. They believe that sub-contracting (fragmentation) is a good thing, but not at an optimum at this moment. They also indicate that the main contractor provides aspects like energy, water, tools, insurance and safety.

Sub-contractors deal with material suppliers and the main contractor deals with the sub-contractors. This is something that my mentor at BAM, Joep Radermacher, mentioned as well after the interviews and it is something that will have to change in the process model. Another aspect mentioned in two discussions was the communication between the main actors. Communication depends on the contract form chosen and is often not influenced by the main contractor, the developer, the client or the architect. Furthermore, the contracts with sub-contractors are impressionable and are an aspect that could prove to help the process in a positive manner.

#### *2.4.4 Place*

As opposed to the production industry, construction always takes place outside and not within a controlled environment. Weather influences determine the process a lot and methods of working are dependent on the climate in different countries. This location is often unique and has its own characteristics. The site preparations deal with the main aspects of the location in order to prepare for the conditions on site.

#### *2.4.5 Time*

When designing an abstract model for projects, the time factor is something that is difficult to incorporate. This is due to a number of factors, the main of which is that construction processes are often performed in projects. These projects are unique in time, costs and design. When designing an abstract model with activities that can correspond to all projects, the time scale is still different for the activities. Therefore, the time line will include a variation of time spent on activities. The construction phase incorporates two-three years compared to 25-100 years in the exploitation.

## 2.5 Supply chain

The construction process can be described as a process that assembles a building on-site within a specific time and budget, by following different steps. A process is still not tangible without the materials that are used during the process. The construction process, processes materials on location (place) following an order of activities. The materials are often derived from the material suppliers who also get their materials from material manufacturers, who use the raw materials quarried. This chain will be looked at in-depth (part three in figure 2-10). But can be seen as part of the process needed for the construction process to take place.

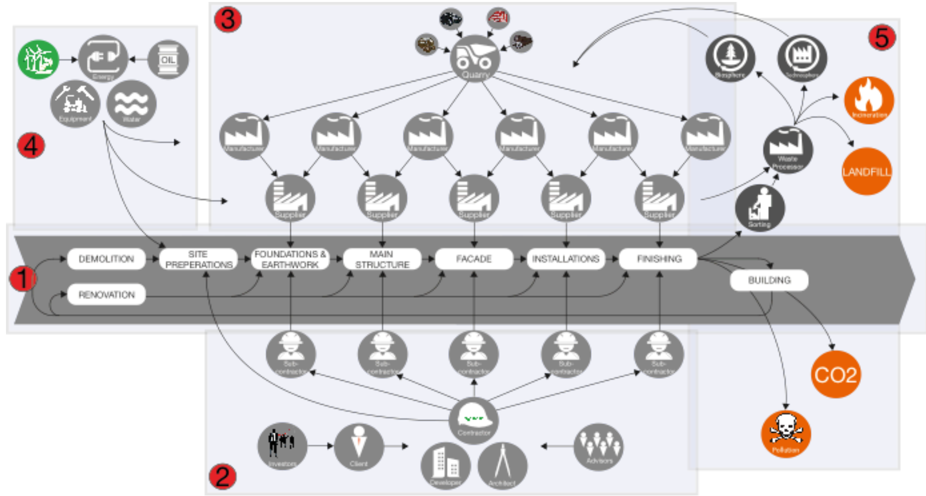



**Figure 2 - 10**: Parts of the construction process

There are more elements of the process that are needed in order to achieve the process result. Various forms of process input (part four of figure 2-10) like, energy, water and equipment. This is not only used by the construction process as defined but also by the supplier feeder industries.

The goal of the process is to construct a building. Together with this building the rest materials (waste) and $CO_2$ emissions from activities in the process and supplier industries also come to being. Together with the pollution these form the process output of this design (part five of figure 2-10).

The buildup of the model into different layers and manner of layout was the first point of reflection all the interviewees they all agreed upon. This led to the buildup of the model as it is now, with its various layers and segments in order to make it insightful. The other experts had somewhat different reflections on the construction process model made.

Hans Korbee from Agentschap NL thought that the model was in need of more hierarchy and layers, together with a clear view of lines ‘lines: are often crossing each other’ (Korbee, 2012).

### *2.5.1 Material industries*

Contractors, and therefore sub-contractors, are supplied with materials by the material industry. According to the interviewed experts these suppliers are often also the sub-contractor at the same time, this is not always the case. This industry is separate from the construction industry, yet it is part of the supply chain (vertical cycle) and not the property life cycle (horizontal cycle). The material supply chain goes from quarrying the materials to the material processors, manufacturers and suppliers. This industry is seen as the industry that has the most impact on the $CO_2$ counting of materials due to the large distances travelled over the world and $CO_2$ from production lines (Carpenter, 2001c). The construction industry is part of the supply chain and is involved in different parts of input. The material input has to run through a whole industry that produces CO2 and used energy. Nowadays this is referred to as embedded energy or $CO_2$ (Koster, 2010)).

The industry behind the different materials which are used during construction, has to do with the life cycle of the materials. During construction more than 10-50 different materials are used. This means that there is a different life cycle for every material. The basics behind the material life cycle is that natural resources from the earth crust are transformed into useful materials for construction. This transformation starts with mining the raw materials and transporting them towards the manufacturing plant. This plant is part of a manufacturing chain where the raw material is often transformed into material that is directly useful for construction or to material that will need to pass through new manufacturing processes in order to become the materials necessary on-site. This can repeat itself up to five times (for aluminum or paint) and then the material is transported to the suppliers and engineers of systems used on-site. These supplier design standard product in which the materials like metal, plaster, wood, concrete can be used in buildings. They then produce the materials that are actually transported towards the site. The main abstract processes found involve mining, manufacturing of materials and the suppliers that supply the contractors with construction materials. This process requires energy and produces $CO_2$ and pollution. What happens on-site with energy usage, $CO_2$ production, pollution and equipment use also happens in the within the material industries.

Peter Fraanje is director of the NVTB Netherlands. This is an organization that looks at interests of supplier industries for construction. He states that the model should show that multiple material manufacturers supply different material suppliers and that various suppliers supply various projects.

### *2.5.2 Process input*

Next to the materials needed, various other forms of input as previously discussed are needed. For example energy, equipment and water. These form the basic elements needed to perform the process. This research would see them as part of the process (within the scope).

**Energy**

The energy used on-site and in other production processes involves a chain up to the energy production, by using limited and unlimited resources like solar and hydro energy. The suppliers of this energy are seen as a separate supply chain that also delivers the materials to manufacturers and suppliers. The responsibility for energy usage lies within the main contract domain, but, without paying, sub-contractors may use the electrical grid as well. The energy that one buys comes from energy companies and is created by different sources. This is often measured in kilowatt hours (kWh) and megajoules (MJ).

**Equipment**

The used equipment from excavators, transportation and cranes run on diesel and therefore consume natural resources while they also contribute to $CO_2$ pollution. These are used during the production processes and also during construction. These elements in itself are not sustainable, but it is part of the production industry for these machines and transportation means. To examine these production lines on sustainability of the construction process is hard. Still the pollution and energy consumed by the specific construction project can be taken into account and are part of the construction process.

**Water**

In the construction process, water is used as material in various forms, e.g. concrete. It is also used as cooling of equipment or for cleaning construction equipment. This is often done by using water lines that provide clean water for homes meaning that this water becomes contaminated. It is used in large portions, and its is used as a waste stream in river beds for wastage.

### 2.5.3 Process output

The construction process also includes various elements that are produced next to the building itself. This is what will be referred to as the process output, involving:

- Material waste
- $CO_2$
- Pollution

**Material waste**

This part will elaborate on the aspect of waste. In the previous paragraph it is stated as an important factor in the construction process. The CIB proceedings and a book by Uly Ma (2011) indicate that this can be an important factor in the construction process. Waste is often defined as sustainable, yet incorporates different meanings and definitions. Uly Ma has defined five different definitions of waste and related them to the construction industry (Ma, 2011):

1. Waste is anything that is discarded, but can still be used to deliver value: This is used by environmental managers, and seen as a tangible product that needs some finishing to be reusable. This definition does not incorporate the full meaning of value, related to ideas of time and effort. Managers also waste employee time on useless activities while they hold the key to innovation.
2. Waste is any activity that does not add value: This definition can be seen as to simplifying the definition of waste. This can be done in the same way Toyota motors has defined waste: work= value adding activities + value enabling activities + wastage. The client pays for work and because work includes waste this also has value.
3. Waste is anything that the client does not want. This definition is too simple and is something that can be strived for but cannot be used as a definition of waste. The Toyota definition shows that waste is something a client has to pay for.
4. Waste is the difference between the final result and effort. This is a definition that shows that when making an effort for a final result there will always be waste. For example, while writing this thesis many literature read is not used and could therefore be seen as waste in the final result.
5. Waste represents a source of funds to pay for sustainable activities. This definition incorporates a number of things. The first is that waste costs money and that companies do not like to spend money. Secondly, it implies that sustainability has a cost and that this is doubled in expense when dealing with sustainability. The definition shows that waste can be a fund to pay for activities that are needed and thus pays for itself.

These definitions show that there are various meanings to the word ‘waste’, however, the last meaning shows an opportunity for waste reduction initiatives to take place and this definition can thus be used. The next step is to see what waste in a construction process includes. Toyota has indicated seven main wastage aspects in their factory: waiting, over-complex procedures, not working according to plan, overdoing, excessive transport, overstocking, defect and loss of ideas. These aspects are for a production industry but can also be seen projected on the construction process.

For this report, waste will be seen as: ‘Waste is anything that is discarded, but can still be used to deliver value in the same process or in an other process’ (Ma, 2011)

Currently, most of the construction and demolition waste worldwide is being landfilled. The Netherlands is taking good initiatives to decrease this amount and is a frontrunner in the sector (CIB, 2011). Landfilling is the process of disposing the waste materials, burying them and covering them up with soil. A significant part of this waste is being processed at material level or applied in foundations of infrastructure. A minor part is being combusted for example, wood and plastics. Recycling of building products remains limited to plastic window frames and PVC sewer pipes. Figure 2-8 shows the way in which construction takes place in various projects and shows that there is still some waste which is going to be landfilled. This is reduced by recovered materials (reusable demolition waste) and by sorting and reusing waste materials.

The flow diagram shows the different lines that waste can take. The first line shows that recovered materials can be reused instantly, and that other waste must be sorted in order to determine what is useful and what is not useful. The useful parts will be recycled and then reused as secondary raw materials in other industries, for example in production industries. The waste in this flow diagram only refers to construction waste. Demolition and renovation waste must also be processed in this manner in order to do something with waste. Waste that is created by construction can be divided into categories:

- Damaged waste: due to construction
- Designed waste: due to faults in the design
- Estimated waste: which is often due to extra ordering by contractors to ensure that enough materials are on-site
- Process waste: by processing the materials, other waste additional to intended process output is created. For example equipment or additional anode paste needed to make aluminum.

From a purely economic point of view, recycling construction and demolition waste is attractive. A recycled product is competitive with natural resources in relation to cost and quantity. Recycled materials will be more competitive in regions of resource shortages, or where landfilling sites are full. A macro-economic model of integrated resource management and its costs of traditional and selective demolition shows that with the use of recycled materials, economic savings in the transportation of building waste and primary raw material may be achieved. A good opportunity is to combine the demolition process with the construction process, in order to keep the transport of waste at a minimum (Winkler, 2010).

Costs are an important factor. In the past, simply knocking down the structure as quickly as possible was common and cheap. Demolition was removed in the state in which it arose; fully mixed. This approach slowly changed due to the new charges from the disposal companies of construction and demolition waste. If recycling companies charge more for processing mixed demolition than separated rubble, there is a financial incentive for selective demolition and construction and the separation of waste streams.  Important is to understand that waste separation itself is not sustainable but is part of the process of recycling which in its turn is sustainable (Bossink & Brouwers, 1996).

CIB publications of waste reduction in the construction sector show that in various countries there is an improvement of the waste reduction. Waste reduction and recycling have a strong link to other impact areas such as greenhouse gas emissions, (like methane from landfill) which can raise the profile of construction and demolition waste. Therefore, understanding the carbon impact of this waste is important to raise its profile or to encourage further action at a policy level, as is the case in Canada (CIB, 2011). What is momentarily also taking place is the categorization of the construction sector in the waste figures. All the waste together is produced by different sectors: residential, non-residential and civil engineering/infrastructure/public works. Waste reduction in larger civil works will be mainly about minimizing excavation, landscaping and reusing materials on-site, like the retention of contaminated materials on-site. Construction deals with separating the various different waste streams in the way that BREEAM using eleven waste streams.

The waste reduction, reuse and recycling industry is an industry that is capable of dealing with these processes and has the possibility to do so. In this manner, they allow for a reduction in new resources demand and therefore make construction processes more sustainable. Most recycling and reuse happens in breaking down the systems (buildings) into elements (walls and floors) or components (rubble) and then reusing these components into new elements and systems. This manner of recycling is even more efficient. This impact and phenomena is studied by Nanda Naber (2012) who did a research on the feasibility on the reuse of hollow core slabs from old office buildings to new residential buildings.

**$CO_2$**

The aspects energy and $CO_2$ are related due to the fact that energy from finite sources (oil, wood, coal)  produces $CO_2$. Measuring $CO_2$ and the impact on world in itself is an important issue in construction companies and started in 1970.

We can see that, with the embedded $CO_2$ and energy the impact of materials on the environment has already been examined in the book 'Milieukunde' by Peter Fraanje (2012). This book has evolved into the modern material data bank of Michiel Haas, director of the NIBE. In this data bank, the impact of materials can be found and is also monitored. The methods that are used at construction companies like BAM, with their Carbon Footprint Calculator to measure their impact on the environment, are based on the different data banks including that of the NIBE. With these calculators it has become clear that the largest part of the $CO_2$-emissions results from the delivered products in the exploitation phase (80% in housing and 91% in offices) (BAM, 2011). The energy requirements and the possibilities are better now and we are able to produce energy neutral and $CO_2$ neutral housing.

Energy is directly linked to $CO_2$. This has to do with the manner in which the energy is produced. In the traditional manner, fuel is used in power stations, where boilers start turbines that produce energy in a generator. This energy/power is then transported to the buildings and used. In this manner, the $CO_2$ that is produced from the fuel and the $CO_2$ that is used in the power station are related. If the energy comes from windmills or PV cells, the impact of $CO_2$ will be far less. The energy used by buildings must decrease in order to also have an effect on the $CO_2$ production. The materials that have a calculated impact on $CO_2$ also have to be purchased by the construction companies and used in a building. This will also impact the carbon calculator.

Energy consumption remains the single most important green building issue, because of its recent possibility to decrease energy costs (Kibert, 2008). For example, in 2002, 80 million buildings in the US consumed 33 quads (1 quad equals 1 quadrillion BTUs, or 1 million billion BTUs) which is equal to 36% of the primary energy in the country. Lighting and heating are the prime energy consumers in the building, sharing almost half of the energy consumed. Reducing these aspects will deliver both a revenue and an environmental impact. This indicates that energy used during the exploitation is of great importance and that design must ensure that daylight and good isolation can reduce these figures drastically. During the construction phase of the building, which is often only 1-2 years, the energy bill is even higher than the average during the exploitation phase, indicating that this is an important aspect to consider during construction (Kibert, 2008).

Energy is an aspect directly linked to costs, and because it has an economic return on investments for organizations and consumers, this can be changed easily. This is a good example where economic and environmental aspects reinforce each other. This is often one way (economical influencing environment in a positive manner). In contrast, $CO_2$ is an aspect that is not closely related to costs or returns on investments. Reducing this aspect has the name of being costly and having no return on investment. These aspects will be more difficult to change because they are dependent on government regulation or initiatives that can change. These regulations or initiative often do not have enough impact. We also need to understand that $CO_2$ is not a bad gas, we breathe it as we speak. It is the fact that too much of this gas is bad for global warming. $CO_2$ equivalents are often used to indicate what the impact is of other gasses, like $NO_x$ or $SO_4$ and therefore, $CO_2$ is often seen as a harmful gas.

**Pollution**

Pollution deals with the impact of construction and demolition activities on on the environment. This has already been assessed by the 'National Pakket Duurzaam Bouwen' in 1990, where they indicated that impacts of encasement oil was very harmful because it was washed from the encasements and into the soil. This and more aspects have been discussed in the document and include various small initiatives that could decrease pollution of the construction activities (Carpenter, 2001b). These aspects are:

- Air: Aspect that relates to dust and spraying measures that need to be taken in order to improve the air quality.
- Water: This aspect deals with cleaning of equipment and filth going into the soil.
- Soil: Already mentioned in the previous examples but looks at oil leaks of machinery or oil refills and chemical wastes as well.
- Nuisance: Has to deal with sound nuisance of certain methods.
- Ecology: Related to the impact of the building on the ecosystems in the neighborhoods.
- Health: An important aspect when dealing with pollution, is the health of the construction workers on site.

Pollution deals with all the small aspects happening on site that have an impact on the ecosystems and the environment of the area. These are also important pieces of output to consider in order to find the full scope of the output during construction. Various initiatives have been made in this respects, however the impact of these activities are, although not less important, small. The $CO_2$ equivalent of shading costs (NIBE term for pollution of materials) are often used to indicate the manner of pollution caused by certain activities or materials.

**ISO 14001**

ISO (International Standardization Organization) was founded in 1947 and sets international standards for various industries including the construction industry, regarding safety and quality norms. The principles of ISO are that the norms are:

- Consensus - with all actors
- Industrial wide - global solutions
- Voluntary - not a law but a guideline

The work done by ISO is executed by technical committees (TC). The ISO 9000 safety standards have been founded by TC-176 and the ISO 14000 have been founded by TC-207. It is often seen that during procurements or demands from governmental organizations the ISO standard is required in order to proceed with tendering and procurements. In order for organizations to understand and manage the impact of construction companies on the environment, the technical committee 207, of the ISO in Oslo developed a norm for environmental impacts. In 1995, this committee was addressed by the Norwegian prime minister, Gro Harlem Brundtland to find a method that allowed organizations to understand the impact they have on the environment (Schoffman & Tordini, 2000). ISO 14000 mainly focuses on two areas, the environmental managements system (EMS) and the environmental attributes of products and processes. This shows that ISO provides standards that involve the sustainability of processes in construction (also in other organizations). This gives a good look into the impacts of their activities and thereby focuses only on the output of processes while not looking into the roots of the output, the so-called input.

ISO 14001 is the specification for the EMS and up till now only this document is the one with which an organization must comply to meet its standard. The other ISO 14000 paragraphs include environmental auditing, performance evaluations and environmental labeling including LCA methods and environmental aspects in products.

The ISO 14001 has a number of steps that have to be taken in order to determine the impact of the organization's activities and also allow for mitigations. The following steps are explained (Schoffman & Tordini, 2000):

1. The environmental policy: this should be incorporated in the core values of the company and top management to ensure a long lasting existence. In order for sustainability to succeed, this is of great importance. Top management must formulate a strategy and policy in order to achieve sustainable construction.
2. The second aspect is the Initial Environmental Review (IER), involving a number of aspects like regulatory requirements, response to past performance problems, potential impacts of an organization activity products and services. It also includes how an organization currently manages its impact on the environment and how interested parties perceive an EMS.
3. The next step would be policy. Top management will write policy and define organization's environmental policies to ensure commitment to the decrease of pollution, compliance with environmental regulations, make a framework for reviewing objectives and target and allow for documentation.
4. The next step will be for the organization to determine environmental aspects. These are elements of organization activities and products or services which interact with the environment. The next part also determines environmental impact, and any change to the environment caused by the elements.
5. Together with the steps above, the organization must establish and maintain a procedure like the plan-do-check-act in order to achieve the goals.
6. Last part in order to prioritize the elements, will be to connect them to their significance. This will allow for the highly significant aspects to be helped first in order to achieve the goals.

The model on the next page will allow to make the next step in this list of ISO and thereby linking the output back towards the input and providing insights on how the output is generated.

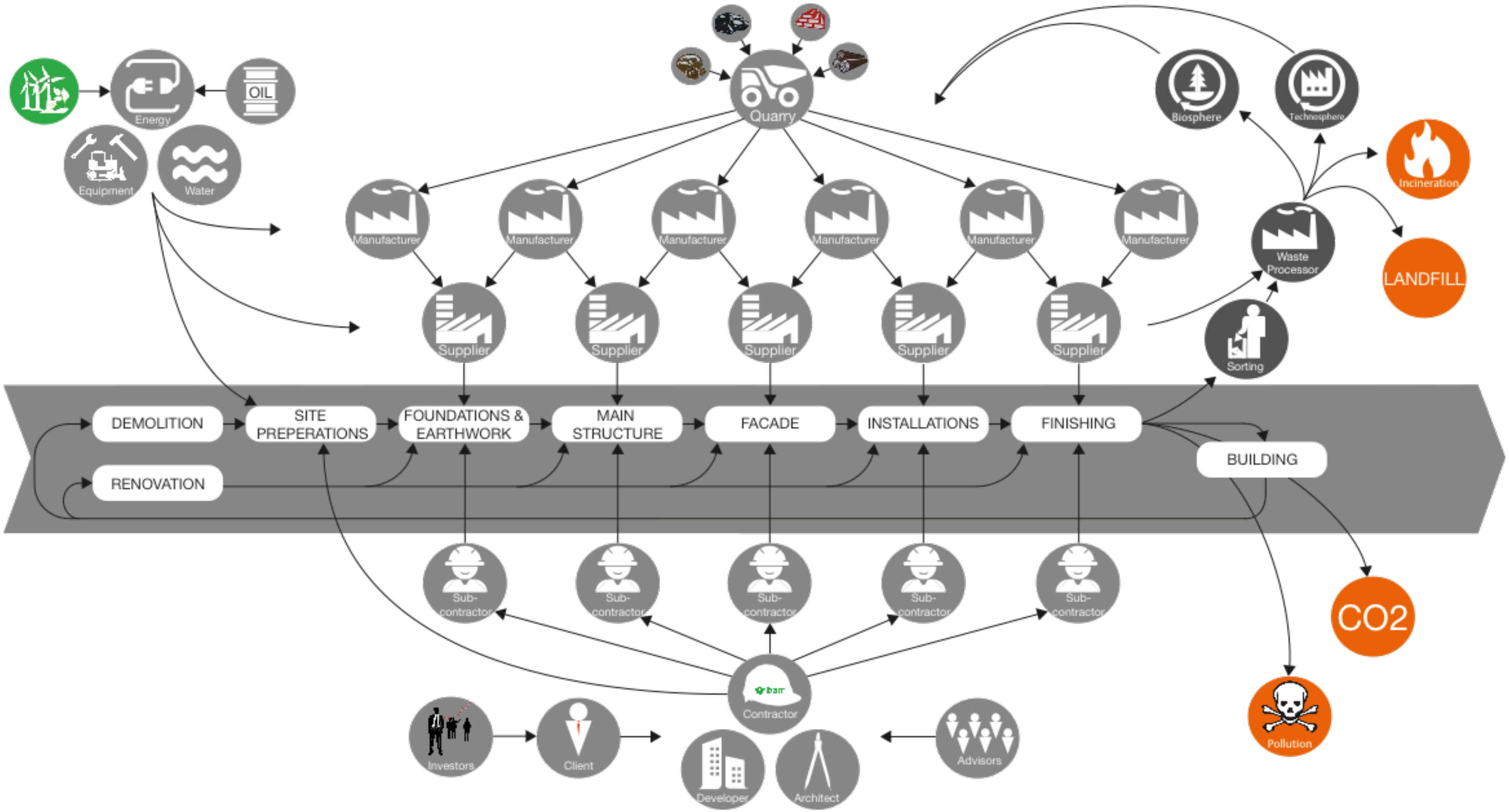



**Figure 2 - 11**: Current construction process

# 03 Sustainable construction

In times like these, where the vacancy rate of buildings is high, it can be questioned whether or not it is socially responsible to even build at all (van Doorn, 2012). However, there are always private organizations that issue new construction projects for various reasons. When issuing the need for a building, at this moment, there is an increase in demand for sustainable buildings (de Nie, 2011). A good example is Capgemini who are building a new office in the 'Leidse Rijn' after renting their previous building (also newly built) for only 7 years and hereby contribute to the vacancy in the Netherlands (Zwaga, 2012). It is of critical importance that these new projects are sustainable. However, if the building that organizations leave behind is left vacant, the discussion on what is more sustainable arises. If we would see these buildings as secondary raw material resource banks. the problem could be solved. This is not yet the case. These examples show the inclusiveness of the subject and also the fact that it is often more about looking further towards the client and other stakeholders instead of just looking at your own processes.

The construction process of a new building like Capgemini has to deal with a process in which the construction is done on-site. The construction site is the best place to implement sustainability because it is in the middle of the material life cycle and part of the building lifecycle (van den Dobbelsteen, 2001). The responsibility lies with the contractor and the sub-contractors. Making this process sustainable is difficult for many reasons. The obstacles to attain sustainable construction are often hard to overcome, because we do not know why we are not achieving a certain goal. By defining sustainable construction first, this will help answering the sub research question: *'What are the elements of a sustainable construction process, and how are these elements related?'*. This will start by discussing the history of sustainability and indicating the relation to the history of construction in order to look at patterns.

## 3.1 History

The historical development of sustainability has been written in clear fashion in the book of Alijd van Doorn, "The sustainable design project", in which she starts the first chapter with the historical context of the term sustainability (van Doorn, 2012). In this paragraph, a brief summary of the history of sustainability will be given in order to place it in the context of construction.

The first time the term sustainability was used was in the context of hygiene. Hygiene was an important factor in the industrialization period, in the beginning of the 19$^{th}$ century. Bad hygiene caused high death rates in cities, which made the need to improve the infrastructure of cities inevitable. Furthermore, sociologists started writing about the beauty of the environment in comparison to the ugly industrialization, which started the movement of 'nature monuments' (Natuur monumenten).

It was not until 1962 before people made the connection between human and nature, and the threat for the nature due to the growth of cities. In the book 'Silent Spring' by Rachel Carson (1962), the threat of pesticides is described, until then, were seen as harmless in agriculture. Other books follow upon this publication and the first environmental emissions and quality norms are assessed and established.

The sixties and the seventies are important for the development of the term sustainability, because of the Club of Rome and their report on the limitations of growth. This report gives a prognosis on the mineral and food usage of humans, along with a doom scenario of several decades until resources are depleted.

After this, it takes until 1987 for the establishment of the UN-report 'Our Common Future', also known as the Brundtland-report for sustainability. Brundtland's report draws attention to the global depletion problem (World Commission on Environment and Development, 1987). The report outlines the critical state of the global and related issues of environment and development. It also suggests that there are limits to growth made in the biosphere because the effects of human activities cannot absorb more when development is not reversed (Brundtland, 1987). The report therefore suggests that there is a need for Sustainable Development and defines this in the following way:

> *"Sustainable development is defined as development that meets present needs without reducing the possibilities for **future generations** to meet their needs "*
>
> *(Brundtland, 1987)*

This definition is very broad and not specifically related to the physical environment, which leaves room for term expansion. John Elkington even defines sustainability to his 'Triple Bottom Line' concept.

> *"Sustainability is achieving an effective balance between the financial (**profit**), social (**people**) and environmental (**planet**) choices when carrying out business activities"*
>
> *(Elkington, 1994)*

This is closely related to the sustainability definition in the problem analysis: people, planet and profit. These aspects are always important in the decision-making processes of an organization (in which leaders make the actual decision). The necessity for sustainable development since the publication of the Brundtland report, has made more people understand the importance of sustainability nowadays. This consciousness is strengthened and expanded by the many reports, research and environmental conferences that followed, and more recently by the film 'an inconvenient truth' by Al Gore on climate change (van Doorn, 2012). These development are only the most common.

**Findings**

Sustainability is not as old as construction, but it dates back further in time than is often perceived. The nomads only used local materials, which could be reabsorbed by nature and did not require transportation. This was very sustainable, opposed to the time of the industrial revolution, in which there was high-energy usage from coals and oil and high transportation numbers. Since the industrial revolution, sustainable development is linked to global warming and resource depletions. This started the various initiatives in the construction industry to reduce the product and services they deliver.

Sustainability has its influence on the construction industry but always seems to be a step behind, for example with the hygiene aspect, where it first had to go wrong in order to understand the problem and then improve. This is still somewhat the same. We slowly comprehend the implications people have on the environment through activities like construction this is where sustainability will play a role in improvement with respect to the two main themes: global warming and resource depletion. We are now able to deliver houses that are energy neutral during the exploitation. Because of this $CO_2$ reduction can be realized and pollution is minimized.

This shows us that sustainable developments can be linked with the rapid growth of factories (industrial revolution), were people moved to the city, which with the coming of bad hygiene problem dealt with by the sustainable movement, material usage increasing tremendously and the publication of the report from the club of rome. The material depletion and global warming effects followed the current increased demand and the oil usage. This show that sustainability is a counter movement to industrialization. The example of the housing in Kenya shows that we used to build very sustainably, indicating that industrialization is the largest contributor to our unsustainable world as it is nowadays a different definition will be looked at that can be related to the desired sustainable construction process. We see that the building in Kenya can be reabsorbed we can indicate it's cyclic nature and the re-absorption by the environment (ecology). Brundtland and Elkington provide insights on how to deal with sustainable development, linking it to people and profit, while it has less impact on the environment (planet).

## 3.2 Definition sustainable construction

Defined the current process of construction allows for the design of a sustainable construction process. When dealing with sustainability, we can say that it is hard to define what is 100% sustainable. With the goal of defining sustainable construction, the 100% sustainable construction process would entail that all the materials used can be reabsorbed by the earth, without producing emissions, and polluting the earth. The methodology of Cradle-2-cradle, industrial ecology will be used as inspiration. During the problem analysis, the definitions of Brundtland and Elkington were used, but these did not provide insights on sustainability related to the construction process. This process approach will entail the use of the flow principle, is described in the theory of Koskela (2000). A more cyclic nature is needed in order to achieve a cyclic nature of construction as perceived in the housing in Kenya.

### *3.2.1 Cradle-2-cradle*

Cradle-2-cradle is an initiative of Willem McDonough and Michael Braungart. They have defined the Cradle-2-cradle design as an ecologically intelligent approach to architecture and industry, that involves materials, buildings and patterns of settlement which are fully healthful and restorative. Until not so long ago, our production paradigm was focused on manufacturing products as cheaply as possible. The products would later be discarded into landfills (worst case) of burned up energy (in best case), meaning that we were producing or processing materials (cradle which would later be rendered useless because they were being buried or destroyed (grave). (McDonough & Braungart, 2003).

This is a radical shift from the inanimate and one-size-fits-all structures into which we plug power and largely toxic materials, towards buildings being life-support systems, embedded in the material and energy flows of particular places. It is clear that they have also made a link with the material and energy flows from industrial metabolism and that they acknowledge the fact that the current design and construction is a statement of footprint creation, while it should be embedded in the environment.

In the past decade, the Cradle-2-cradle philosophy has grown into not just a wishful thinking concept, but also developed into a philosophy which drive is to devote focus on developing safe materials, products, supply chains and manufacturing processes throughout architecture and industry (UNEP, 2003). The philosophy has been adopted by influential corporations, including BASF (chemical company), DESSO, a carpet supplier in the Netherlands and Ford Motor and its major suppliers in the auto industry. The Ford River Rouge factory is an excellent example of the philosophy of Willem McDonough and Michael Braungart.

The reason that this method has become so successful is the fact that Cradle-2-cradle is based on ecological intelligence. This means that in the natural world, the processes of each organism contribute to the health of the whole. One organism's waste is food for the other: nutrients and the energy flow in nature are perceptually closed loop cycles of growth, decay and rebirth. Waste is food. This can lead to materials that can be recycled infinitely and can become high-quality, high-tech ingredients for future generations.

The Cradle-2-cradle principle has a new perception of the relationships of materials, energy and the making of things. The old eco design where the negative impact of toxic materials and polluting fuels are minimized. Re-materialization, on the other hand, is a process of chemical recycling that adds value to materials, allowing them to be used again and again in high-quality products. The term can also be seen as a metaphor for design strategy, aimed at maximizing the positive effects of materials and energy and participating in the earths materials flows. It is not comparable to recycling, where over time a loss of value takes place and materials lose their entire value. For example, when metals like copper, nickel and manganese are blended in a melting process their value is lost forever, while the 'Nylon 6' is a polymer and is easily recycled to caprolactum usable for high-quality carpet fiber. The key to the effective re-materialization is defining material chemistry and tracking material flows (McDonough & Braungart, 2003).

Cradle-2-cradle design also makes extraordinarily good sense economically and socially. This is especially visible in the workplace. When designs for large-scale factories and offices are modeled on nature's effectiveness, they generate delightful, productive places for people to work. This not only encourages a strong sense of community and cooperation, it also allows efficiency and cost effectiveness to serve a larger purpose. Furthermore, the Cradle-2-cradle design can maximize the local energy flows through different methods and the close material flow in the construction process. A link can be made with an essential part of the construction process, namely the materials. The closing of the cycle and flow of energy, in order to make the construction process a more effective one, with less waste generation and low value waste-products.

### *3.2.2 Industrial ecology*

Next to Cradle-2-cradle there is the methodology of industrial ecology. Industrial ecology differs from other approaches (like life cycle management, industrial symbioses) in its comparison to industrial systems and the natural ecological system. This comparison is considered a tool for the redesign of the industrial system on various levels of aggregation aimed at achieving increased sustainability (Lambert, 2008). The most industrial ecologists see this closing of material cycles as an essential path towards the end of waste production. Industrial metabolism is the method of quantitative materials and an energy flow analysis. This is seen as a means to achieve the industrial ecology goal. The definition of industrial ecology by Evan is:

'Industrial ecology is an interdisciplinary systems approach to environmental problems arising from industrial activities (production, consumption and disposal of manufactured products and their raw material and energy inputs) as well as from related mining, agricultural transportation and construction processes' (Evan, 1974).

In this theory, the six aspects of industrial ecology are discussed: technology, environment, natural resources, biomedical aspects, institutional and legal matters and socioeconomic aspects. The focus leas on closing material and energy cycles in the industry. This was the basis for a new large development in the research of Frosch and Gallopoulos, concluded in the article on managing planet earth. This focused on global impact of human issues such as population growth, food shortages, fresh water scarcity and the constant need for energy. They developed an ideal view on how sustainable industrial systems should be organized. The industrial ecosystem would function as an analogue of biological ecosystems. 'An ideal industrial ecosystem may never be attained in practice, but both manufacturers and consumers must change their habits to approach it more closely if the industrialized world is to maintain its standard of living to a similar level, without adversely affecting the environment' (Frosch & Gallopoulos, 1989)

This has a close resemblance with the definition of sustainable development as expressed in Brundtland's report. Brundtland, however, focuses on the development of future needs and does not focus on the value of the ecosystem itself. Frosch and Gallopoulos focus more on recycling in the global context and on different systems. They observed that waste from certain industries can serve as raw materials to new systems. Industrial metabolism is part of the industrial ecosystem and is explained as follows: "Industrial metabolism is the whole integrated collection of physical processes that convert raw materials, plus labor, into finished products and wastes in a steady-state condition. The stabilizing controls of the system are provided by its human component" (Ayres & Simonis, 1994). This definition has led to a reuse of the word 'industrial ecology'. The focus still lies on closing material cycles, as is introduced in the sustainable construction design below (Reduce, Reuse, Recycle) as well. Dematerialization, material substitution, recycling and waste-mining are considered the principle strategies to be implemented.

Lambert concludes that, despite all the theories and practices of the industrial ecology, it sometimes appears as a theory of everything. It has no structure in various scientific journals. There is no unified relationship between economic activities and the ecosystem. There are multiple elements in the body of knowledge that can be found to structure the whole discipline. The core topic in industrial ecology is the analysis of anthropogenic physical flows (industrial metabolism). The core domain of industrial ecology is the comparing of human economic activities with ecology (seen as science of the interaction between organisms, as well as with organisms and the environment). Lambert has also referred to the term industrial ecology in a manner that will be of additional value to the report and its placement within the construction industry.

With the theory of construction as production (part of the industry) and the industrial ecology and metabolism, a link was made to the cycle flows of the construction process. The process will transform raw materials with additional materials and energy into a product (namely a building). This process incorporates waste products and energy usage, which could be used by other industries as input for their production or construction process. This flow is very linear, and in order to make the process more sustainable, the linear process must be put into a wider context in order to cycle the process and realize that waste for one is input for another. This moves towards a circular economy that does not talk about waste, but about drop-out (from a process that can be reused in the next line). This way of thinking allows for a more sustainable construction process, together with the reuse of energy from the buildings we make as electricity for the next process.

The translation of these methodologies and definition towards a concept of sustainable construction will involve a definition that can form the basis of the model as the one expressed in the previous chapter. After I formulated that a sustainable construction process must be cyclic, a concrete answer and definition was consulted in the expert interviews.

### *3.2.3 Definition experts*

The first part of the interview involved the definition of sustainable construction, by the experts, in order to define sustainable construction. Thereby answering the research question: *What, in practice is meant by sustainable construction and how can this be visualized in the theoretical sustainable construction model?* The answers given will be assessed and compared, by means of a SWOT analysis.

***Question***

The following part will focus on the first question in the research framework (appendix 3) and is therefore related to what sustainable construction (the desirable situation) is: *Sustainability is a broad concept, how would you define 'sustainable construction', what would it involve?*

This question is used to relate the expert's opinion on what sustainable construction is in relation to sustainable development. Before this question was asked, they were given two definitions of sustainable development. The first definition was Brundtland's (1987) *"Sustainable development is defined as development that meets present needs without reducing the possibilities for future generations to meet their needs".* The other was by Elkington (1995) *"Sustainable development is about achieving effective balance between three dimensions, social quality (people), economic quality (prosperity) and environmental (planet)".* The question will assess how the experts define sustainable construction and thereby the desirable situation in the research model.

**Results**

The results from all the interviews have been analyzed in a comparison table in the program 'Numbers'. The full results and the table can be found in appendix 3. The summarized results can be found in the following table and graph.

| | DEFINITION | FREQUENCY | PERSPECTIVE |
|---|---|---|---|
| 1 | Construction that does not impact the environment (planet) and people, while making a profit. | 5 | CM2/SM2,3/SI/AC1 |
| 2 | Sustainable construction is about creating and recreating elements in the environment that also future generations would want to receive, use or inherit. | 2 | GO/AC2 |
| 3 | No clear definition | 2 | CM3/SM1 |
| 4 | Constructing in such a way that meets the needs of the present without compromising the future needs of future generations and environment | 1 | AC2 |
| 5 | Sustainable construction is more than energy and materials and involves social sustainability, this is the next step in sustainability | 1 | D1 |
| 6 | Sustainable construction is about sustainability and not about durability | 1 | D2 |
| 7 | No Opinion | 1 | CM1 |

**Analysis**

The table shows that five of the twelve interviewees have answered the question by talking about the construction process related to the impact on the environment.

| Strength | Weakness |
|---|---|
| The definition is related to the construction activity<br>Involves the poeple planet (environment) and profit definition<br>Various different actors mentioned this definition | Definition only talks about the abstract definition of construction related to construction activities<br>Developers did not mention this as definition |
| **Opportunity** | **Threat** |
| Very broad definition, involves almost everything | People, planet, profit was used as example<br>Easy way out definition |

This SWOT above (about the first definition) shows that the definition given is very broad. This is illustrated in de definition of Michel Haas: ‘construction that does not have an impact on environment’. Environment can be ground, air, water, $CO_2$, material waste or pollution. This indicates the inclusiveness and completeness of the definition with respect to sustainability. The danger of using this definition is that it is an easy way out, for the interviewee, by using the definition of Elkington mentioned before the question was asked. Definition six, ‘referring to sustainability and not durability’, is closely related to the first definition. The same accounts for the other definitions, that are not specified towards construction but are specified more towards sustainable development. This is a weakness of the other definitions.

The first interesting thing to see, in the overall answers, is that two people use the definition of Jon Kristinsson: “Sustainable construction is about creating and recreating elements in the environment that also future generations would want to receive, use or inherit’” (Kristinsson, 2012). This definition derives from Brundtland's definition.. The word ‘future generation’ is also mentioned in two other definitions and indicates that together with the Elkington definition these definitions are used as a definition in 75% of the interviews. This means this definition is either very integrated in the construction industry or that the interviewees used definitions presented to them beforehand.

The second interesting aspect is that two definitions have been formulated in a vague and inconclusive manner. When asking for a definition of sustainable construction one interviewee brought up various aspects of sustainability: ‘Material choice is very important as well as awareness on the construction site’ (Heye, 2012). This shows that the interviewee is explaining what is of importance in his construction company (management perspective) and how he wants to deliver sustainability by awareness. This is not usable definition for sustainable construction. The other interviewee talks about that ‘the time to investigate the different options can reduce the faults and waste (materials and labor)‘ (van der Hoeven, 2012). This indicates that he is trying to solve sustainability in construction and that he talks about designs that influence the sustainability more than construction. This also is not usable for a definition.

The third interesting aspect is the interviewee that had no opinion on what sustainable construction is. The answer to the question was as follows: ‘Not to deviate from the question, but my client determines the amount of sustainability used during construction sustainability’ (Troost, 2012). This answer seems odd when asking a construction manager for the definition of sustainable construction, but in the true nature of a contractor, the client is the most important for the organization. The interviewee had a commercial background. This makes it understandable, but a contractor should strive for sustainable construction in his primary process, regardless of the client. Apple has defined the way we use computers and we as clients have not demanded it but are using it. The construction industry could use sustainability to become a frontrunner in their industry.

### *3.2.4 Conclusion*

The definitions given were closely related to the definitions of sustainable development provided in the interview, which could mean that the definitions are widely known. It must be said that it is interesting to see that explicitly these definition were given. Despite this fact, a clear definition for 38% of the interviewees was given:

> *‘Sustainable construction is construction that does not impact the environment (**planet**) and **people**, while making a **profit**’.*

The other answers could be specified towards construction and towards the environment. The focus is on more than merely the environment, for example, on social responsibility. A possible reason of the definition being inconclusive is that the interview question did not explicitly ask the formulation of sustainability towards the construction process. The other definitions are closely related to each other. Therefore, this definition will form the basis of the further research.

**Figure 3 - 0**: People, Planet, Profit (Illustrations from (Google, 2013))

The definition forms a good framework for the definition of sustainable construction in the process model. The 'planet' aspect, 'having no impact on the environment' is in line with the definition of Cradle-2-cradle and industrial ecology. The 'profit' aspects is an interesting one because it seems as if the expert states that sustainability has to involve making profit. This will be looked at in-depth in chapter four. The 'people' aspects is a bit out of scope and deals with social sustainability, construction is also about people but emphasizes the impact on the environment. This is irrelevant to examine any further in this research. The 'NO IMPACT ON THE ENVIRONMENT (PLANET) will be explored at in the design of the sustainable construction process. Figure 3-0 visualizes this definition.

## 3.2 Designing the sustainable construction process

We can conclude that industrial ecology and Cradle-2-cradle principles can help us to define sustainable construction because they are in line with the definition provided by the experts. The manner in which the definition is translated towards the process model is explained in the following paragraphs.

The use of the Ladder of Lansink (1979) will help bring hierarchy in the model and allows steps to be taken in order for construction to become sustainable. This has already been looked at by different academics like Ad Lansink and Andy van den Dobbelsteen with his new interpretation of the Trias Ecologica.

**Trias Ecologica**

This is a roadmap for sustainability, which is more applicable than just energy or materials. According to the Trias Ecologica, the first step to decrease the demand for the use of resources (raw materials, water, energy, etc.) as much as possible. If you still need a source, one should use endless, inexhaustible sources. If is not possible, use finite resources (Lysen, 1996). They indicate how to deal with the input aspects of the process model and the output aspects of the model that have a relation to the impacts on the environment. This can be done in the following manner:

INPUT (Energy)
- Reduce the demand
- Use sustainable sources
- Use endless sources responsibly

OUTPUT (Materials, Pollution, Carbon Emissions)
- Reduce (prevent)
- Reuse waste at high level
- Recycle waste responsibly

**Ladder of Lansink**

The Ladder of Lansink is a standard in the field of waste management. The ladder is named after the Dutch politician Ad Lansink, who submitted a motion in parliament for this method in 1979. Internationally, the general principle behind the Ladder of Lansink is often referred to as the "waste hierarchy". Waste policy aims to give priority to the most environmentally friendly processing methods. These are at the top of the 'ladder'. The policy of the government should focus on climbing up the Ladder of Lansink with their waste reduction. In practice, this means there will always have to be a consideration whether a particular step can be realized. If this is not the case, a lower step is eligible. This is mainly related to the materials used but it also applicable to the energy usage and $CO_2$ wastage.

Sustainable construction will not involve the landfilling, incineration and energy creating from waste. This is because in all cases, the materials, carbon emissions, pollution and energy is lost forever. This means that in a cycle there is output that is not usable as input in other processes or in the same cycle. Therefore, the first step would be to exclude these three steps.

The ladder forms the basis for further steps in a sustainable construction process. As mentioned, the ladder is about climbing. This structure is also used to describe how the elements of a sustainable construction process are defined. This is the sub-question that needs to be answered in this part of the research.


**Figure 3 - 1**: Ladder of Lansink (Lansink, 1979)

## 3.3 Recycling

Within the current system, we can state that recycling is already being done at this moment. Metals like aluminum are worth money and are already being used as input for manufacturing products and materials. This could be done in a better manner, because eventually at the bottom of the ladder (position of recycling opposed to reduction and reuse) it is a last resort and therefore should compete with new materials quarried. Because buildings at this moment contain many materials, this should form the buffer for materials that are a substitution for new materials needed. Knowing that the population is growing and the demand for materials grows as well, indicates a problem. Recycling could prove to be an aspect that the new way of construction should want to achieve. Reduction and reuse should also compensate the need for new materials.

**Technosphere & Biosphere**

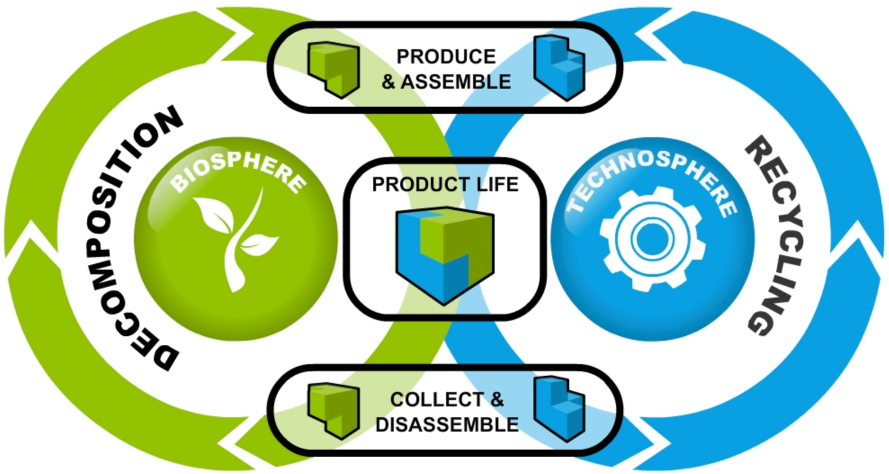



**Figure 3 - 2**: Biosphere and Technosphere Cradle-2-cradle(McDonough & Braungart, 2003)

Recycling deals with two different cycles. The Cradle-2-cradle design is inspired by the natural processes taking place in the bio-systems in which the discarded material from one entity becomes the nutrient for other entities within the system. An example of such a system is the natural ecosystem, in which animal feces become the food for animal feces that become food for other species or decompose to become nutrients in the soil, which are in turn used by plants as the cycle continues (circle of life) (waste=food).

The idea behind Cradle-2-cradle is that this is also made possible in the technosphere, by using the recycling cycle which will allows for the same approach as in the biosphere. The sustainable construction model shows both cycles, including the biosphere. To further explain the biosphere, one could take the example of trees cut into beams that are then regrown by planting one tree for every tree used. This is closing cycles. The manner in which the old beam is dealt with is of importance, because if this is landfilled or incinerated this is not a contribution towards sustainable construction. Using it as fire wood for energy is debatable, because a new tree is grown for the tree used and the beam has already had a life time in a building and can then deliver energy. The manner in dealing with the biosphere is of importance to contribute towards sustainable construction.

The manner of sustainable recycling will still need to go hand in hand with the reuse and also reduction of impact on the environment. In the process of recycling, the supply chain is very large and the integration is therefore a hard case. The chain will need to work together in order to reduce the impact on the environment.

Figure 3-2 shows the difference in the model opposed to the current construction process model. This difference will be discussed, explained and will include the following:

- Recycling directly through the supplier
- Recycling directly from supplier to manufacturer
- Replace mining by secondary raw materials

**Recycling through supplier**
The process diagram illustrates that recycling can be more efficient when waste is sent back directly towards suppliers that can then reuse the materials, thereby not following the traditional recycling route. There are various materials, like isolation that suppliers would like to reuse. The materials would normally go towards the waste sorting company. This also accounts for plastering materials and aluminum or other metals.

Interesting to see is that BREEAM has credits that state that this manner of recycling is not possible (de Graaf, 2012). This is because the waste has to follow a line that is made insightful and the supplier often cannot prove where materials end up. This is the reason why waste processors do give this insight. This is an indication that transportation distances can be reduced, because recycled materials often pass through different transformational processes in different factories all over the country or even all over the world. The reduced impact on the environment is greater in this way.

**Recycling from supplier to manufacturer**
The suppliers that often used raw non-coated materials can also directly send materials back directly to the manufacturers. This would save wastage, in lean terms. Direct recycling could take place by sending back the material waste to the manufacturer. This would also ensure that transport vehicles would have double loads. Normally they only transport goods towards the supplier and return empty. In this manner this return with be with materials transported and therefore the transportation towards the different waste processors is not necessary anymore. This is the same for the previous aspect. It is interesting to see that materials like aluminum where reduced from facade to aluminum scrap and that is shipped all over the world to re-melters. This is often done due to the prices of the different melters and this means that this cycle is so large that we can really impact the industry in a better manner when implementing both steps.

**Replacing mining by secondary raw materials**
This is the first step made in order to close the cycles we are using currently. The recycling cycle that existed already was closing the cycles and replacing new materials by the recycled process. In sustainable construction we need to reuse all the materials that have once been manufactured and we need to ensure that this is recycled permanently in the cycle. This means that we will not need new materials from this earth and this indicates that we could solve the depletion problems. The technical feasibility of reusing materials endlessly will depend on different materials. Some materials, like aluminum, it is only possibility to make aluminum with 94-96% recycled scrap. This means that we still need 4% new materials every time. In the real sustainable construction process this, however, is the new standard.

This also shows us that, in this manner, we would become self sustaining. The fact that we currently do not have the amounts of recycled materials at our disposal due to increasing demands, is partially true. The amount of recycled materials can certainly increase in the form of using material from vacant buildings. Michel Haas, professor in sustainable materials at the Delft University of Technology, states that the vacancy rate is up to 15% in the office sector. This means that we have been building too much in the past, but it also indicates that these vacant buildings actually consists of raw materials that are recyclable and reusable in new projects.

This means a new form of mining is introduced; Urban mining. In theory, this plan sounds perfect, because in this manner the model would increase the amount of recycled materials. Financially, however, the vacant buildings are still worth money and this would therefore cost more money than new raw materials. This also indicates the first problems that occur in achieving sustainable construction, part of the next chapter.

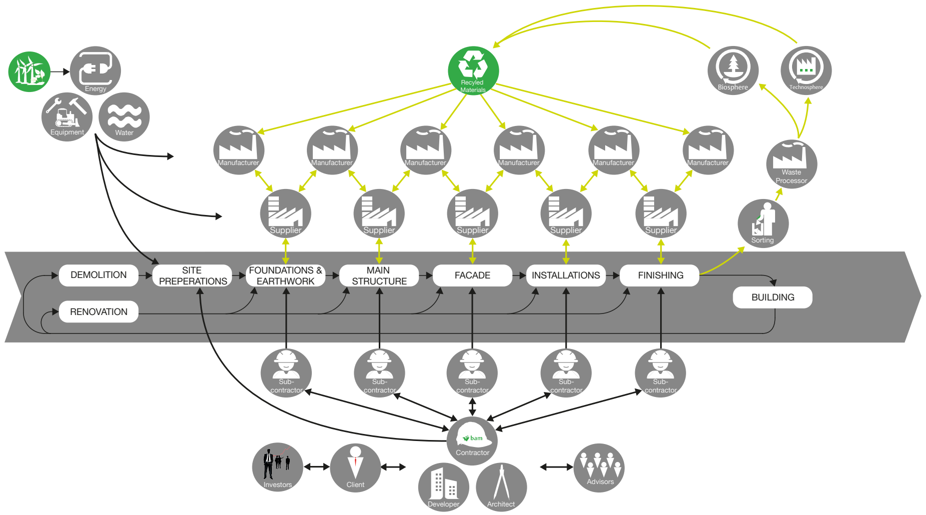



**Figure 3 -2**: Recycling as first step in sustainable construction

**Status Quo**

In order to define sustainable construction, the current construction is used. We have to consider that the current buildings in use and also construction have not been conducted in the manner described in chapter two. This manner already involves 40% recycling of aluminum in the materials and 20-30% recycling of concrete in the materials. This percentage means that we currently already have created a percentage of recycled materials, this can be referred to as the status quo of the current construction process that will need to be increased towards 100%. With the amount of materials in use all over the world this should, theoretically, not form a problem.

This is the first step in the ladder of Lansink. The next step will involve the reuse of materials, energy. It could be said that recycling is already part of reuse, but this is not the case in the ladder and therefore they have been separated.

## 3.4 Reuse

The graduation report of Nanda Naber (2012) explains the different levels of reuse in her example of hollow core slabs, which provides insight into the building levels. These building levels indicate that a building consists of different sub-systems, elements and components. The reuse of the different parts of a system has a hierarchy in which the parts are reusable and the components level is actually the level of recycling. This indicating that this is the lowest level of reusability possible.

### *3.4.1 Building levels*

Reuse and recycling has a lot do to with levels in which you are operating (and other steps in the Ladder of Lansink) related to systems, elements and components. Eekhout

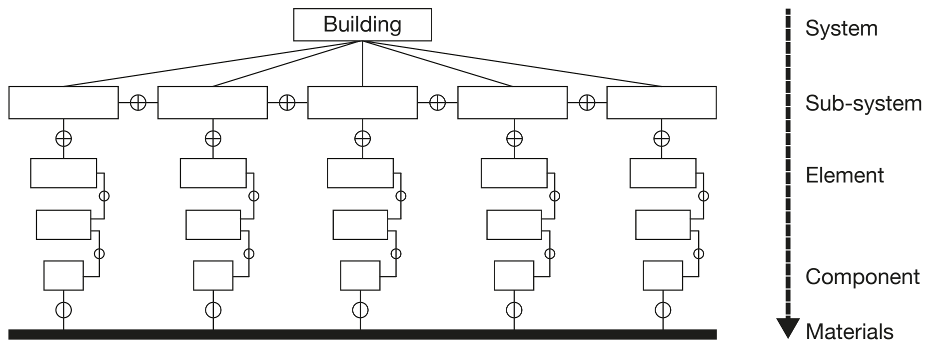



**Figure 3 - 3**: Different levels in a building according to (Eekhout, 1997) & (Durmisevic, 2006)

(1997) developed a pyramid in which these different levels are indicated. Every step higher in the hierarchy means that there has been an increasing value of labor, energy, material and use of equipment (Eekhout, 1997). In her dissertation on transformable building structures, Durmisevic (2006) has named the steps in a clear manner. This involved a top-down hierarchy of levels in which a building can be disassembled. This is of importance in the reusability of elements that depends on de level of reuse. The example of aluminum will be used to indicate the different levels in the form of examples.

**Components**

The lowest level discussed in the previous parts is the reuse of components (also referred to as recycling in this paper). For aluminum, this means the shredding and de-coating the materials into usable scrap metals for the aluminum re-melters. These will form the secondary raw materials that will replace the new raw material quarried. This is an essential step in the chain.

**Figure 3 - 4:** Components

**Elements**

Elements related to the aluminum example are aluminum elements used in a facade. If these were to be reused, the waste processing would not need to take place. If this process would not take place, the transportation involved and the emissions of this process and energy usage would reduce the overall impact of the total process. This indicates that the impact on the environment would be reduced. This has been explored in the research of Nanda Naber, were she looks at concrete hollow slab floors. The reuse at a higher level is explained in the following paragraph.

**Figure 3 - 5:** Elements

The highest level of reuse in a structure should be determined beforehand and depends on the technical feasibility involved with the new process. The higher the level of reuse, the less energy is needed to break the connections and to form new connections in the building in which the constructive parts are applied. The different building levels are shown in figure 3-3. The higher the building level, the less embodied energy gets wasted and the less new energy needs to be added to construct a new building. A higher building level also means that the level of integration is higher. The level of sustainability is higher as well. As mentioned, the most embodied energy is kept when a building is transformed into another function. When a whole building is decomposed to the level of raw materials, the biggest amount of energy is required and the biggest amount of embodied energy gets lost (Naber, 2012).

The report from Nanda Naber will form the example in this case, in order to indicate the levels of sustainability in relation to components, elements and systems. A prefab hollow concrete slab is composed of: sand, gravel, cement, water, iron oar and coal. These are put together in the element of a concrete hollow slab. This is done in a factory under good circumstances, thereby reducing the impact of $CO_2$ during the chemical reaction of cement, sand, gravel and water. This element is transported to the site where they are assembled in the form of a building (a ‘system’). The size and weight of the components are adjusted to the maximum possible transportation and disassembly size. Disassembly (deconstruction) is building in the opposite direction. The construction should favorably be disassembled on the same level at which it was assembled. A higher level is harder to realize, because of transportation and equipment are needed for disassembly. A lower level would not be favorable since this is less sustainable indicates the levels in which a higher level is more sustainable. The same would be true in the reuse of facade and installation elements and systems.

The process model includes the reuse of elements by sending them back to the suppliers. The other route for the demolished elements and systems could be through the current recycling industry. This industry could manipulate the material elements in order to ensure the right quality is met for the reused materials. This is an aspect that could prove to be of importance in realizing this step.

### Sub-system

A sub-system level means that an aluminum profile is often combined with other material to form a sub-systems. This indicates that a sub-system consists of more than one materials. As for the elements, reuse, this would also lead to a reduction of processes, It would also provide the step needed for a sustainable process.

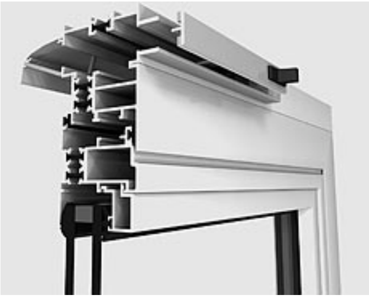


**Figure 3 - 6:** Sub-system

### System

The highest level of reuse is the reuse of a whole building. The possibilities of this should be examined first. This can involve renovation or change of function. In the Netherlands, a good example is the reuse of a farm from Margot Ribberink (weather presenter of news station RTL) and moving her residential home 800 meters, because at its current location a tunnel was about to be built. This is the ultimate example of the reuse of a building (system) and counts as the highest level. This is closely related to the reduction factor of renovation (figure 3-8).

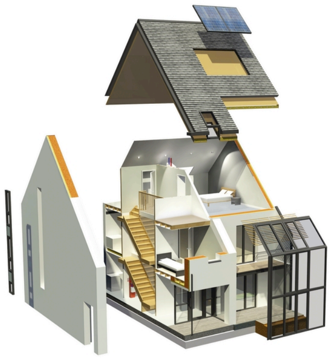


**Figure 3 - 7:** System

**Figure 3 -8**: Reuse of system, farm example (RTL,2012)

### *3.4.2 Energy reuse*

Another important aspect or recycling, the extra sustainable energy that is derived from buildings realized. These buildings could provide an supply of energy through various initiatives that could then be used as energy for new processes. This manner of recycling energy is actually part of the idea of Jeremy Rifkin (2011). Rifkin states that the current energy problem it can be solved in this manner. In a sustainable construction process it is always the goal to deliver a sustainable product. According to Rifkin, an american economist, we need to stop depending on fossil fuels if we want to be able to solve this.

This all has been converted in the model based on the current construction process. The difference is that the colors in the ladder, for reuse, recycle and reduce, are applied to the model. The lines in the diagram are shorter and already indicates less processes are involved. This means the model has become more sustainable while it moves up the ladder. The model has also put forward the cyclic nature of cradle-2-cradle by closing the waste streams.

### *3.4.3 BREEAM*

While talking to Martin the Graaf, BREEAM expert at BAM Utiliteitsbouw , we came to the conclusion that minimal points can in fact be achieved during construction. Credits MAN 2,3,6 and WST 2 are the most important ones for the construction process. The main problem of BREEAM is that other sustainable solutions are often not rated in the label. Furthermore, some aspects not related to the building (like bat houses) are easy to score, but the goal is to realize sustainable buildings. In other words, the means overreach the goal of the labels. More innovation points are needed to stimulate thinking out of the box. BREEAM needs to become an ideology that is freely interpretable. The material points are hard to meet in the realization and design of the projects. Discussing this model indicates that sustainable construction goes beyond BREEAM and could prove to be an addition for the credits and also the way of thinking (de Graaf, 2012). BAM, on initiative of Martin de Graaf, is talking to material suppliers to investigate the possibilities for more sustainable materials. Thereby, they are already working towards something that is much more sustainable than BREEAM alone.

## 3.5 Reduce

The Dutch construction industry produces 25 million tonnes of waste every year. They have to pay 18 euros per tonne which is equal to half a billion euros (Riley & Cotgrave, 2009). With this the same amount of money, it is possible to build almost four hospitals. Construction organizations are having a hard time managing waste. The ISO 14001 Environmental management systems (EMS) were introduced as a first step in the visualization of waste and other output elements (carbon emissions, pollution and materials). The current process will include all elements related to the impact of the activity on the environment and all elements related to sustainability. This will be the first step in the research design made and will provide insights on how to design the sustainable construction process.

The construction market is stagnating and does not seem to improve at the moment. Renovation seems to get a boost from this stagnating construction market and a sustainability perspective is often preferable. After all, 30% of the environmental impact of a building arises during construction. This would reduce the impact on the world, no construction means no energy, no materials and no equipment usage. This is not realistic and therefore minimizing would have the biggest overall impact. Reducing the amount of energy needed and consumed and the carbon emissions. Together with the reduction on the output side when using materials and energy. These aspects are dealt with in the reduction part of the ladder. Reuse and recycling almost always concerns materials and by changing the cycles, reduction takes place. This involves more awareness and understanding. This step will involve all the actors involved in the construction industry before having an impact that counts.

One can use the strategy of Trias Energetica, a strategy that focuses on saving energy, to illustrate what happens with, for example, energy. With this strategy it is very simple to translate initiatives into steps of reduction..

- Step1 Reduce the need for energy, use as little energy as possible;
- Step2 Use renewable sources, such as solar or wind power, for the remaining energy.
- Step3 Use the energy (generated from fossil fuels) as efficiently as possible.

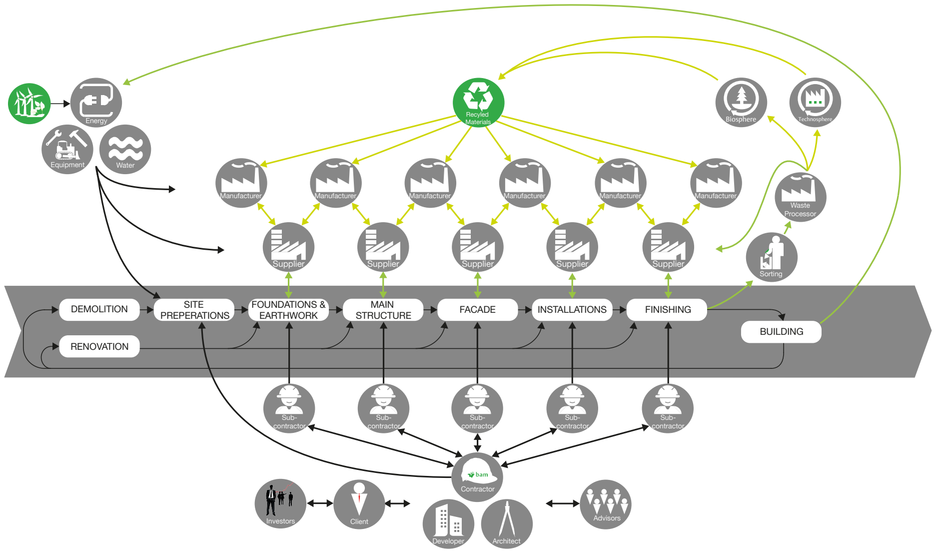



**Figure 3 - 9:** Reduction

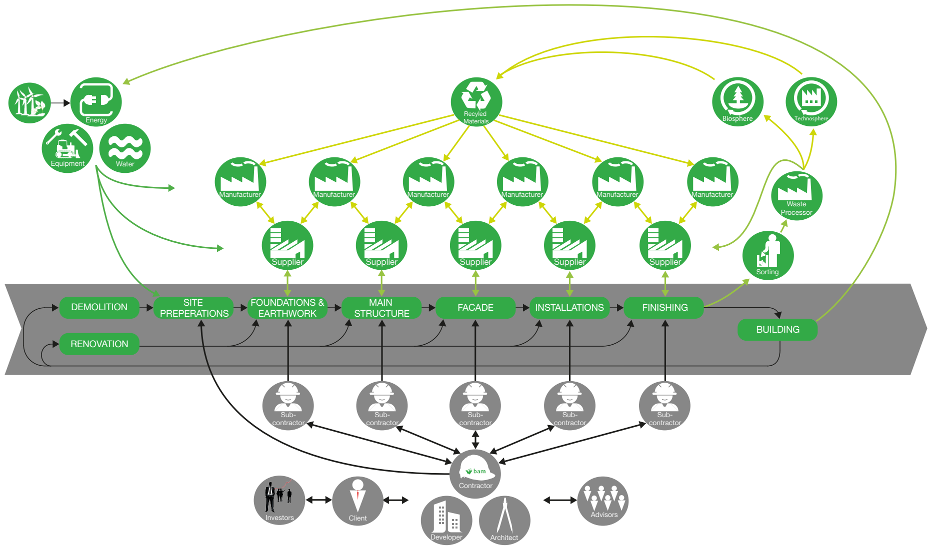



**Figure 3-10**: 'Future situation' Sustainable construction process model

The Trias Ecologica, explained on page 55, already incorporates the manner in which reduction should lead to a better impact on the environment. If all the activities in the supply and construction chain would reduce their impact, the overall impact would be tremendous. This could be done by using the same way of working as we currently do. This actually is closely related to lean, which it mainly focusses on a team in construction (a contractor with his organization of sub-contractors). This manner of lean thinking would progress to lean working in the supply chain.

Because of all the processes in the process mode have been transformed into the reduction color of the ladder of Lansink. This indicates that these steps form the basis for the sustainable construction model. Lean and supply chain integration are also visible in this process model and will be looked at in more detail in the following parts.

**Lean**

Koskela (Koskela, 2000) is one of the co-founders of lean thinking. Lean is a new manner of thinking that is strongly related to the process manner of thinking. Lean thinking comes from the production sector, in which Toyota-boss Ohno desired his production line to produce as minimum waste as possible. It is comparable to the innovation of Henry Ford and his supply chain, but Ohno was critical about the manner in which efficiency was achieved. Ford achieved efficiency by fragmenting the production line in order to create maximum repetition and efficiency in his supply chain. Due to mass-production and a focus on the continuing building process, flaws that were built into the product would then have to be repaired by another production line. With ‘lean production’, employees have the power to stop the production line and repair the flaws right away. This meant that the product could be improved constantly. Management was decentralized and through emerging transparency, employees could make efficient decisions themselves, by using figure 3 - 3 (Howell, 1999).

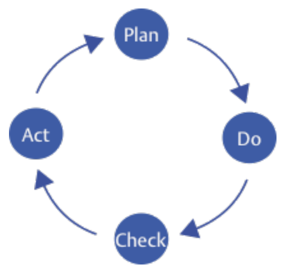



**Figure 3 - 11**:Plan-Do-Check-Act (Howell, 1999)

There was no prescribed method to organize a production/construction process in a lean way. It was “a philosophical, holistic process with a specific target on the removal of waste, while maintaining and improving productivity” (Howell, 1999). The goal is to minimize wastage in the production/construction process. This is done in two manners: improving the processes that add value and reducing processes that are waste processes.

The lean philosophy also made its way to the construction industry. For many years this seemed impossible, because the construction industry exists of a complex and unique process, which is related to the location of the production. In construction, as mentioned in previous parts, there is an activity centered approach (transformational processes). This is due to the mass-production and because of this, there is no focus on so-called ‘flows’ or value-enhancing activities. According to the lean principle, the best way to manage projects in the shortest possible time is to manage the interaction between activities and the combined effects of dependence and variation in the process (Howell, 1999). It aims to reveal the underlying factors of construction, the effects of dependence and variation in chains to reveal chain integration. Lean is a way of thinking that has an impact on the construction process. Lean supports the development of teamwork and the willingness

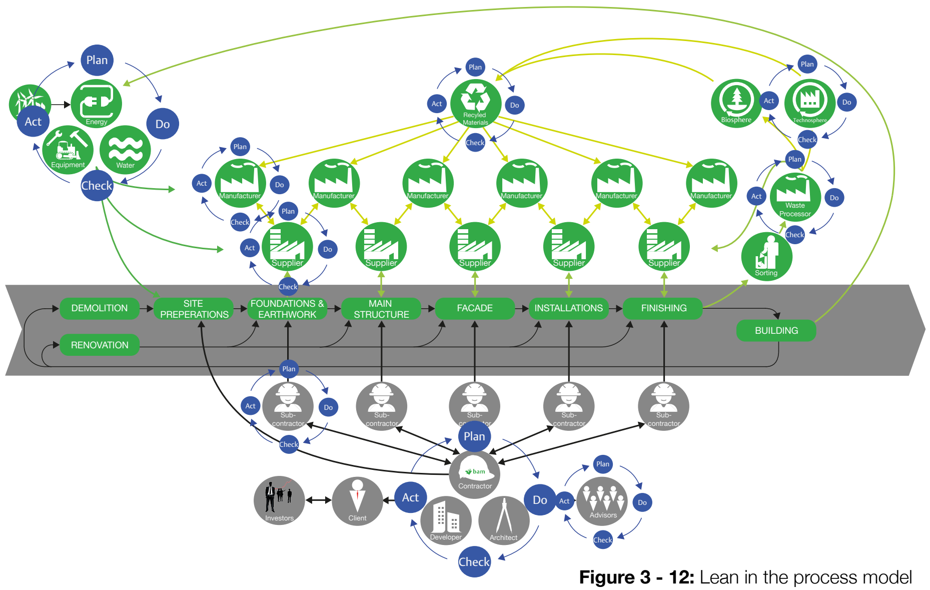



**Figure 3 - 12:** Lean in the process model

to challenge boundaries in chains (Howell, 1999). It focuses on a team culture and internal cooperation (Buch & Sander, 2005). Because the work culture is addressed, there is a shift in the multipolar, antagonistic behavior of partners into a more collaborative and merging position (Egan, 1998). This results in fewer conflicts and partners become motivated to work as a team.

Lean provides insight into the failure of central control and into management production/ construction in complex and uncertain situations, such as the construction sites (Howell, 1999). There is a focus on the knowledge, skills, attitudes and motivation of employees in relation to the building and it is understood that each person contributes to the process (Buch & Sander, 2005). With lean, employees are encouraged to make suggestions and changes to the organization. This puts them in a position to take control over their own work (McBride, 2004). This creates involvement and thus commitment to the work (in teams) at a higher level of supply chain integration.

**Supply chain integration**

By designing the process in a more transparent and understandable way, one knows even more about each other. It is increasingly recognized that the work the actors in the chain do is part of the production chain and thus one will probably also organize in a way that others can use it faster. If each person only tries to optimize its own performance, the production system will not work. One must understand that what actors in the chain do affects the bigger picture (Howell, 1999). Partners are interdependent and one can see what it can do for another. This creates confidence. One partner knows what to expect from another partner. This form of reliability establishes people to trust each other. Reliability is the result of the way in which the process was lacking. Trust is an attitude in terms of reliability (Howell, 1999). However, if we like it or not, the relation that we have with one another is never one-sided but is always in a cyclic nature. Therefore, it is of part of the term supply chain integration which illustrated in figure 3-5.

The term ‘supply chain integration’ already exists for a longer period of time. It is recently becoming a booming term. It is the repetition of the process where independent companies come together with the goal to deliver a construction project (G. Winch, 1989). It has been for a while that companies are cooperating with each other in order to tackle problems. This is done on the basis of good faith and good relations. BAM currently does this by using preferred suppliers like De Groot & Visser. A term that describes this process is partnering. This is described as "a long-term commitment between two or more organizations for the purpose of specifying achieving business objectives by maximizing the effectiveness of each participant's resources" (CII, 1991)).

In other domains, these lasting partnerships between developers, production companies and suppliers have existed for a longer period of time, but these domains also contain a also a high repetition rate. The mobile phone, for instance, came back after 2 years with secondary raw materials. This means that the material cycle for the product is very low. Because products are almost always different in construction projects, the repetition rate is low and it is difficult to classify whether the process remains the same, this is often due to aesthetic values and the form of the building. In every project, different interests are at stake. Because of, the risks need to be redefined and long-term cooperation is prevented. The current crisis bring parties closer together, which allows for competition and conflicting interests to be increasingly streamlined to common interests in a positive outcome.

For good cooperation, the parties must find the right 'fit'. This can be in strategic, cultural, organizational, personal and necessary areas (Douma, 1997). This is not really the case for similar organizations, but rather for complementary organizations; one must need each other. For strategic and organizational suitability, according to Douma, a common vision is needed: the strategic importance of cooperation in a chain, the compatibility of strategic objectives, the interdependence and the ability to deliver added value to the supply chain and other partners of an organization (For example, smaller projects or projects that are not in the chain are executed).

Managers of the various parties perform most elements in the supply chain management. The topics that deal with the supply chain integration by Vrijhoef (2011) are listed as integration of operations, cooperation strategies, integration of operations and processes, planning and logistics, quality management, information sharing, product development and design, market approach and marketing, cultural processes and human resources. It aligns certain processes within the organization in order to work together with other parties. An underlying factor, especially when sharing information, is the will to work together. In some cases it is enough to force employees to share information (Post, 2012).

This manner of working provides a better relationship between actors and actors could become more social towards one another instead of always choosing the best price. Often the actor that makes a mistake in the tender gets the job and has a problem. Integration leads to less wastage and in combination with lean this could provide the a more sustainable working method and reduce the useless transportation in the construction process model (wastage).

The reduction of wastage through lean and supply chain integration show the reduction of the impacts on the environment when applied with a sustainable perspective. This is the highest level of the ladder on Lansink and therefore the focus point in sustainable construction to improve. It is also the hardest one to achieve. From the perspective of the contractor the reduction must take place on-site and the reduction focus must be on energy usage, equipment (that reduces the need for crude oil). Less water should used,

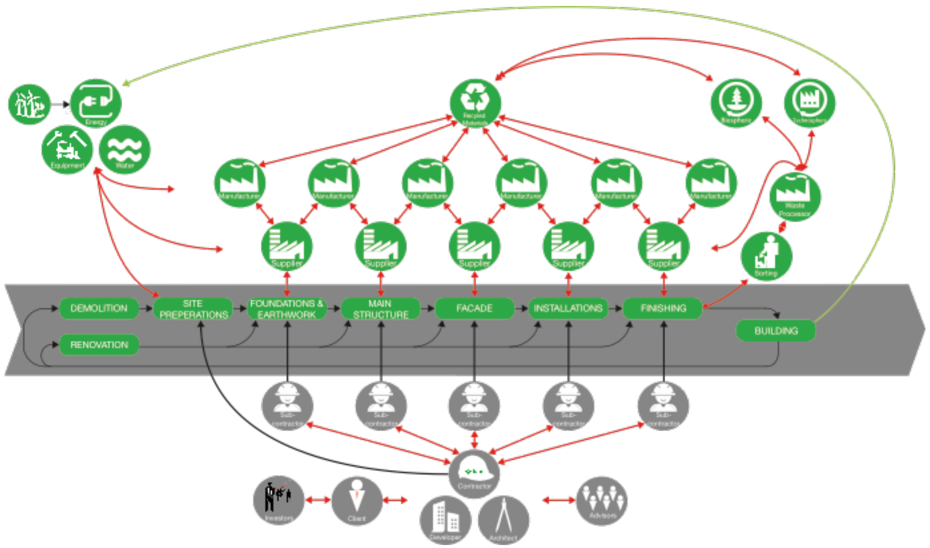



**Figure 3 - 13:** Supply chain integration in sustainable construction

less materials should be demanded from the industry and the $CO_2$ and pollution impact on the earth should be reduced.

**Feedback & Communication**

Extra aspects of importance that has been incorporated in the sustainable construction model is feedback and communication. The lines in communication are in normal construction of a linear nature. In the sustainable construction model more of a cyclic nature. This includes the feedback communication line towards the organization of the construction project, but also the communication with supplier industries and construction companies. This is incorporated in the line of reuse, and indicates that feedback and communication have a positive impact on sustainable construction. The interviewees have mentioned this (75%) as an aspect that will improve sustainable construction.

## 3.6 Findings

The sustainable construction process was defined using the definition provided by the twelve experts interviewed. Together with an in-depth research in sustainable construction in this chapter, provided the following definition: 'Sustainable construction is construction that does not impact the environment (**planet**) and **people**, while making a **profit**'. This definition is based on the famous definitions of Elkington and Brundtland.

These definitions, on the contrary, did not provide the insight needed for a new flow diagram, as in figure 3-14. The ladder of Lansink was used to structure the sustainable construction process model in different steps. The basis of the whole diagram and definition can be found in the Cradle-2-cradle philosophy and industrial ecology. These are based on a cyclic nature of elements related together, like in nature's processes. The sustainable construction process model is the translation of the definition, different tools and philosophies into one process flow diagram. Thereby defining sustainable construction, the first part of the main research question in this research. The elements being defined, together with the relationship between the elements. The definition proves to be an accurate definition for the construction process including all elements defined and related to one another, thereby answering the first part of the research question.

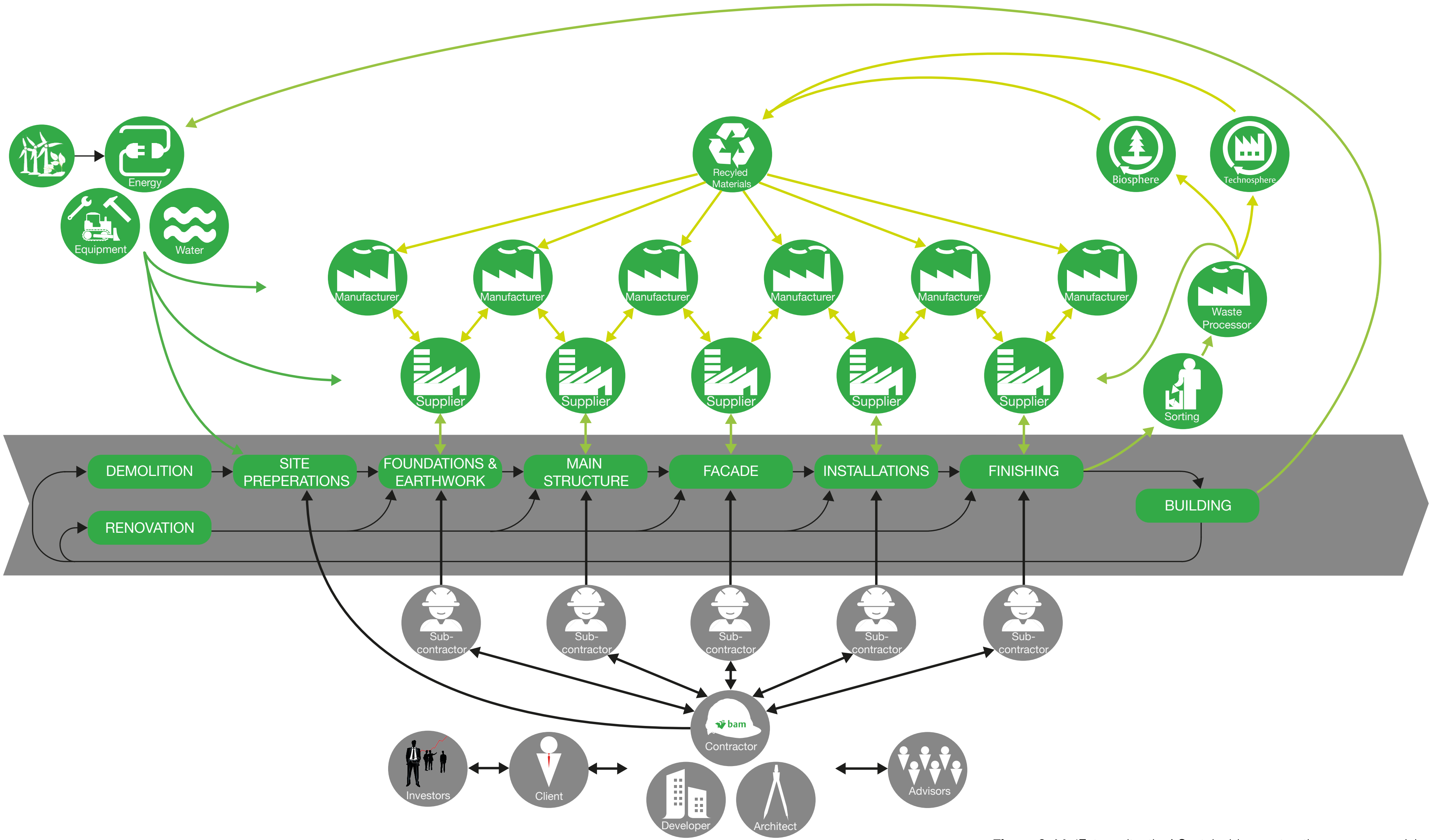



**Figure 3-14**: 'Future situation' Sustainable construction process model

# 04 Obstacles sustainable construction

The development of a theory and the design of the current and desirable situation (sustainable construction) have answered the first part of the research question (defining sustainable construction). However, the process model of this theory is only the first step in achieving sustainable construction. A group of experts answered questions related to the sustainability of the current construction process and defined the desirable (sustainable) construction process already. The main goal of the interview was to investigate 'how to achieve sustainable construction'. Assessing the obstacles in achieving sustainable construction. By asking them about the positive and negative aspect of the current process, the obstacles and an analysis of the answers from the experts provides strengths, weaknesses, opportunities and threats that will be assessed in a SWOT in order to find an answer to the research question.

## 4.1 Interview Setup

The interviews will be used for three specific reasons. The first aim of this interview is to acquire useful knowledge and information about achieving sustainability in the construction process. The required information contains:

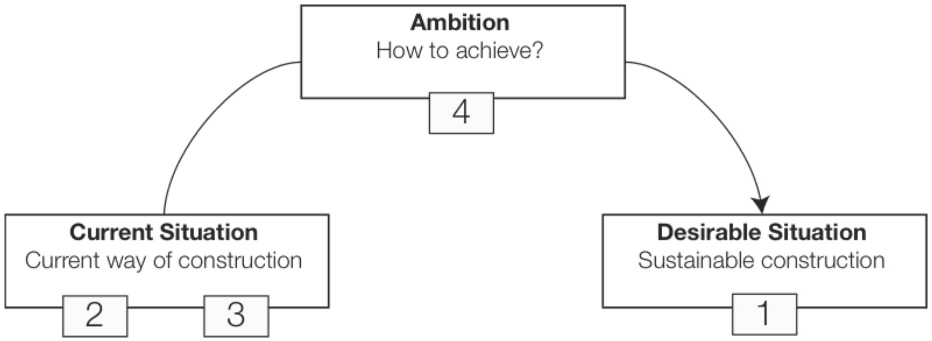
- Definition of sustainable construction (discussed in previous chapter)
- Current status of the construction process with respect to sustainability
- Improvement aspects of the construction process in relation to sustainability
- Obstacles for the improvements and causes for these obstacles

The second aim of the interview is to acquire useful knowledge and information about the elements (and their relationship to one-an-other) in the sustainable construction process model. Already conducted in the previous chapter. The information required from this part of the interview is:

- Improvement aspects of the construction process in relation to sustainability
- Reflection of the theory process model.

The third aim was to acquire the definition of the sustainable construction process that could be used as the basis for chapter three.

In order to acquire the information in the first objective, questions have been formulated. These are open questions that allow the interviewee to give his/her own opinion. The questions seek the specific knowledge on the subject through the perspective of the expert. Looking at the research method, the questions will be related to the current situation, a desirable situation and the obstacles for achieving sustainable construction. The numbers in the diagram below show which interview questions (Appendix 1) are related to the research domain of this paper. The results will then give a visualization of the four questions and will answer the second part of the research question.



The second part has been set up in a manner that the construction model as it was four months ago, was reflected on (figure 2-9). This allowed the interviewee to react freely and allowed them to visualize their ideas in the model and allowed them to contribute to the completeness of the model. This allows us (the interviewee and myself) to discuss the sustainable solutions for the construction industry, while using the model as tool to communicate these solutions.

The various answers will be assessed for the usability in strengths and weakness analysis. This will show the usefulness of the answers together with a critical reflection on the content of the answers and shows the reliability of the answers for the further analysis.

Underlying, the answers mentioned by multiple experts, are the strengths and weaknesses of the in current construction process (system). Together with the threats and opportunities (as external factor) influencing the system, also mentioned in the answers, will provide the basis for the SWOT analysis at the end. These answers must have been mentioned by a minimum of three persons from different perspectives in order to be useable for this analysis. The SWOT analysis should provide the answer to the sub-research questions: *What are the strengths, weaknesses of the current construction process (system) that interact with the external threats and opportunities for the system?*

## 4.2 Positive aspects sustainability in construction

The first filter of analysis will include the structuring of the answers provide by the experts. The results from the interview were sufficient, but were formulated in different manners and therefore needed to be structured. By using a program (Atlas.ti), the answers have been coded and brought together in a summarized code of positive aspects. In this case, coding means clustering answers that involve the same aspect mentioned. Coding these answers is useful for the second step in the filter system.

Looking at the strengths, weaknesses, threats and opportunities of the answers, will assess the answers given to this question; Important to note is that strengths and weaknesses refer to the system, in this case, the construction process. The opportunities and threats are aspects that influence the system but can only be controlled by the strengths and weaknesses of the system. This assessment is part of the third step after having analyzed the answers and filtered the information of the previous steps.

These frameworks will provide some strengths, weaknesses, threats and opportunities for the SWOT in section 4.6. This diagram will then be used to determine which strengths and weaknesses are linkable towards threats and opportunities that have been mentioned.

### *4.2.1 Question*

The following part will focus on the second question in the research framework and is related to the current situation of the construction process:

*What are your positive experiences with sustainability in the construction process?*

This question will allow the interviewee to react freely on positive aspects in construction related to sustainability. The answers are diverse due to the different perspectives.

### *4.2.2 Results*

The table contains ten aspects that have been mentioned by more than one person. The other aspects have been put together in the a separate part and include answers like:

- Using main goals for sustainability in organization
- Better cooperation leading to sustainable processes
- Delivering energy neutral homes
- Energy neutral construction sites
- Laws and regulations
- More renovations
- Most innovation involves sustainability

Interesting to see in this list is that energy neutral homes and construction sites have been mentioned, by only one person, while it has a lot to do with the sustainable construction process. This means that these answers are not widely known by others and are therefore often a scattered initiative. Another interesting part is interesting to see is that from the three managers of construction companies only one has main goals for sustainability (first point above), and shows a real structured approach (Koolen, 2012). Other companies could such an approach as well but did not mention this. Obviously, it is of importance in this organization and could also be of importance to the other organizations.

| | POSITIVE ASPECT | FRE-QUENCY MENTIONED | FREQ. PEOPLE MEN-TIONED | PERSPEC-TIVES |
|---|---|---|---|---|
| 1 | Sustainable material usage | 11 | 9 | CM2,3/SM1,3/AC1,2/GO/D1/SI |
| 2 | Energy usage awareness | 7 | 6 | CM2,3/SM2/AC2/GO/D1 |
| 3 | Tools contributing to sus-tainability | 4 | 3 | CM1/SM3/GO |
| 4 | Demand for sustainability growing | 3 | 3 | CM1/SM1/AC1 |
| 5 | Corporate Social Respon-sibility (CSR) | 3 | 3 | CM3/AC1/SI |
| 6 | Sustainable equipment | 3 | 2 | SM1/SI |
| 7 | Reduction $CO_2$ (through transportation) | 3 | 1 | CM2 |
| 8 | Flexibility/Adaptability of buildings | 3 | 1 | AC2 |
| 9 | Construction process adds value | 2 | 2 | SM2/D1 |
| 10 | Certified labels | 2 | 2 | D1,2 |
| 11 | Others | 7 | 6 | CM1,2,3/SM1/D1/SI |

#### *4.2.3 Analysis*

The table shows that nine of the twelve interviewees (75%) have answered the question by saying something about the sustainability of the material usage in the current construction process. This answer will be examined in more detail by assessing the strengths and weaknesses.

| **Strength** | **Weakness** |
|---|---|
| Mentioned by 75% of the interviewees | Most only deal with waste separation and is not about recycling and reuse |
| All different actors interviewed mentioned this aspect | On-site manager mentioned this as a negative aspect in the next part |
| 66% of the construction experts mentioned this | Not yet visible in BREEAM scores materials |
| Experts on-site contribute to solutions with correct answers | Aspects mentioned related to previous literature like ‘Nationaal Pakket Duurzaam Bouwen’ |

This answer is one of the only answers that has been provided by at least one of all the different types of experts interviewed. This means it is an aspect that all experts are familiar with. Within this cluster, *sustainable material usage* ‘waste separation’ is also included. It is interesting to find that construction management experts Jeroen Troost and Robert Koolen both agree that waste separation is a positive aspect in the construction industry related to sustainability. This is illustrated by the following quotes: “We are realizing 90% waste separation rates" and "there is a financial incentive for the waste separation due to rising prices of unsorted waste from waste production companies".

Construction site managers, Jan van der Hoeven and Danny Burgstede do not agree with the waste separation argument. Jan van der Hoeven mentions "I do not truly believe that waste separation costs less money due to the labor hours involved in waste separation. However, I cannot prove it". Danny Burgstede states "separating at the source" could make the waste separation profitable. He also states that "Waste separation itself is not sustainable. It is what we do with this waste, as stated in BREEAM, that is important". This can be substantiated with literature evidence; CIB (2011) states that waste separation is an activity that helps with the reuse and recycling of materials, which in its turn is sustainable.

The fact that experts mention sustainable material usage and that this deals with the construction process is a positive finding. However, most aspects, like the "ban on PUR foam" mentioned by Andy van den Dobbelsteen, will be treated in the examples of the 'National Pakket Duurzaam Bouwen'. Another interesting aspect is that materials, a category in BREEAM, is hard to get credits for (de Graaf, 2012). This could indicate that all specialists are mentioning BREEAM to prove something or that it is an aspect they believe is dealt with in the construction process. The threat in this story is that people are aware of the aspect of sustainable material usage but no policy is made and the credits in BREEAM are still not met. Sustainable construction has been defined as construction with no impact on the environment and materials still have a large impact on the environment at this moment. This is closely related to the supply feeder industries and could indicate that this must be an opportunity for supply chain integration. However no expert mentions this.

The table on the previous page shows that energy usage awareness has been mentioned by half of the interviewees. Many experts with different perspectives have mentioned this. The answers are often related to the products (buildings) and not to the process of construction. These two aspects are interconnected. This is a weakness in the answer because we are looking at the construction process and not at the product. The 'energy awareness' shows that energy and materials are positive aspects mentioned in the construction process (system) at this moment. These are related to the resource depletion and global warming. However, when examining the answers they only indicate aspects of small improvement, such as: "we use 100% sustainable wood" according to Robert Koolen and Thomas Heye. Furthermore, "energy reduction during construction" mentioned by Andy van den Dobbelsteen or "installation of energy meters" by Robert Koolen. These are all good aspects of improvement but do not indicate the solution for sustainable construction.

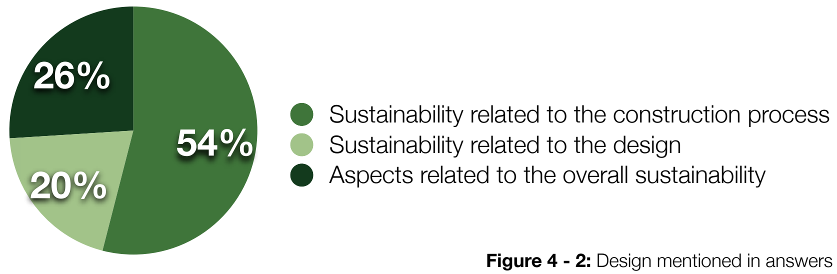



**Figure 4 - 2:** Design mentioned in answers

The pie chart indicates the percentage of aspects mentioned that are related to the design process, the construction process and the answers relating to the overall sustainability. This shows us that when asking about the positive aspect of the construction process, the experts mentioned something positive about the design. This could mean that the design can have a positive influence on the construction process. However, this means that currently it does not have this effect. This is substantiated by the quote of Andy van den Dobbelsteen: "It is known that 65% of the failure costs are related to the design". There are various other reasons for why experts do not mention the construction process, for example, Marit van Rheenen is not involved in construction directly and does not judge this industry: "my expertise does not lie with the construction of a building".

The other aspects in the table, involve aspects like CSR and the increase of sustainable demand by the clients. These aspects have an extremely high impact on overall sustainability. The CSR reports have contributed towards the awareness of sustainability in the primary construction process of various diverse types of organizations and changed the way an organization works. The demand from the client shows that if clients want something from the construction industry, the industry must deliver. Making it easier to implement, posing as an opportunity for the system.

### *4.2.4 Conclusion*

This investigation into the answers of the expert has brought to light a number of interesting aspects. The aspect of CSR and the increasing demand for sustainability have not been mentioned by all experts but do indicate that we are making steps towards sustainable construction. Most answers are related to energy or materials, which shows that these aspects are being used. However, not in a manner that sustainable construction are achieved anytime soon. The site visit to the Danone Innovation Center, for the interview with Danny Burgstede (Site manager) and a tour around the construction site did show that within the construction industry and the engineering need to improve. The site manager possesses knowledge that is not often utilized during engineering, but this knowledge could have more impact on sustainability. In order to make the construction process more sustainable, the experts of this phase will need to be consulted.

### *4.2.5 SWOT current construction process*

The following part will assess the answers given by the experts and will define whether these answers contain strengths/weaknesses of the current system (construction process) or threats/opportunities (external factors) influencing the system. For each category, (strengths, weakness, opportunity and threat) the answers will be sorted. The answers need to be mentioned by at less 25% of the interviewees (three different experts) in order to be useful in the next analysis.

**Strengths**

The first strength mentioned in these answers is the *high percentage of recycled material* used and sorted. With quotes such as "60% recycled asphalt together with 40% less energy usage" by Robert Koolen and "we are able to recycle more waste each year" by Andy van den Dobbelsteen, this strength is properly motivated.

The second strength is that the *biosphere materials are used in a sustainable manner*: "we use 100% FSC and PFC certified wood" and also "we implement as much sustainable wood as possible by planting one tree for every tree we use" mentioned by all three construction managers. This is in relation to the system itself and how this system uses materials.

The third strength is that *design reduces the materials needed through slender dimensioning.* Michel Haas illustrates this with an example of a different perspective used by two constructors. In both design the one for instance by saved 40% of materials in the design, due to his sustainable perspective. Site management and general management also confirm this: "the design can reduce the amount of materials needed" is a quote from Jeroen Troost, but one of many hoe agrees.

The fact that *waste separation* is an important aspect and strength of the current process has to do with the fact that this is creating awareness on site. With quotes like "waste separation is up to 95%" by Danny Burgstede, this strength is properly motivated.

**Opportunities**

The first opportunity mentioned is the *corporate social responsibility*; this is an aspect that has no relation to the system of construction, but is an external factor for the system being assessed. It should be regarded as an opportunity, because it could influence the system in a positive manner. As one expert said: "larger contractors can use the CSR reports". A weakness related to corporate social responsibility in the system mentioned by Thomas Heye, Peter Fraanje and Michel haas, is that it is not used in the whole supply chain.

The second opportunity mentioned is that the *demand for sustainability is growing*. This is also an aspect that has no relation to the system. It is an external factor that can influence the process in a positive way and therefore is an opportunity mentioned by three experts, Michel Haas, Jan van der Hoeven en Jeroen Troost. They state: "the demand for sustainable construction is growing" and "there is more support for sustainable construction than five years ago".

The third opportunity mentioned is that *energy usage has return on investment potential*. This is an aspect that is also not related to the system but shows that sustainable energy usage has a return on investment. This is an aspect that could be used by the system as an opportunity. The experts mentioning this opportunity (CM2,3/SM2/AC2/GO/D1) state aspects such as: "potential of energy consumption" or "energy has a return on investment" and 'what we construct now is very sustainable, in relation to energy". This indicates that the current construction process (system) is already takes profit from the opportunity.

The last opportunity is that *various methodologies and tools can contribute sustainable construction*. The fact that this is mentioned as an opportunity has to do with the answers given: “3D BIM does not seem to play an important role initially but could play an important role” according to Jeroen Troost and “lean helps to get rid of wastage” according to Danny Burgstede.

**Weakness**
Together with the opportunity of ‘energy usage has a return on investment potential’ comes the weakness of the system: i*t is dependent on return on investment*. Robert Koolen mentions “installing energy meters for monitoring the energy usage on site”. This initiative succeeded due to the return on investment and not because of the sustainable initiative, thereby, indicating the dependence on money and value.

## 4.3 Negative aspects sustainability in construction

This section will assess the answers given by the experts in the different frameworks.

### *4.3.1 Question*

The following part will focus on the second question in the research framework and is therefore related to the current situation of the construction process:

*What are your negative experiences with sustainability in the construction process?*

### *4.3.2 Results*

These results have been handled with in the same way as in the previous question. The full length interviews can be found in the appendix four. This question has delivered three aspects that have been mentioned by more than one person. There is a total of thirteen different aspects mentioned in relation to answering the question on what are negative experiences with sustainability in the current construction process.

| | NEGATIVE ASPECT | FREQUENCY MENTIONED | FREQ. PEOPLE MENTIONED | PERSPEC-TIVES |
|---|---|---|---|---|
| 1 | Not enough sustainable material usage | 3 | 3 | D1,2/GO |
| 2 | Legislation not up to date for sustainability | 3 | 3 | SM1/SI/GO |
| 3 | Cost saving decisions | 3 | 3 | CM1/GO/AC2 |
| 4 | Bad cooperation | 2 | 1 | CM3 |
| 5 | Bad governmental pol-icy steering | 1 | 1 | SI |
| 6 | Client not willing to pay | 1 | 1 | CM2 |
| 7 | Labels are overreaching their purpose | 1 | 1 | SM3 |
| 8 | Limitations recycling | 1 | 1 | SM1 |
| 9 | Maturity of sustainability | 1 | 1 | SM2 |
| 10 | No social sustainability | 1 | 1 | D1 |
| 11 | No supervision on site | 1 | 1 | AC1 |
| 12 | Understanding | 1 | 1 | AC1 |
| 13 | Useless research into aspect we already know | 1 | 1 | D1 |

### *4.3.3 Analysis*

The answers given did not include inconclusive answers. Because of this reason the strengths and weaknesses of the answers will be analyzed.

| Strength | Weakness |
|---|---|
| Construction management and site management very critical about their own processes. | Various answers given |
| Academics provide usefull sollutions for aspects they mention | No inclonclusive answer to one negative aspect |
| Nothing mentioned about design | No policy made to take care of negative aspects |
| | Answers contribute to blaming eachother |

It is interesting to see that when mentioning positive aspects of there were many aspects mentioned which were related to the design while when asking for the negative aspects of the design is not mentioned at all. This could have various reasons. One of the reasons could be that the experts are fairly negative towards the construction process or positive towards the design. In this case, there are more positive than negative reactions and we can say that the design phase can have a positive effect on the construction process. This could be viable but not be proved and therefore this will be assumed.

The second finding is that 25% of the experts state that (non)sustainable material usage is a negative aspect in the current construction process. In the previous section, "100% sustainable (FSC certified) wood is used" was mentioned by Robert Koolen. A other interviewee states that 'the contractor or sub-contractor did not do this according to requirement of 100% sustainable wood' (Rheenen, 2012). The interviewee that expressed that: "we are still lagging behind, but making steps" (Dwars, 2012) makes a point on this aspect. Construction is improving and we are becoming aware of the resource depletion but are not yet moving towards the ultimate sustainable construction. This is related to the definition given by the interviewees: "construction with no impact on the environment". This has to do with "that is has not gone wrong yet" according to Hans Korbee

The third aspect of interest is that all experts not directly related (spectators) to the processes on site, mention a lot of negative remarks about this process. Aspects mentioned, such as "the understanding in the construction industry" and "no supervision on site", according to Michel Haas and Andy van den Dobbelsteen are clearly derived from the spectators viewpoint. When talking to site management, they talk about other topics such as the "legislation not up to date, making it an unfair competitive aspect", or "labels are overreaching their purpose". This indicates that everybody is blaming a negative aspect one another, which shows that the circle of blame still exists in the current construction industry. When talking to the site management and experts it became clear that they did reflect on their own process as well. As my main mentor, Aad van der Horst, said, they do also reflect on there own process: "first look at ourselves and then towards the rest".

The last interesting aspect is that cost saving decisions influence the sustainability in the current process. This is motivated in answers, such as time and budget are key or sustainable goals vanish when time and money is running out. This has already been confirmed by the studies of De Nie (2011). Experts still believe that sustainability costs money, which indicates that an important weakness exists in the process of achieving sustainable construction.

#### *4.3.4 Conclusion*

The reason for why the results are diverse and non-conclusive has to do with the fact that construction experts in this interview have mentioned numerous negative aspects of the current process but non of the answers are correlating. The results do however bring forwards aspects that should be looked at in the construction industry and which could be can be improved. This is useful when designing a sustainable construction process and is a weakness of the current process.

#### *4.3.5 SWOT current construction process*

The following part will assess the answers given by the experts and will define whether these aspects are strengths/weaknesses of the current system (construction) or threats/opportunities (external factors) influencing the system. For each category (strengths, weakness, opportunity and threat) the aspects will be mentioned. The aspects need to be mentioned by at less 25% (three different experts) in order to be motivated properly. In this case it will only involve three aspects mentioned. These answers only involve threats and weaknesses of the system and no strengths and opportunities.

**Threat**
The first threat that we can mention is the changing legislation. Experts (SM1/SI/GO) mention that: "changing legislation means that we have to change all the time" according to Jan van der Hoeven and that "legislation on energy is changing all the time" according to Hans Korbee. This is clearly a threat, and not a weakness for sustainable construction, because it does not influence the system, unless it corresponds with a weakness or strength. Thereby only having indirect control.

The second threat is related to the previous threat and is about the fact that *no legislation is made on material usage*. The quote "While there is a lot being done on energy legislation, materials do not have requirements yet" by Hans Korbee indicates this as well.

The third threat is that the focus on *'energy' leaves 'material depletion' in the shadows*, which is motivated by saying from experts, such as: "the energy problem will be solved in the upcoming years" by Jeroen Troost and Hans Korbee. Together with Hans Korbee mentioning "material depletion is not yet a problem because it doesn't hurt the wallets yet".

**Weakness**
The first interesting weakness is the time involved in a project, and its importance for sustainability. Experts indicate that: "if a project developer had to choose, he would use single glazing, but in a PPP (public private partnership) we would use triple self cleaning windows" according to most construction managers. This means that the sustainability is *dependent on the time the contractor is involved or depends on the demand of the client*.

The second weakness has already been mentioned in the previous section as a side effect on a return on investment for energy, the *dependability on a return on investment*. This is also mentioned as a negative aspect of sustainability and is, therefore, a weakness of the system.

The third weakness is related to the second threat (no legislation available). This means that if you do use sustainable materials and these cost more (another weakness dependent on return on investment), "the competition is not fair" according to Jan van der Hoeven. The weakness of *equal competition* is that the *dependability lies within legislation*.

## 4.4 Obstacles sustainability construction industry

These answers will be filtered in the same way as in the previous two questions and will provide the input for the SWOT analysis in the next section.

### *4.4.1 Question*

The following part focusses on the third question in the research framework which is related to 'how to achieve' the construction process:

*What are the obstacles for the construction industry to improve with respect to the sustainability (environmental impact) of its activities?*

### *4.4.2 Results*

These results have been handled in the same way as the second question and the full-length interviews can be found in appendix number four. This question revealed eleven aspects that have been mentioned by more than one person. A total of nineteen different aspects were mentioned in response to the question: what are obstacles for sustainable construction.

The other aspects have been put together in the 'others' part and include:

- Hype (Media and Green)
- Larger life cycle buildings
- No sustainable demand from the client
- Not learning from others
- Quality limitation recycling
- Shuffling responsibilities
- Time
- Traditional sector

| | OBSTACLES | FREQUENCY MENTIONED | FREQ. PEOPLE MENTIONED | PERSPECTIVES |
|---|---|---|---|---|
| 1 | Profitability | 9 | 9 | CM1,2,3/ SM1,3/D1/ GO/AC1/SI |
| 2 | Not quantifiable (in labels) | 6 | 5 | CM3/SM1/ D1,2 |
| 3 | Commitment | 6 | 4 | CM1/D1,2/SI |
| 4 | Not integrated in supply chain (awareness) | 5 | 5 | CM2,3/SM1/ D1/AC2 |
| 5 | Education construction workers | 4 | 4 | CM2/SM1/ AC2/GO |
| 6 | Bad communication | 3 | 3 | CM1,3/AC1 |
| 7 | Not learning from others | 3 | 3 | CM1/SM1,3 |
| 8 | Engineering not integrated enough with implementation | 2 | 2 | SM1,3 |
| 9 | Habits | 2 | 2 | CM1/GO |
| 10 | Project working (no communication between projects) | 2 | 2 | CM2/SM1 |
| 11 | No sustainable perspective | 2 | 2 | AC1 |

#### 4.4.3 Analysis

The following SWOT shows the overall answering of this question and the results themselves. These answers will provide insight into the answers, and leaves room for individual assessment.

| Strength | Weakness |
|---|---|
| Various aspects mentioned by almost all interviewees | Often blaming others |
| At least 4 clear obstacles agreed on by all types of interviewees | Some obstacle taken already in other organizations |
| 19 aspects mentioned | No policy made to take care of negative aspects |
| Most obstacles deal with aspects in supply chain management and lean | Answers contribute to blaming eachother |
| | If not working together everybody will solve the same problem indiviually |

The fact that so many answers to this question are mentioned, means one thing: the sustainable awareness about obstacles for the achievement of sustainable construction is among all these experts. The experts seem to some knowledge about the obstacles for the achievement of sustainable construction. The strength is that various aspects have been mentioned by at least 50% of the experts. A weakness in the answers, provided by experts, is the need to solve the obstacle within the same answer provided. This is often seen in interviews because people want to show that they are handling the obstacles in a professional manner. Another weakness of is that experts often blame someone else when they talk about obstacles in the achievement. Quotes, such as “Some materials do not have credits in labels” by Marit van Rheenen or “the practical reality is that we are judged on aspects like BREEAM” by Onno Dwars, indicates that credits in labels (blaming the label) determines sustainability. A positive result of the answers is that 47% of the obstacles mentioned are related to the construction process itself. It does not blame outside factors but reflects on the construction process itself.

What is striking is that construction specialists mention the most obstacles related to the construction process (83% of the obstacles). Construction specialists, who show that they know what and how the process works and how it can be improved, mention 68%

of the obstacles that are influenced by external factors. This is not the aim of the interview. The other non-construction specialist experts mainly focus on the obstacles because they often only observe the process. These experts also indicate that they do not precisely know what happens on-site and how this can be improved. As one expert mentioned: “this is outside my scope of expertise”, according to Marit van Rheenen.

The aspect of the education of employees is an interesting one because it reveals the group of people that are not aware of sustainability, “10% of the people on-site are illiterate” is an estimation by Jan van der Hoeven. Not being aware is illustrated by a site manager in the following manner: “If a construction worker finds a stainless steel bolt (worth 30 euros) he would throw it away, but when he finds 10 euros on the ground he will put it in his pocket” according to Jan van der Hoeven. The question that arises from this obstacle is if it is really blocking the ability of the construction process to move towards sustainable construction? The answer will be found in the final SWOT.

The bad communication and the unawareness of being part of a supply chain are closely related. Communication deals with aspects such as “giving feedback to one another on site, but also towards suppliers. Currently this is being done” mentioned by Hans Korbee and “one must work together to solve problem, this is not done enough at this time” . This communication can improve the sustainability of the construction process and can be linked to the supply chain integration where one looks at other actors in the chain and the influence has on these actors. This is also posed as a solution by an interviewee, who mentioned that: “forced cooperation” according to Thomas Heye can positively influence the achievement of sustainable construction.

The profitability is a main obstacle for sustainable construction to take place. It is closely related to the sustainable construction definition (people, planet, profit). However, in times of crisis an easy obstacle mentioned because money (profit) is currently a problem. Aspects that deliver money like ‘Energy’ mentioned by Jan van der Hoeven. The same is the case with the recycling of metal. Nobody would throw away aluminum due to its value. Concrete waste has no value and is therefore not looked at. The aspects that deliver money go hand in hand with sustainability and are easily implemented. Jeroen Troost mentions “cost pricing does not include sustainable measures and cost reduction for these measures” thereby indicating the dependability on no extra costs or value creating. This shows that in achieving sustainable construction, the factors money and profitability are important issues to consider. This also shows the value of providing evidence that sustainable solutions do not in its case cost money. Danny Burgstede told me at the Danone site that he casts concrete blocks from the rest concrete in the trucks and sells this. This shows that with an innovative mind one can improve sustainability while making profit, but it also shows that it is about the mindset of people and the willingness to change.

The aspect of quantifiability of the sustainable interventions and the credits available in labels is an aspect that is shared throughout the whole construction chain. The experts indicate that BREEAM and other labels are good in energy performance and interventions but that these labels lag behind in materials and social sustainability. This makes it an obstacle for the industry to provide solutions that can not be shown in labels or demonstrable for the client. This prevents sustainable construction, from taking place because they only want to show others the labels their buildings have. The sustainable labels do help the willingness to pay of the client, because a goal can be to build the highest ranking within a certain label mentioned by Marit van Rheenen.

These obstacles are all interesting to look at and most of them can be confirmed by the literature referred to in the previous chapters. However, the quantifiability of sustainability (also linked to credits) and the fragmentation of the construction industry seem to be the two aspects that occupy the minds of construction specialists and other experts, which makes them interesting to investigate.

#### *4.4.4 Conclusion*

Interviewed experts mention many important obstacles. Various solutions are also mentioned. A SWOT will give insight on sustainable construction obstacles and shows the aspects that threats/opportunities and strengths /weaknesses of the construction process. The overall answers provide a good insight and the detailed top 4 answers can be very useful for awareness on threats on achieving sustainable construction.

#### 4.4.5 SWOT current construction process

The final SWOT in 4.5 will examine weaknesses, opportunities and threats hidden in the answers.

**Weakness**

The first weakness is the *bad communication issues within the process*. This is mentioned by the following experts (CM1/CM3/AC1): “construction workers removed the sticker (indicating outside/inside) on the window after being confronted by the fact that windows were put in in the wrong manner” and “we as management are good at giving dual signals: make profit and be sustainable” and “openness in communication is a problem in construction”. These aspects show that the weakness in the construction industry lies within the internal communication.

The second weakness would be that there is *not enough commitment towards sustainability within the process.* Experts (CM1/D1,2/SI) mention weakness: “set backs lead to extra costs and these are often taken from the sustainable initiatives”. This quote illustrates what other experts confirm as well. This weakness, however, deals with a weakness of the system and not with an external threat.

The third aspect that is weak in the current system is the *educational level of construction workers.* Experts (CM2/SM1/AC2/GO) mention that: “schooling and explaining is an important aspect” and that “10% are illiterate so it is hard to tell them about sustainability”. This shows that this is a weakness of the current construction process and that is not related to external factors that influence the construction industry.

The fourth weakness that can be stated from the obstacles is the the construction industry is *not learning from other industries and companies.* This weakness is stated as follows: “the industry can provide good examples of how to deal with processes” mentioned by Jan van der Hoeven and also “the effect of not invented here, we see that within our organization the regions do not share best practices” mentioned by Jeroen Troost.

The fifth weakness is that *labels are used as an unjustified definition of sustainability.* This can be shown by various quotes of experts, but the following two quotes illustrate the best why this is a weakness: “some materials do not have credits in BREEAM” according to Marit van Rheenen and “the practical reality is that we are judged on aspects of labels like BREEAM” mentioned by Onno Dwars. This means that the system is dependent on the definition of sustainability by labels and clients.

The sixth weakness is that the current actors are *not asking the right (sustainable) questions.* According to Onno Dwars: “if the right questions were asked the process would become more sustainable”.

**Opportunity**

The first opportunity is linked to the aspect considered with bad communication. The opportunity is to provide more feedback between main actors and to learn from previous experiences as is mentioned in the following quote by Hans Korbee: “No feedback is given while this is an opportunity for the sector”.

The second opportunity linked to the weakness of commitment is that of *best value procurement*. Experts have mentioned this as an opportunity that can deal with the weakness of the system: “predetermined sustainability from a client can lead to problems during construction but a chance is best value procurement” mentioned by Peter Fraankje. This is a good example of opportunities that were mentioned when asking for an obstacle.

The opportunity for the fourth weakness has been mentioned as *supply chain integration.* Most answers (almost 37%) are related to the supply chain and therefore worthwhile to mention. Marit van Rheenen states that: “supply chain integration could help”.

A weakness that has been mentioned in previous parts but also in the obstacles has also lead to an opportunity at this moment: *some aspects of sustainability have a return on investment*. This is illustrated by Jeroen Troost and Andy van den Dobbelsteen when they talked about energy: “When you look at energy we can tell people it has a return on investment within ten years” and “The reason why energy is succeeding is due to its return on investment model”.

**Threat**

Together with the second opportunity, a threat has also been located in *predetermined sustainability.* This can be from the client but also by labels as other experts mention "sustainability can be a label". This is a threat because it does not incorporate everything and does not leave room for alternation during the process or by other actors.

The second threat is related to the last opportunity in which some aspects have a return on investment. This is sometimes related to government subsidies and if these change, or the model of return on investment changes, this could become a threat. This will lead to a return on investment models that are not viable anymore. This is related to the weakness of *dependability on return on investments*.

## 4.5 Organizing data from the interviews in a SWOT

The following SWOT incorporates the strength/weaknesses of the current construction process (also called system) and links them to the opportunities/threats from the external world (effecting this system) in a SWOT matrix. The next step is to see if the system does not utilize the potential of opportunities or does not mitigate threats. If the sustainable construction model possesses the internal strengths to optimize the opportunities and to mitigate the threats, it could be successful. The full matrix is shown in the SWOT layout in figure 4-3 with a colored box that indicates whether if an external factor influences the systems (strengths/weaknesses) or the other way around. The following questions (in the matrix on the next page) will be used to determine whether or not a weakness prevents an opportunity from happening (weakness-opportunity) or whether a weakness can be solved by an opportunity. If this is the case, the box between the weakness and opportunity will be blue and indicates the relation between the two. This will be done for all four the aspects.

| | Strength | Weakness |
|---|---|---|
| Opportunity | Do the strengths influence the opportunities? | Do the opportunities have a relation to the weaknesses of the system? |
| Threat | Do the strengths to minimize the impact of threats | Do the weaknesses influence the threats? |

By doing this assessment we can see what strengths and weaknesses the future (desirable situation) will need to have, in order to deal with the opportunities and threats in a correct manner. Only if the new system is able to have enough strengths to utilize the potential and to mitigate the threats, it will become achievable.

### *4.5.1 Strength & opportunity*

In this part we see whether or not the strengths are able to utilize the potential of the opportunities. This will then create a simple win-win situation for the current construction process. In the SWOT matrix we can see that the strengths of the system filtered from the interviews with the experts have the capability to influence the opportunities. The opportunities 'supply chain integration' and 'better communication' are, however, is not yet utilized in the proper way with the strengths mentioned. These aspects mentioned do not prevent sustainable construction from happening, but could help the sustainable construction process and therefore and will, therefore, not be looked at in detail. The design reduction of materials needed in the current system does however influence various opportunities and is an aspect that will be needed in the new (desirable) situation as well.

### *4.5.2 Strength & threat*

By examining the strengths of the current system in more detail, one could see that these strengths can be used for some opportunities. However, these strengths are not useful for minimizing the threats on the system. The strength 'design that reduces the materials needed' is the only strength that can prevent threats from happening. The other strengths only interact with one or two other threats. The threat of focusing too much on energy and not on material depletion is a threat that can be mitigated with the current strengths, but when one examines the weaknesses of the system we do see that it will be hard. This is due to the fact that various weaknesses prevent the strengths and make it difficult for this system to deal with this threat.

### *4.5.3 Weakness & opportunity*

We can see that when asking the experts about positive aspects, negative aspect and obstacles, there are more weaknesses mentioned. Obstacles often include weaknesses combined with threats, the experts often don't realize that an obstacle includes a weakness. Because of this observation, more weaknesses have been mentioned in this research. Some extra opportunities presented as solutions for the current system were provided as well. Because of this reason the SWOT includes more weaknesses that can interact with the opportunities/threat under certain circumstances.

The following examines opportunities that can be used to provide new strengths that mitigate the weaknesses in the new system and we will look at weaknesses that prevent the opportunities from happening. The weaknesses that influence the opportunities from taking place involve aspects such as:

- Not enough commitment towards sustainability within the process
- Sustainability dependent on profitability (return on investment)
- Not asking the right (sustainable) questions
- Decreasing level of sustainable ambition as the project progresses

These aspects can be influenced by the opportunities presented however need other strengths that can compensate in a new system or a system that does not have the same weaknesses. The opportunities however are not yet used in the current system and can be seen as opportunities for the new system to take care of. The desirable situation will have to use the opportunities in a better manner.

There are also weak aspects in the system that can not use the opportunities in the system, for example 'bad communication' or 'sustainable labels used as unjustified definition for sustainability'. These aspects are aspects that will not require as much focus as the four aspects mentioned above, because they do not interact a lot with opportunities or threats and almost fall out of scope for this research.

The last weaknesses, 'bad educated construction workers' and 'learning from other industries', utilize some opportunities but have no threats to the weaknesses in the system. Therefore these will be a findings that are preconditions for the system. This finding is the part of the system that has influences on the system, however out of the scope of this research project.

#### *4.5.4 Weakness & threat*

Weaknesses and threats combined can form a very dangerous situation for the sustainable construction process (system). This means that the system has weaknesses that are related to threats and has no strengths to compensate. Often strengths can compensate, the weaknesses.

The first interesting finding is that two weaknesses can stay in the system and are influenced by the threats from outside (external). Therefore, these aspects do not form a direct threat for the system itself, and form an obstacle for achieving sustainable construction. Another interesting aspect is that bad communication only has an indirect focus on energy and not on materials. Therefore, this weakness also does not have to fear threats from outside.

The threats that influence the weaknesses the most are:

- Not enough commitment towards sustainability within the process
- Sustainability dependent on profitability (return on investment)
- Dependability (for equal competition) lies on legislation
- Dependent on the time the contractor is involved or from the demand of the client

This means that these weaknesses in the system are the weaknesses that need the most attention; they have the potential to interact with the threats. The main weakness is 'sustainability is related to profitability'. This means that if the desirable situation is not dependent on profitability, this would help in achieving sustainable construction. The first two weaknesses are also compensated by the opportunities that could help in preventing these aspects but still there are more threats than opportunities that this weaknesses deal with.

The weakness 'sustainable labels used as unjustified definition for sustainability' is the most dangerous, because it has three threats and only one opportunity that can affect it. This also means one should deal better with this opportunity or that the new system is in need of a strength that prevents the threat from happening or does not involve the weakness.

| External / Internal | | Strengths 1: Waste seperation (finacially attractive) | Strengths 2: Various materials with high recycling percentages | Strengths 3: Various bio-sphere materials used in a sustainable way (FSC wood) | Strengths 4: Design reduces materials needed | Strengths 5: Various methodologies and tools can contribute towards sustainable construction | Weakness 1: Bad communication between main actors | Weakness 2: Not enough commitment towards sustainability within the process | Weakness 3: Sustainability dependent on profitability (return on investment) | Weakness 4: Dependent on the time the contractor is involved or from the demand of the client | Weakness 5: Construction workers not educated enough | Weakness 6: Sustainable labels used as unjustified definition for sustainability | Weakness 7: Dependability (for equal competition) lies on legislation | Weakness 8: Not asking the right (sustainable) questions | Weakness 9: Decreasing level of sustainable ambition as the project progresses | Weakness 10: Not learning from other industries/companies (abroad) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Opportunities** | | | | | | | | | | | | | | | | |
| 1 | Best value procurement | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 |
| 2 | Corporate social responsability | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| 3 | Demand for sustainability is growing | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 |
| 4 | Some aspects of sustainability have a return on investment potential (Like energy) | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 |
| 5 | Supply chain integration | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 |
| 6 | Better communication by giving feedback | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 |
| **Threats** | | | | | | | | | | | | | | | | |
| 1 | Predetermined sustainability (Client or labels) | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 |
| 2 | Changing legislation/regulations | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| 3 | No legislation for materials | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 4 | Focus on 'energy' leaves 'material depletion' in the shadows | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 |
| 5 | Return on investment models of aspects are not viable anymore | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| 6 | Bad financial situation organizations (Economical Crisis) | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 |

**Figure 4 - 3:** SWOT analysis

**Obstacles**

To answer the sub-research question: *What are the obstacles for the construction industry to move towards sustainable construction?* the following part will assess the answer to this question.

It is interesting to see that the weakness of the system being dependent on profitability and the threats currently affecting the system indicates that this is an obstacle for sustainable construction, 75% of the experts mentioned this but the diagram shows that it really effects the system in a negative way because this weakness is a combinable with various threats and therefore an obstacle for achieving the desirable situation.

The obstacle mentioned about the quantifiability of sustainable elements in labels is the combination between 'predetermined sustainability' (threat) and the 'sustainable labels unjustifiably used as definition for sustainable construction' (weakness). This also indicates that this is an obstacle for sustainable construction.

The fact that people have mentioned these aspects and that these aspects appear in the table is not strange, because the answers formed the basis for strengths, weaknesses, opportunities and threats. The fact that people mention them as a threat and a weakness together is insightful. The fact that weaknesses also affect other threats only strengthens the obstacles mentioned. The educational levels of construction workers is a weakness but is not dangerous because no threats influence the weakness at this moment. Still, it is mentioned as obstacle. This way of analysis allows one to determine the importance of the different obstacles and to see how one should prevent them in a future system that contains new strengths and weaknesses that can compensate those of the current.

## 4.6 Findings

This part will answer the question: '*What are the obstacles for the construction industry to move towards sustainable construction and what are the causes of these obstacles?*' The SWOT analysis has brought some insight into what information we were able to filter from the interviews with the experts. This has been cross-analyzed in the previous part and revealed aspects of the system that need to be improved in order to achieve sustainable construction. In order to answer the question on how to achieve sustainable construction we could say that the following obstacles need to be dealt with. The system needs to improve with new strengths that can compensate the weaknesses of the current system.

This part will look at aspects that are of importance for the system to change and responds to the external opportunities and threats in a better manner than the current system does. It provides the obstacles that can help to answer the question on how to achieve sustainable construction:

1. *The current **linear** way of thinking opposed to the **cyclical** (desirable) way of thinking.*
2. *The **commitment** needed during the process.*
3. *Using labels as an **unjustifiable definition** for sustainable construction.*
4. *The **profit** that is needed for sustainable construction (reduced impact on **planet**), that not all initiatives have currently.*

The other interesting aspects are that the weaknesses of the system are being referred to as 'bad educational level of construction workers' and 'the looking at other industries'. These aspects are weaknesses that are included in the system but do not seem to be a threat in relation to sustainable construction, this aspect could still be incorporated without affecting the achievement of sustainable construction.

An aspect of interest is the 'asking the right sustainable question'. It can use the opportunities to improve in the current system and is, therefore is achievable in the current system. This is an aspect that could be changed towards a strength of the current system. It is an opportunity that is easy to utilize.

The last important thing to mention is that the current system and external factors are the only answers given by the experts in these interviews. There are probably more threats and opportunities and the system probably also has more strengths and weaknesses. however in the overall conclusion this will be reflected upon in-depth.

#### 4.6.1 *Achievement*

Having mentioned four important obstacles that need to be dealt with in the desirable sustainable construction model (new system), it will be tested if the desired definition of sustainable construction contains the ability to overcome the four main obstacles. The assessment if it has the correct strengths to utilize the potential of opportunities and mitigate threats, thereby answering the question: *How can we achieve sustainable construction?*

1. The obstacle of **linear vs. cyclic** nature, has been illustrated by both models below. In the new desirable situation we can see that feedback between the industries and main actors have changed to a one way arrow towards a two-way arrow. The transition towards the cyclic model will take time and convincing, to be achieved.
2. The dependency on profitability, seems to be an important obstacle in achieving sustainable construction. This aspect can not be proven in this model, however in the next chapter will look at the link between sustainable construction (reduced impact on **PLANET**) while making **PROFIT**. Proof for sustainable construction being profitable would help in the achievement due to the fact that it is then using the economical foundations dat will be useful for achievement.
3. The **commitment** is of importance during the implementation and transition phases between the current en desirable situation. If the sustainable situation were to be profitable this commitment is still needed because it still needs convincing of the people working in the processes.
4. The use of label as definition for sustainable construction, limits the creativity of the process and also limits the possibilities of true sustainable construction. This process model en definition of sustainable construction provides the open scope needed and only indicates the foundations of sustainable construction, allowing for free building on the foundations.

The achievement of sustainable construction is dependent on four main aspects, however an aspect mentioned by almost all experts was the profitability, therefore the next part of the research will focus on the testing the profitability of the new system. This will need to be examined closely, in an analysis of a specific element of the process model (scope). This assessment would lead to the investigation of sustainable construction (reduced impact on the planet) while reducing costs (profit). A new step of implementing the desirable sustainable construction process, should provide the answers on how to achieve sustainable construction. The practical application can provide lessons on how to deal with specific steps.

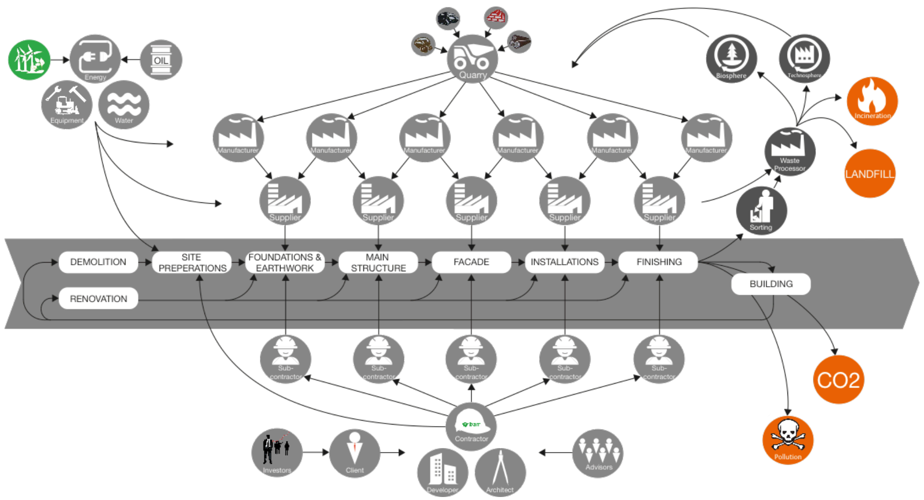



**Figure 4 - 4:** Current construction process

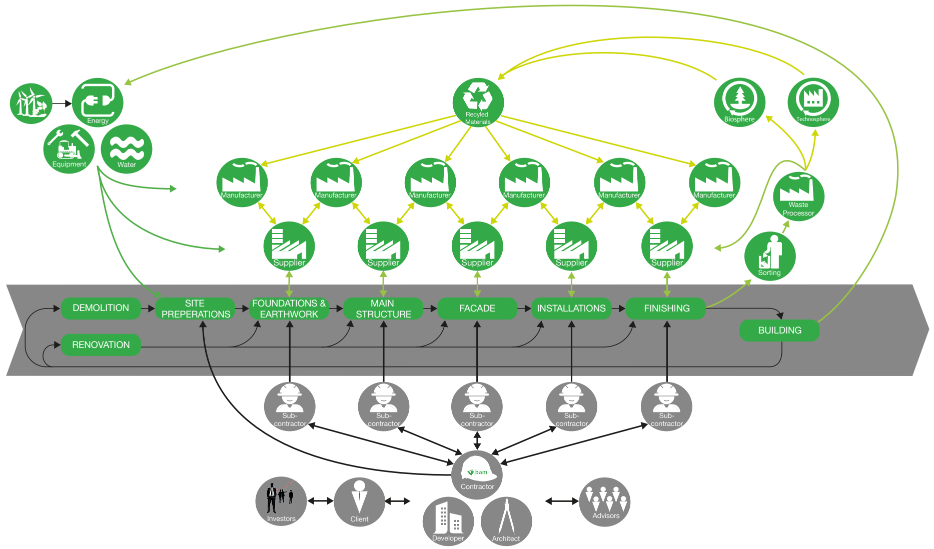



**Figure 4 - 5:** Sustainable construction process

# 05 Implementing sustainable construction

The achievement of sustainable construction in total is far more complex than this graduation research alone. In the quest for achieving sustainable construction the first part has been done: assessing the obstacles. The four obstacles mentioned in the previous chapter do provide insights on what the sustainable construction process must incorporate an overcome. The next step is to achieve this by making a plan of approach.

This part of the research will investigate a plan of approach, that will have to provide the answer on how to achieve sustainable construction. This will be referred to as the step-by-step plan. The step-by-step plan must involve two aspects: analysis and solutions. This will help optimize the construction process, towards a sustainable process.

The design of this step-by-step plan is done by using an element of choice. Investigating in which manner this element of choice would have a reduced impact on the environment and not cost more. One element is chosen because, this will scope the research. Secondly, because more elements make the design and analysis far to complex. This is an addition to the research design made in chapter one and has be visualized in figure 5-1.

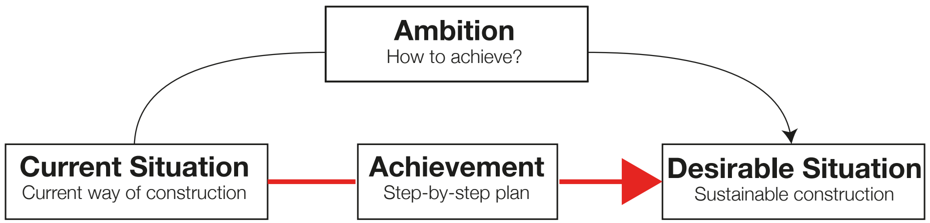



**Figure 5 - 1**: Placement in research design

For designing a step-by-step plan a random element can be chosen because the goal is not to solve the impact on the planet and profit but, to provide insights on how to achieve sustainable construction. The industry must optimize their process towards sustainable construction themselves. This research into the step-by-step plan will provide the insights on how to organize and construct these steps. Therefore the question for this part of the research is: *How can you implement the construction process model as a tool, in order to achieve sustainable construction?* This process will focus on the planet and profit aspects of the achievement of sustainable construction (figure 5-2)

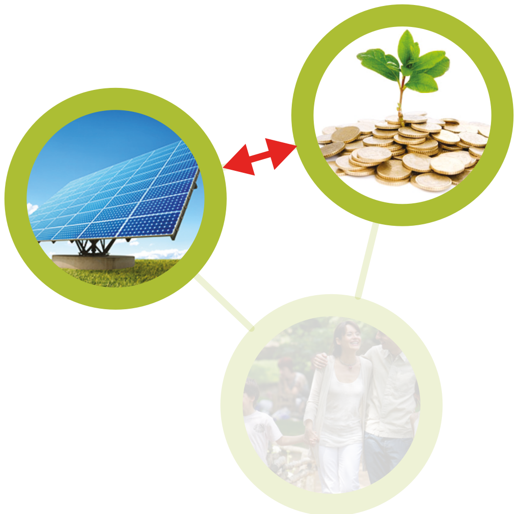


**Figure 5 - 2**: Planet and Profit focus (Illustrations from (Google, 2013))

## 5.1 Background information

The step-by-step plan that is designed for achieving sustainable construction will involve various steps. All steps are explained in the next paragraphs. The step-by-step plan will be used to analyze the current situation and optimize towards the desirable situation. A manual is developed that will help achieve sustainable construction.

**Goal of analysis**

The goal of this step-by-step plan is to develop a method of analysis that will allow for the assessment and implementation of sustainable construction. The goal is not to solve the element used as example, but to use the insight provided by the element example, in order to develop a method for analysis.

**Method**

In order to develop a step-by-step plan, the method is design by using a random element. The element chosen will allow to assess which steps need to be taken and which aspects in the analysis and implementation are of importance. This means that once the method has been established various other elements can run through the step-by-step plan. The element chosen will be analyzed using a case study, which will provide the necessary data needed to assess the different steps and the sequence of the different steps.

**Case introduction: The Monarch I**

The project The Monarch, is a project consisting of four office towers with international stature. The project includes a total of approximately 85,000 m2 of office space and consists of three new developments and the renovation of an existing building. Development of the Monarch is a joint venture between Provast and ASR Property Development (BAM, 2011). The Monarch is the so-called Monarch Location within the Beatrixkwartier (a location in the Hague), this is an inner-city business district on the Utrechtsebaan in The Hague (De Monarch, 2012). The Monarch I was the first monarch sub plan of the total Monarch plan and is now completed. It is a redevelopment and expansion of an existing office building from the sixties (the former VNO-NCW office dating back to 1965) and for housing the headquarters of the CAK (De Monarch, 2012). The existing building was completely stripped up to the main construction. The building is made wider by seventy-five cm all around and well covered with a new aluminum facade. The element of interest in this chapter. It was designed by KCAP Architects & Planners and is achieved by BAM Utiliteitsbouw.

**Element of choice**

This case will provide the necessary information on the aluminum facade, the element of choice. BAM has provided the contacts towards the supplier industries and partners that were involved in this project. The industries and partners were visited. First interesting thing was that all partners were very open towards the research and shared the necessary information for this research. Before this choice was made two other options were investigated; Smart Building Logistics and Dry Heating.

## 5.2 Design of a step-by-step plan

The design of the step-by-step plan was a cyclic iterative process. The following is the result of the design process and explains the different steps designed and motivates the sequence in which they are put forward.

Designing a step-by-step plan for a process means the product is not under investigation. The product is closely related to the design process, often headed up by the architect. The design of the product influences the process a whole lot (de Nie, 2011). This design process is often not influenceable by contractors and their supplier feeder industries. Therefore, it has been put forward as constant factor, not part of the scope.

By analyzing the answers in chapter four, the research has put forward that you must focus on internal - influenceable - strengths and weakness. This is because the external factors are always changing and make the process and its initiatives dependable. This analysis focusses on the influenceable strengths and weaknesses. An example of the dependability on external factors are: EMVI criteria that virtually reduces the tendered budget, through EMVI criteria (lets say from 110 million to 100 million) in order to be awarded a project. The real costs are still 110 million without the criteria. If the criteria change, which you cannot influence, you will not be rewarded if an other party has a better bid. Therefore, it is important to reduce the total costs without EMVI criteria, because in this case you will always have the best bid.

### 5.2.1 *Step1: Choose and element of focus*

Investigating the whole impact of a system (all parts of the building during the process) would be non realistic because of the complexity of the total construction process. The first step is to choose an element of interest (scoping). This element can involve a specific process (dry heating) or material (aluminum facades) or method of working (Smart Building Logistics).

In this step the element is chosen and the processes, activities and actors involved determined. This is done mostly by common sense, but mostly by talking to the supplier industries and determining what processes in the current construction process model are involved in the determined element. The result of this analysis into the specific element of choice is - indicating the processes and actors in the current construction model - the models in figures 5-3, 5-4 and 5-5. This indicates the scope of the research and forms the basis for the next step.

Looking into all three elements analyzed shows that aluminum has the most processes and actors involved. Together with the fact that it has a lot of quantified data on energy usage and $CO_2$ emissions. The complexity of the element, will help in the quality of the step-by-step plan because in this manner you learn more about the step-by-step plan.

The fact that all elements mentioned can be analyzed, shows the exclusiveness and possibilities of the model. For the analysis the aluminum facade is used as example, insights in this mapping will be used to develop the step-by-step plan. The following three examples will put forward that specific actors and processes involved in the impact on the environment. These three examples have been examined in this step:

1. Smart Building Logistics (SBL), researched by Basak Karabulut (2012).
2. Dry heating during the actual construction (assembly) process, following the research of Marc de Nijs (2010) at BAM Utiliteitsbouw. In his research he indicates that the largest source of carbon emissions in this process is dry heating.
3. Aluminum facade, this aspect was chosen due to the amount of data available and the fact that this element involves the full supply chain in the construction process.

**Smart Building Logistics (SBL)**

The concept of Smart Building Logistics (SBL) is a new way of working that uses a Just-In-Time (JIT) delivery on-site, that bundles flows of materials in a clever manner and combines the supply of materials with the disposal of waste. The building materials are brought to a transshipment location of UTS Netherlands (partner in SBL) and are then transported to the construction site if needed or indicated. This transshipment site is also referred to as the HUB (also indicated in the figure above). The suppliers deliver to the transshipment site UTS Netherlands and can thus also optimize their load factor (TNO, 2012). Director Pronk (of the Smart Building Logistics) explains that the transportation of materials from an establishment of UTS, to the location is done three to four times in a week. This includes the waste on the way back. This means an optimization of transportation (no empty trucks), At the construction site, waste is separated and made mobile. Then the processed by UTS, and transported towards the recycling center. By reducing the transportation movements and optimizing the empty trucks from the site will allow for less carbon emissions through transportation (Karabulut, 2012).

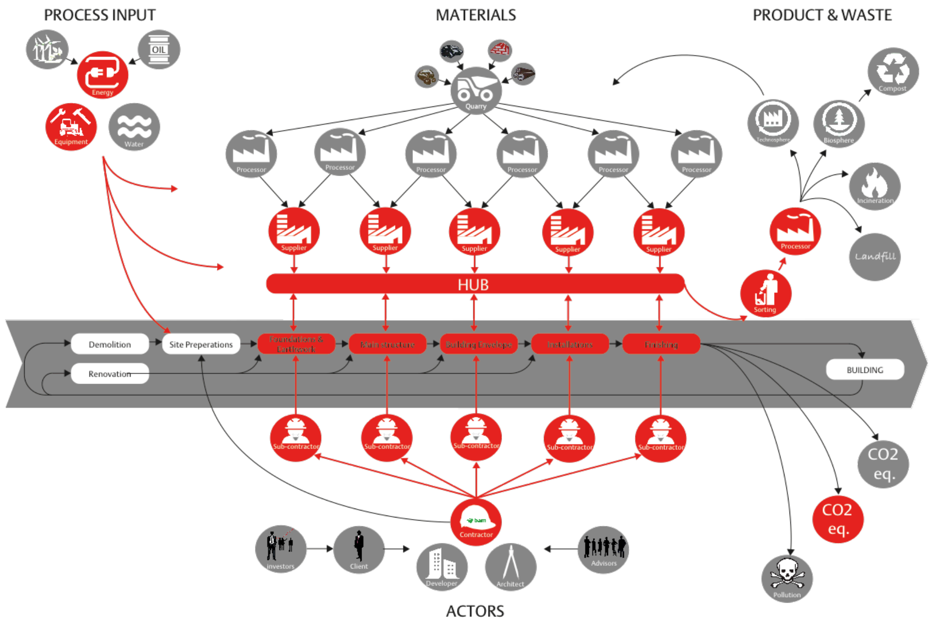



**Figure 5 - 3:** SBL in abstract model

**Dry heating**

By the examination of the total $CO_2$ emissions from energy usage on construction sites, it was found that a key focus lies in the use of building heat, which is also referred to as dry heating. With an average share of 83% of total $CO_2$ emissions by construction projects, it is by far the largest source of carbon emissions on-site (de Nijs, 2010). Dry heating is done in order to remove humid air from plasters and other forms of finishing materials. In order to remove the humid air from the construction, the air must be at a minimum temperature (often 20 degrees Celsius). In order to achieve this temperature, the heating elements are turned on and often run on diesel or gasoline. This aspect is closely related to the main construction process and does not involve the whole chain, in contrast to the materials that need to be dry-heated. A solution could be to use heating from the installations (Burgstede, 2012). This, however, has a lot to do with the design of the process (engineering) and is, therefore, not part of the scope of this research. The design will be seen as an aspect that is already determined and as a constant factor that could, later influence the construction process.

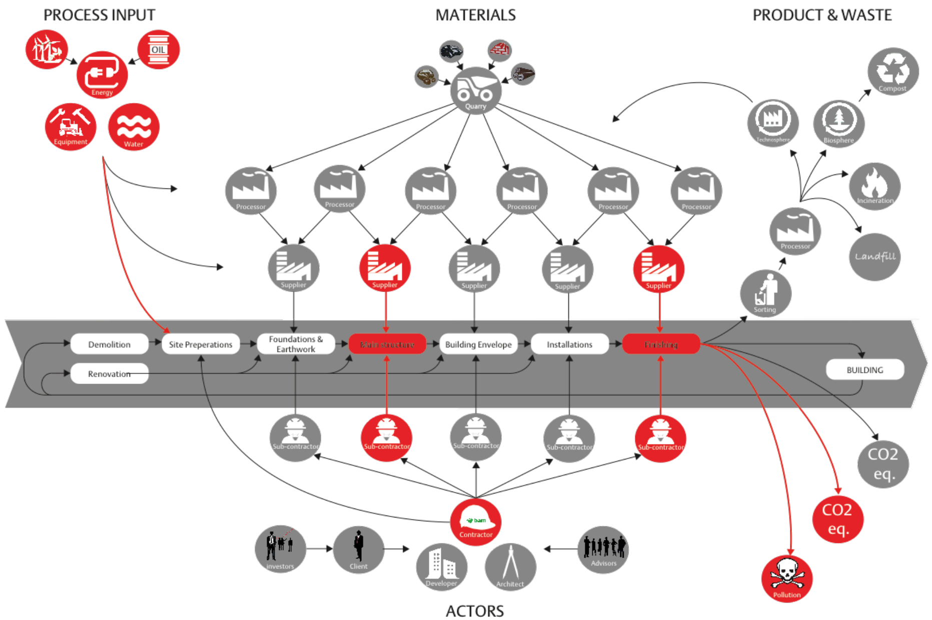



**Figure 5 - 4:** Dry heating in abstract model

**Aluminum facade**

The last element that is of interest is the material aluminum. This metal is made from bauxite, which is mined and refined to create aluminum. It is a metal that can be recycled easily and also without losing its quality. This recycling using 95% less energy than producing primary aluminum. For this material, a lot of research has been done into the whole material life cycle. The material aluminum can be used in different phases of construction. The different construction phases often require a specific form and quality of the material. This material has been examined before. Therefore, information on what happens to the material during its life cycle is known, making it easy to use. This amount of information will allow for more focus on the development of an analysis method and not in retrieving information. 75% of all aluminum used since 1888 is still in use now. Aluminum products are valuable, re-usable resources, which can be efficiently recycled through established collection schemes. Scrap preparation technologies and refining processes are well developed.

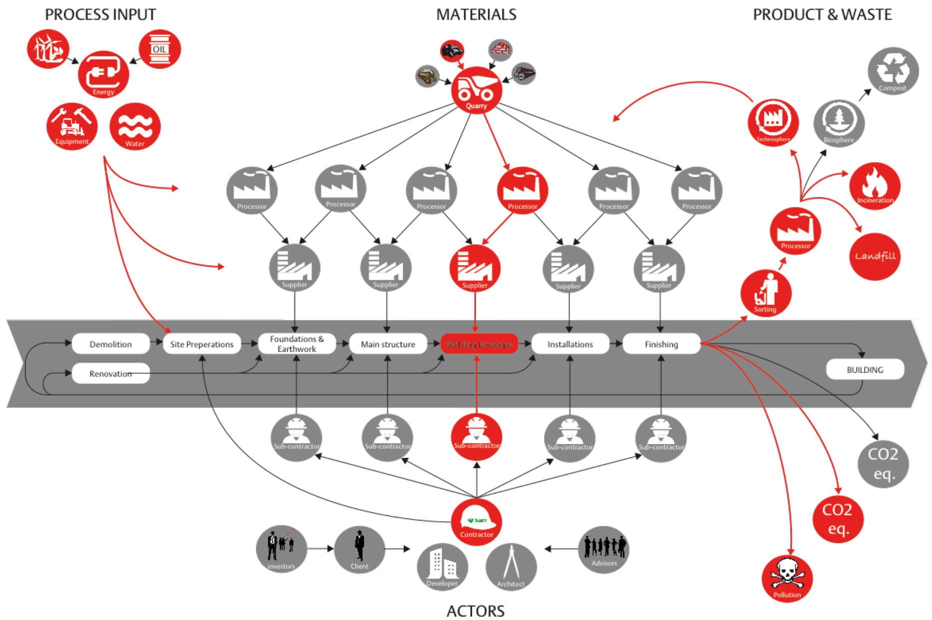



**Figure 5 - 5:** Aluminum facade in abstract model

#### 5.2.2 Step 2: Make a detailed process model

The following steps will form the basis of the analysis tool and answer the following sub-research question: *What are the elements of the analysis tool and how are these elements related?* The steps are the elements of the analysis tool and are described during the explanation of the different steps. The first step has already been examined, therefore the next step will be looked at now.

The second step is using the abstract processes defined in the current construction process. These processes are the basis for a more detailed model with detailed processes and activities. This can be done by using the symbols in the current construction process model, involved in the element of choice. The processes have been determined in the previous step. These processes are still abstract processes and will be placed in the background of the model allowing for more specific processes/activities to be drawn within larger scale activities. The basis for the model is the circular economy, symbolized in the circle of the model.

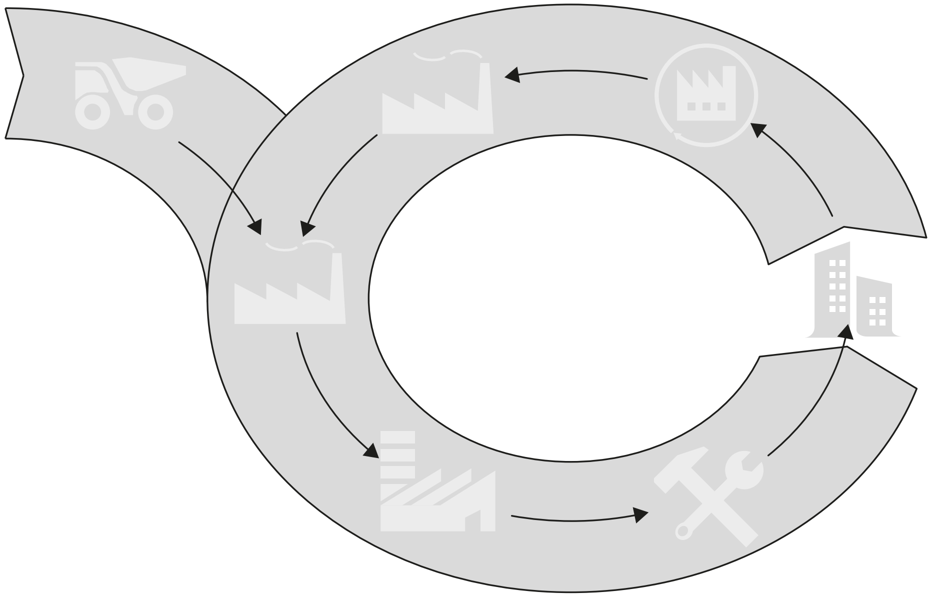


**Figure 5 - 6:** Detailed model based on abstract model

The next step is an investigation of all the different processes involved in the assembly of the element under investigation. Then mapping the activities involved and placing them within the frameworks of the abstract processes. This provides a detailed visualization of the different main processes, together with the sub-processes, for example transportation movements. This mapping of detailed processes varies for every element chosen in the step-by-step plan, this could involve more processes or less, depending on the amount of main processes involved. The following processes are involved in the aluminum case.

**Assembly**

During this part the aluminum facade elements are attached to the main construction, giving the building its envelope/shell. This is done on site, by the main contractor. BAM, in the case of the Monarch used the sub-contractor De Groot & Visser. The facade elements were prefabricated in the production phase. Therefore, the assembly can be done in a fast and swift manner because the elements are produced to fit perfectly on-site. The assembly often involves craftsmen and equipment necessary to assemble the facade. In this case the facade scaffolding and tower crane were used together with the equipment of the craftsmen, for example drilling machines. Not only the assembly but also the management needed for the assembly and the other layers of the organization contribute to the environmental impact of this process. Therefore, all these detailed processes will also be included in the impact assessment on the environment in the following steps to come.

**Figure 5 - 7:** Assembly on site

**Production**

The facade is produced at a production company, ‘De Groot & Visser’. They have made the facade in such a manner that it only needed to be assembled on-site. This means that almost no waste is created on-site. What they do is prefabricate the facade with all the details (corners and other details) in their factory. They do so by ordering extruded aluminum profiles and cutting these done to size and angels. The facade is then assembled with isolation rubbers, coating and thermal additions. This is then transported to the construction site. By working in a lean manner they reduce the wastage created. All useful waste is sent back to the extrusion company for recycling. The machinery and other transformational machines used at their production factory, however, do have an impact on the environment (van der Brugge, 2012).

**Engineering**

Engineering is about designing the facade in a manner that all elements fit together perfectly. The fixings for the facade are design together, while also testing the wind and water tightness of the facade. This engineering is done by a specific organization called Schüco. They develop complete designed systems that can be used for specific buildings. However, in the case of the Monarch they allowed ‘De Groot & Visser’ to make there own extrusion profile, including part of the engineering. Schüco sell the systems with a 100% guaranty on wind and air tightness of the building. De Groot & Visser had to do this themselves for this case, involve more processes. This engineering aspect is of great importance because it determines (through the system and profile) together with the size of the building (m2 facade) the amount of material required, through the thickness and design of profile used. This is mostly related to the design but does influence the process a lot because architects use the systems, as for other facade systems used. Schüco is a partner in the chain that could influence the design without involving client and architect, by designing sustainable profiles with fewer materials (Ypma, 2012).

**Extrusion**

The extrusion process produces aluminum profiles. This is done by using a hot billet of aluminum pushed though an extrusion ingot (also called design of the profile). The result is a several meters long cylinder with a diameter, around 20 and 50 cm and 6 meters long. Depending on the extrusion pressure, the billet can be cut in smaller cylinder pieces before the extrusion process. Just before extrusion, the billet is pre-heated to 500 degrees. At these temperatures the flow stress of the aluminum alloys is very low, this makes it possible to applying pressure by means of a ram. The metal flows through the steel profile designed, located at the other end of the container to produce a profile, the shape of which is defined by the shape of the die (Klopffer, 2008). In this case the extruded profile were bough from a company; Fuchs Germany and Alcoa USA. Schüco is part of Fuchs. Fuchs has a smaller extrusion production plant. This is not enough to foresee Schüco’s demand for profiles and therefore other profiles are bought at other companies. This is hard to trance back but the process with energy usage and $CO_2$ emission can be found in the report of EAA.

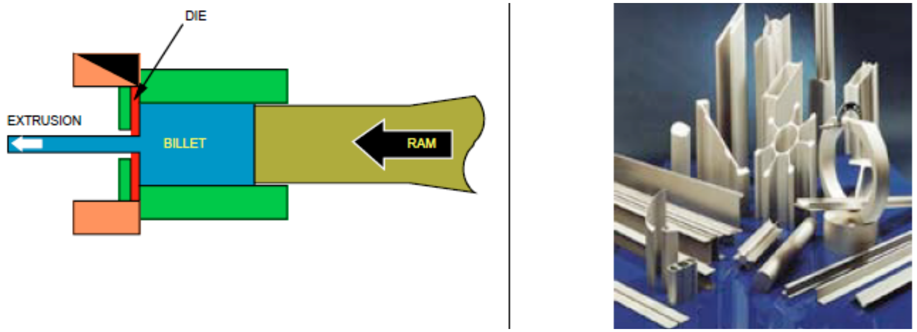



**Figure 5 - 8**: Extrusion process and products (Klopffer, 2008)

**Cast house**

The primary and secondary melted aluminum is transported to the cast house. Here it is alloyed (this depends on the demand from the client) in holding furnaces by the addition of additives, and then casted into ingots. Alloys are related to the quality standards and characteristics of the aluminum. These cast houses do not only provide casts of aluminum for extrusion but a wide variety of products and alloys. Before exiting the cast house, the ends of the rolling slabs and extrusion billets are usually sawed and directly recycled into the holding furnace. The product exiting the cast house is a sawn rolling ingot, a sawn extrusion ingot or an ingot for re-melting. Further treatment of rolling and extrusion ingots, such as homogenization and scalping are covered in the semi-finished products. For the aluminum facade the extrusion will only be investigated (Klopffer, 2008).The amount of primary and secondary aluminum is 60-40, indicating that both streams need to be looked at. The first is the primary aluminum.

**Bauxite mining**

Bauxite, the common raw - primary - material for aluminum production, is composed primarily of one or more aluminum hydroxide compounds, together with silica, iron and titanium oxides. More than 150 million tones of bauxite are mined each year. The major locations of deposits are found in a wide belt around the equator. Bauxite is currently being extracted in Australia, Central and South America, Africa, Asia, Russia, and Europe. Bauxite is mainly extracted by open-cast mining. The environmental data related to bauxite mining have been collected and developed by the International Aluminum Institute (IAI) for the year 2005 (International Aluminium Institute (IAI), 2012). The monarch consisted of 60% new materials, provided by quarrying (Appendix 6).

**Figure 5 - 9**: Mining truck

**Alumina refining**

Alumina used in the smelting process needs to be harvested from bauxite before it can be converted to aluminum by smelting. This is achieved through the use of the Bayer chemical process in alumina refineries. The aluminum oxide contained in bauxite is selectively leached from the other substances in an alkaline solution within a digester. Caustic soda and lime are the main reactants in this leaching process which takes place in autoclaves at temperature between 100 and 350°C. The solution is then filtered to remove all insoluble particles, which constitute the so-called red mud (a rest product). On cooling, the aluminum hydroxide is then precipitated from the soda solution, washed and dried while the soda solution is recycled. The aluminum hydroxide is then calcined, usually in fluidised-bed furnaces, at about 1100°C. The end product, aluminum oxide ($Al_2O_3$), is a fine grained white powder (European Aluminium Association, 2008).

**Manufacturing: Electrolysis (Primary melting)**

Primary aluminum is produced in electrolysis plants (frequently called "smelters"), where the pure alumina is reduced into aluminum metal by the Hall-Héroult process. This reduces the alumina into liquid aluminum in a bath of 950 degrees Celsius mixed with fluorinated while under a high intensity electrical current. This process takes place in electrolytic cells, where the carbon block at the bottom acts as the negative electrode. Carbon anodes (positive electrodes) are held at the top of the pot (place were the process takes place) and are consumed during the process when they react with the oxygen coming from the alumina. All pot lines built in Europe since the early 1970s use the pre-bake anode (European Aluminium Association, 2008).

**Demolition**

**Figure 5 - 10**: Demolition process (Knijnenburg, 2010)

The demolition process is, as mentioned in chapter three, is the dismantling of the materials on site. This process involves various materials that are dismantled during the demolition. These materials are then sorted into valuable and non-valuable materials that are then sold. In an extreme case it could be said that; demolition companies are the competitor of mining companies, because there processes both involve the selling of raw material. For demolition companies this would be referred to as raw - secondary - materials. Aluminum is a metal - a non-ferro metal - and therefore worth a certain amount of money depending on the prices at a certain time. This material is already recycled and not landfilled or incinerated due to its perceived value. The facade of the monarch consisted of 40% recycled aluminum (appendix 6) meaning that 40% of the materials came from this process.

**Metal collector**

Old aluminum scrap comes into the recycling industry via a very diversified and efficient network of metal merchants and waste management companies. These companies have the technology to recover aluminum from vehicles, household goods, etc. Waste sorting companies and metal collector often separate the rubbers in the extruded profile and also the silicone. In this manner it is worth more for a larger metal company. This process is often done through machines or even by hand. The collecting and sorting again is part of its main process in order to make a profit. In the Netherlands the firm 'Jansen' often takes care of different streams of metals including aluminum. The larger collection is then sold to a large metal distributer.

**Large metal dealer**

Most scrap that arises during semi-finishing processes may be coated with paints, ink or plastics. This scrap can be de-coated by passing scrap through an oven or a mesh conveyer, whilst hot gases are circulated through the mesh to volatilize or burn off the coating. De-coating is usually the only significant scrap preparation step, which can be applied to the scrap input need for the re-melters. This is often done using heavy equipment such as shredders, together with magnetic separators, to remove iron, sink-and-float installations, or by the use of eddy current installations to separate aluminum from other materials (European Aluminium Association, 2008).

**Re-melters**

Most new aluminum scrap comes into the recycling industry directly from the fabricators. It is therefore of known quality and alloy and is often uncoated. It can then be melted with little preparation, in the re-melters, in reverbatory furnaces in order to produce new wrought aluminum alloys. After collection, sorting and preparation, these old scrap are usually purchased by the so-called refiners and are melted into casting alloys, also called foundry alloys. Refiners recycle not only scrap from end-of-life aluminum products but also, scrap from foundries, turnings, skimming's (dross) and aluminum metallics. Several melting processes are used. The choice of process depends upon a number of variables. These include the composition of the scrap, the processes available within a given plant, and economic and scheduling priorities (European Aluminium Association, 2008).

**Transportation**

The transportation will be assessed by looking at both the recycling and primary aluminum industry transportation distances. The detailed model (figure 5-11) shows transportation taking place from semi-finished materials, from various processes. For primary aluminum this is on average for Europe 8000 km by sea. The report also considers 1000 km as the transport distance for bauxite used in the alumina plants (European Aluminium Association, 2008). For the recycling industry the secondary raw materials also travel around 5000 kilometers before it reaches the cast houses. The market is dominated by the best price for the scrap and the distances do not matter. The transportation from extrusion companies to production companies in this case was no more the 1000 km in total and from the production factory to the construction site 70km.

BREEAM in the case of the Monarch only monitored the 70km distance between the De Groot & Visser factory to the construction site. Interesting to see is that this distance is very small compared to the distances travelled prior to this transportation distance.

**Detailed model**

This all has brought can be put forward in the following detailed diagram. This diagram shows the process in which aluminum travels during its life cycle. The effects on the environment of the whole process - including all the detailed processes - can be quantified in the next step. This will provide the basis for the analysis into the impact on the environment of the total process and how this can be reduced.

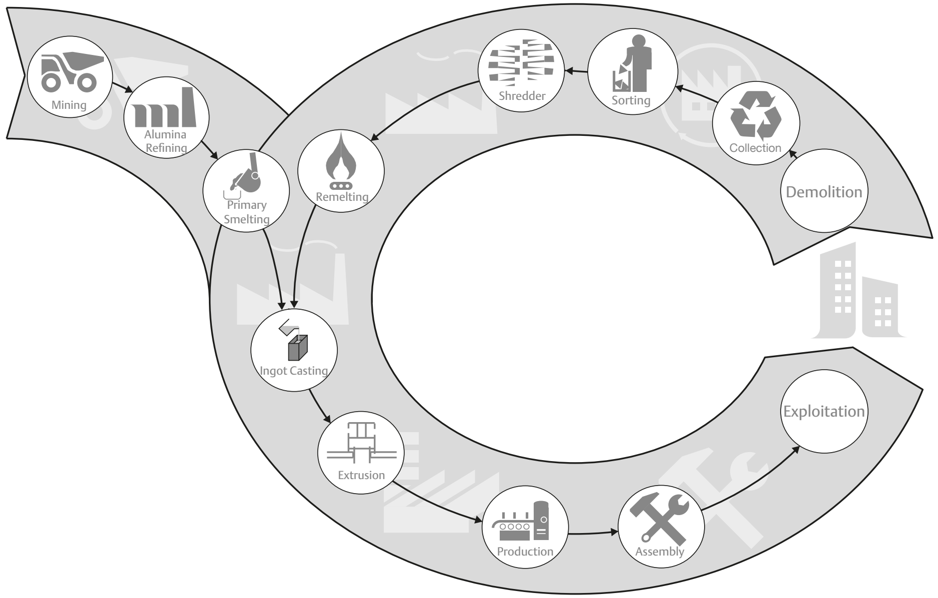



**Figure 5 - 11**: Total detailed model

#### 5.2.3 *Step 3: Define the environmental (PLANET) impact*

The next step in the process will be to make insightful in which manner all the steps in the process of aluminum have an effect on the environment. This has the following categories:

- Materials lost, this will include all materials lost including water
- Energy used will involve the kilo Watt hours (kWh) of energy used during the process
- $CO_2$ emissions (kg/$CO_2$)
- Pollution classification by NIBE for the phases (with a ++,+,0,-,--,n.a.).

In order to find the impact numbers for the four aspects above, the supply chain must be consulted. The $CO_2$ reports and other sustainability reports, like CSR report, form the first basis for the data needed for the analysis. For this case the various industries involved have made there production processes insightful through umbrella organization, like the EAA report on the life cycle inventory of aluminum. These organization can help in providing the necessary data. For additional information on how the figures have been derived for aluminum the report of the (European Aluminium Association, 1999). This report was the easy way to retrieve the data needed for the step-by-step plan for aluminum but normally the supply chain should provide transparent numbers on the different impact criteria in order to optimize the results together. The transparency in the industry currently is not optimal and therefore these report help in the initial investigation.

The pollution aspect has been done by using the NIBE database from Michel Haas and is rated in the form of ++,+,0,-,--. This is the review by the NIBE in the different phases based on five categories (physical agents, chemical agents, biological agents, ergonomics, safety). The other quantified data need for the other three categories can be found in the reports and the model in appendix seven.

It is important to understand that one kilogram of aluminum used on site there are different factors of materials needed further upwards in the chain. One kilo of bauxite is not directly one kilo of primary aluminum. Therefore the first aspect we need to know is that the Monarch uses 109,627kg of aluminum. The detailed analysis and data retrieved and translated towards the case have been done in an excel sheet (Appendix 6).

| | Factors | Materials needed |
|---|---|---|
| Materials (Bauxite) | 4.26 | 467,011 |
| Alumina (Alumina) | 1.98 | 217,061 |
| Material lost (Red Mud) | 2.28 | 249,950 |
| Water lost | 1.20 | 131,552 |
| Primary melting | 1.12 | 122,782 |
| Secondary melting | 1.12 | 122,782 |
| Ingots | 1.08 | 118,397 |
| Extrusion | 1.06 | 116,205 |
| Finished (G&V) | 1.01 | 110,175 |
| Used on site | 1.00 | 109,627 |
| Demolished goods | 1.00 | 109,627 |
| First sorting shift | 0.98 | 107,434 |
| Second sorting shift | 0.95 | 104,146 |

These factors and amounts of materials needed above, a the basis for the calculations below. The report of the EAA includes case examples that can be used to derive the figures needed for this analysis. This is done by finding the amount of energy, $CO_2$ and material losses for one kg of the material in a process. The amount of materials in the diagram above will provide insights on the total impact on the environment.

All processes designed in figure 5-11 will have their separate table with their individual impacts on the environment. In this manner the total impact on the environment can be examined and compared to the individual processes.

**Assembly**

| | |
|---|---|
| Materials lost (kg) | 548 kg of aluminum (recyclable) |
| Energy used (kWh) | 21,318 kWh |
| Carbon emissions ($CO_2$ eq)(kg) | 11,183 kg |
| Pollution | - (mainly ergonomics) |

**Supplier (Production)**

| | |
|---|---|
| Materials lost (kg) | 6,029 kg of aluminum (recyclable) |
| Energy used (kWh) | 24,485 kWh |
| Carbon emissions ($CO_2$ eq)(kg) | 12,845 kg |
| Pollution | - (chemical and ergonomic agents) |

**Extrusion**

| | |
|---|---|
| Materials lost (kg) | 2,191 kg of aluminum (recyclable) |
| Energy used (kWh) | 116,827 kWh |
| Carbon emissions ($CO_2$ eq)(kg) | 140,494 kg |

**Ingot Casting**

| | |
|---|---|
| Materials lost (kg) | 4,385 kg of aluminum (recycled) |
| Energy used (kWh) | 46,836 kWh |
| Carbon emissions ($CO_2$ eq)(kg) | 59,279 kg |

**Primary smelting (electrolysis)**

| | |
|---|---|
| Materials lost (kg) | 94,279 kg rest products and 8,226m$^3$ of water |
| Energy used (kWh) | 512,827 kWh |
| Carbon emissions ($CO_2$ eq)(kg) | 269,029 kg |

**Secondary smelting (re-melting)**

| | |
|---|---|
| Materials lost (kg) | 1,096 kg rest products and 7,933m$^3$ of water |
| Energy used (kWh) | 131,234 kWh |
| Carbon emissions ($CO_2$ eq)(kg) | 171,859 kg |

**Alumina Refining**

| | |
|---|---|
| Materials lost (kg) | 249,950 kg of red-mud |
| Energy used (kWh) | 661,487 kWh |
| Materials lost (kg) | 249,950 kg of red-mud |
| Carbon emissions ($CO_2$ eq)(kg) | 905,131 kg |

**Total Manufacturing**

| | |
|---|---|
| Materials lost (kg) | 6,578 kg of aluminum 94,279 rest products 8,226 m$^3$ water and 249,950kg red-mud |
| Energy used (kWh) | 1,337,977 kWh |
| Carbon emissions ($CO_2$ eq)(kg) | 1,373,933 kg |
| Pollution | -- |

**Mining**

| | |
|---|---|
| Materials lost (kg) | 280 m$^3$ of water |
| Energy used (kWh) | 8,873 kWh |
| Carbon emissions ($CO_2$ eq)(kg) | 6,615 kg |
| Pollution | - |

**Demolition**

| | |
|---|---|
| Materials lost (kg) | 2,193 kg other materials |
| Energy used (kWh) | 33,500 kWh |
| Carbon emissions ($CO_2$ eq)(kg) | 19,749 kg |
| Pollution | 0 |

**Sorting**

| | |
|---|---|
| Materials lost (kg) | 3,829 kg other materials |
| Energy used (kWh) | 11,938 kWh |
| Carbon emissions ($CO_2$ eq)(kg) | 7,648 kg |
| Pollution | 0 |

**Waste processor**

| | |
|---|---|
| **Materials lost (kg)** | **1,096 kg other materials** |
| **Energy used (kWh)** | **20,252 kWh** |
| **Carbon emissions ($CO_2$ eq)(kg)** | **26,743 kg** |
| **Pollution** | **0** |

**Transportation**

| | Carbon emissions ($CO_2$ eq)(kg) | Transportation (km) |
|---|---|---|
| **Recycling** | **22,900 kg** | **16,080** |
| **New materials** | **62,220 kg** | **18,054** |

The transportation factor is included but only has an effect on the $CO_2$ factor. This is because no materials are lost during transportation. The energy would only be the case if this were to be electrical trucks, which is not yet the case in the transport sector. The manner in which the carbon emission factor for $CO_2$ is calculated is by: multiplying the tonnes of material by the kilometers multiplied by the kg $CO_2$ tonne-km factor (tones*km*kg $CO_2$ tone-km) (Trust, 2011). This is divided by one million in order to get the kg equivalent of $CO_2$. This will be done by looking at the transportation during the primary and secondary material life cycle.

It is interesting to see that when examining the transportation distances the secondary materials do not involve less transportation than the primary materials. The difference in impact on the environment is that the amount of materials in the primary cycle is more because of the material factors. However, the recycling industry could still reduce the kilometers in order to reduce their impact.

**Total**

| | Energy | % | $CO_2$ | % | Material losses | % |
|---|---|---|---|---|---|---|
| **Mining** | **5,324** | **0.5%** | **3,969** | **0.4%** | **0** | **0.0%** |
| **Manufacturing** | **920,745** | **92.3%** | **973,024** | **90.9%** | **213,375** | **95.9%** |
| Refining | 396,892 | 39.8% | 543,089 | 50.8% | 149,790 | 67.3% |
| Primary melting | 307,696 | 30.8% | 161,418 | 15.1% | 56,568 | 25.4% |
| Secondary melting | 52,494 | 5.3% | 68,744 | 6.4% | 439 | 0.2% |
| Ingot Casting | 46,836 | 4.7% | 59,279 | 5.5% | 4,385 | 2.0% |
| Extrusion | 116,827 | 11.7% | 140,494 | 13.1% | 2,193 | 1.0% |
| **Production** | **24,485** | **2.5%** | **12,845** | **1.2%** | **6,029** | **2,7%** |
| **Assembly** | **21,318** | **2.1%** | **11,183** | **1.0%** | **548** | **0.2%** |
| **Demolition** | **13,400** | **1.3%** | **7,900** | **0.7%** | **877** | **0.4%** |
| **Sorting** | **4,775** | **0.5%** | **3,059** | **0.3%** | **1,316** | **0.6%** |
| **Waste processing** | **8,101** | **0.8%** | **10,697** | **1,0%** | **439** | **0.2%** |
| **Transportation** | **0** | **0%** | **46,494** | **4,3%** | **0%** | **0%** |

The Sankey diagram (figure 5-12) is a visualization of the 40% recycled materials and 60% new materials. This is the current situation that is in need of improvement. Thereby we have now analyzed the current situation in the construction industry, related to the one element under investigation. The next steps will involve implementing sustainable construction.

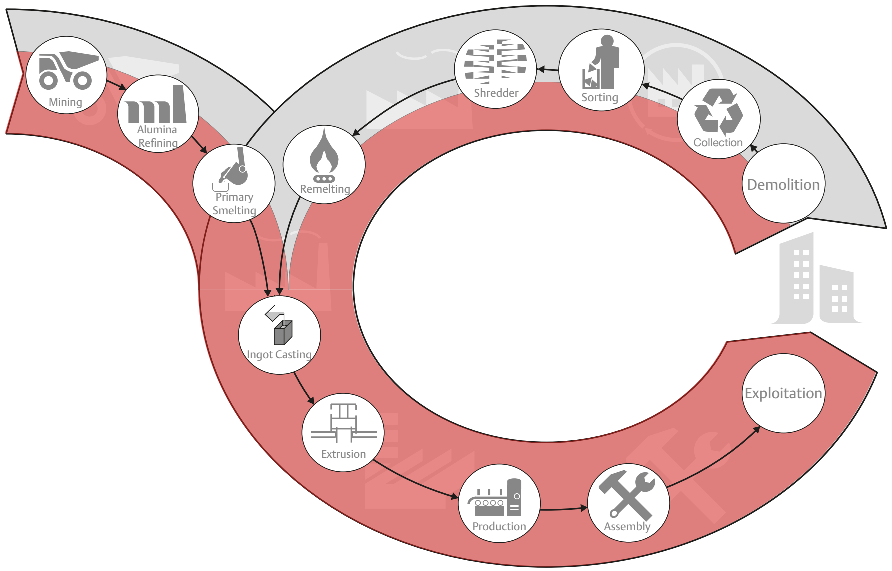



**Figure 5 - 12**: Reduction due to the current recycling percentage

### *5.2.4 Step 4: Design three scenarios sustainable construction*

The model, designed in step three, incorporates processes that have an impact on the environment (planet). The sustainable construction process designed in chapter three, involves the three steps of the ladder of Lansink: Recycle, Reuse, And Recycle. In the coming section, the impact of the steps made in the sustainable construction process are discussed separately. The different steps will be designed in the new process model including the reduced impact on the environment. The reduced impact has been calculated by using the spreadsheet model developed in appendix 7. The designed scenarios involve different processes that need to be changed. The expert meeting is organized to test next step. During this meeting the experts reflected upon the different scenarios. The results from this reflection are discussed in this step.

**Recycle**

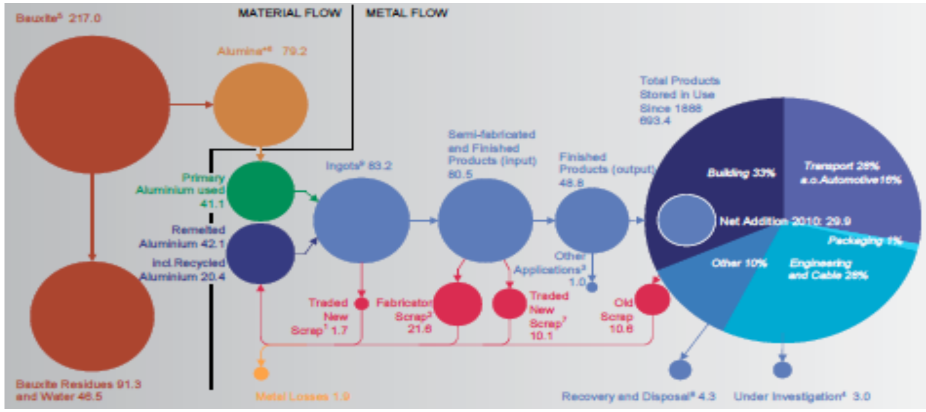



**Figure 5 - 13**: Aluminum mass flow model (Institute, 2011)

The scenario is based on the idea that secondary raw materials replace primary raw materials. The scenario diagram on the right shows that when increasing the recycling percentage, all environmental categories show a reduction, except pollution. We have increased the recycling percentage up to 50% in total. This is a realistic figure because the world aluminum industry (figure 5-12) uses 50% recycled aluminum.

The processes ingot casting, extrusion, production and assembly will not have a reduced impact on the environment in this case. The same amounts of materials are asked in this scenario for these processes. The focus is on the primary and secondary streams.

The total impact on the environment overview shows us that the recycling process (with all sub-processes involved) has less impact on the environment than the primary cycle. Increasing the recycling amounts will also increase the impact on the environment from this stream in the model. On the other hand, the amount of primary materials needed and processes involved, will decrease. This reduction in the primary stream is larger than the increase in the secondary stream. This tells us that in total there is a reduced impact on the environment.

Technically it is possible to make aluminum consist of 94% recycled aluminum. This percentage means that we still need at least 6% new aluminum for all aluminum used in the sustainable construction process. The reason that we are only recycling 40-50% is because the demand for aluminum in the world is high. This implies that the sustainable construction model would still currently need 6% primary aluminum.

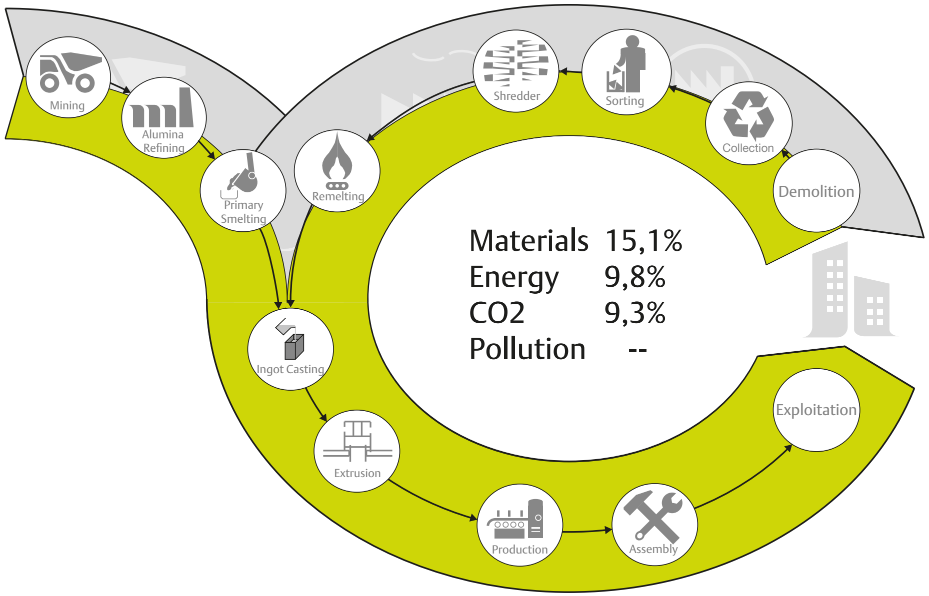



**Figure 5 - 14**: 10% extra recycling

Interesting is that if for one project we use more recycled aluminum, this would reduce the impact on the environment. However, the other projects (all over the world) need to use more new aluminum because the amount of secondary aluminum is less due to the one project. The recycled amount is dependent on the market supply and the recycled reserves; these can only be supplemented by aluminum scrap. Therefore, by increasing the recycling percentage in a project, it would not have a reduced impact on world level, but only on project level.

The focus in this scenario will be to provide more aluminum scrap, which can be done in several manners. Firstly, you can ensure that aluminum is sorted in a better manner, this would mean more sorting of materials so two different materials do not get tangled up. Secondly, you can demolish more buildings. This could mean recycling the empty buildings. Thereby providing the market with more secondary raw materials. The reason that we have vacant buildings is because we have built too much. Thirdly, the amount of recycled aluminum in other industries is shared equally with the construction industry.

**Reuse**

The reuse has, as discussed in chapter four, involved (has involved or involves) various levels. Recycling is the lowest level of reuse (component level). In this case we will look at the impact of reusing at element level and therefore reusing 50% of aluminum facade elements.

The reuse of materials has put forward a new stream that skips five steps used during the recycling process: waste processing, re-melting, ingot-casting, extrusion, production. This would also reduce the amount of new materials needed, thereby reducing the environmental impact of the primary aluminum used as well. This reduces the impact on the environment, however it is compensated by a new activity that will need to be introduced. This new activity is a different manner of demolition; this could be seen as deconstruction involving more time and a different manner of working. The extra treatment of materials - processing them - in order to make the aluminum useful (quality needed) for the new construction process. This process involves energy and probably carbon emissions. These impacts on the environment have been taken into account. The new process is estimated to involve an impact that is equal to the production, demolition, sorting and assembly times a factor three. This still however shows a reduction of 50% of the materials lost and also 40% energy reduction and 46% $CO_2$ reduction. A perceived problem is however matching the supply to the demand, because the disassembled goods are often not immediately needed.

**Figure 5 - 15**: Aluminum extruded profiles (Institute,

However, reuse is applicable to other materials like prefabricated concrete slab floors as well. The research by Nanda Naber with the concrete slab floors has already provided the hope for feasibility. The basis of the models is however that common sense is used when designing the scenario. This scenario involves reuse at a higher level. This level must be determined prior to the design of this scenario, together with a realistic amount of materials reuse. The design can be as far reaching as possible.

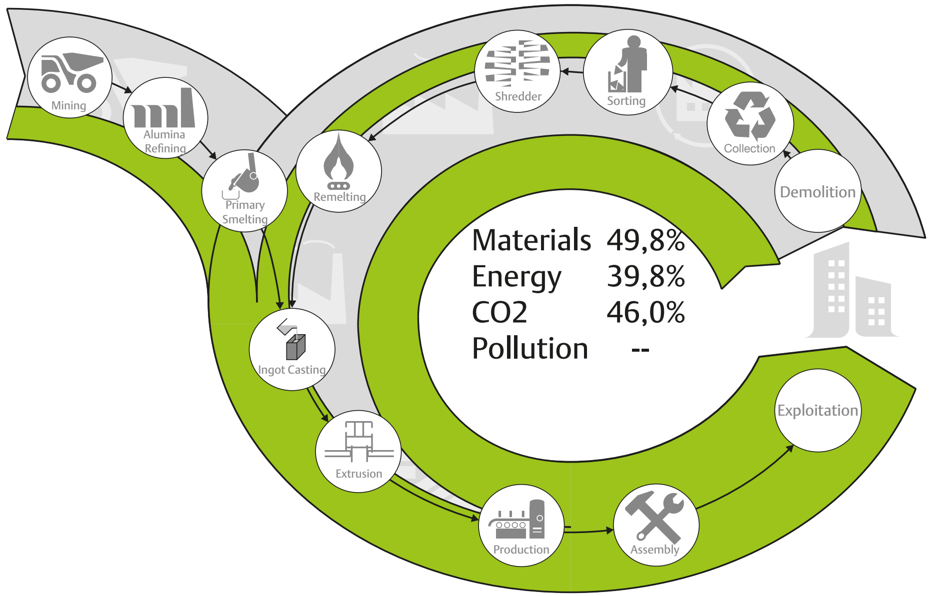



**Figure 5 - 15** 50% reused facade elements

## Reduce

The reduction step is the last step in the ladder of Lansink but it impacts the entire cycle in the most effective manner. It involves the reduction of materials used during the entire process. Reduction is different for all categories and can take place on the input side (usage of materials) and output side of a process.

The sustainable construction process shows energy and materials on the input side, while carbon emissions, pollution, energy and materials are on the output side. Material usage and energy, therefore, are both related to the input reduction and output reduction.

First of all the input aspects are discussed and related to the reduction scenario. This involves energy and materials. The energy needed for all the processes can be dealt with in a manner that less input is needed for a process to take place. This focuses on all the processes in the chain. All processes in the chain need to reduce in a lean manner (in figure 3-4), and thereby reduce the impact on the environment. This means designing the processes in a manner that less energy is needed. The materials are part of the product. You can only reduce the amount of material till you do not have a building left. This example indicates the limitations but also the relation to the design - the building - and thus beyond the of scope of this research, nevertheless an important aspect in the process. This shows the interaction between design and the construction process.

Secondly, the output aspects are discussed and related to the reduction scenario. Reducing the amount of energy loss during a process and reducing carbon emissions from a process, lower the pollution factor and also the materials wasted. In order to deal with all the aspects at once, the definition of waste (chapter two) is used: Waste is anything that is discarded, but could still be used to deliver value in the same or another process. All the aspect that influence the impact on the environment produces waste. Energy that is lost is waste. Materials lost are waste. This means that we need a method to reduce the waste in the process. The lean methodology, focused on dealing with wastage (any form of waste) within a process.

In this scenario the construction industry can reduce the need for materials by prefabrication, something that has already been done. It is the most effective way of reducing the impact on the environment. First of all, the previous scenarios did not involve all the sub-processes, this scenario does. Secondly, the relation to the reduced impact is almost linear.

It is striking that design initially deals with the building and not the process. This brings us back to the history as well. In the time before the world wars, we had master builders that had a lot of knowledge about the construction of structures, which included not only the product but also the process. This integrated in one person, meant that the master builder was able to impact both the process and the product. However, history changed and shows us that the construction industry has been fragmented with all the positive aspects than come from this. Therefore, supply chain integration and the communication between actors will need to be very good in order to achieve the reduction in combination with the product. The design must understand the influence of its decisions on the construction process and vise versa. This is also a bit beyond the scope of this process. Therefore the combination must be made with the reuse and recycle. The power of these steps together will help achieve sustainable construction.

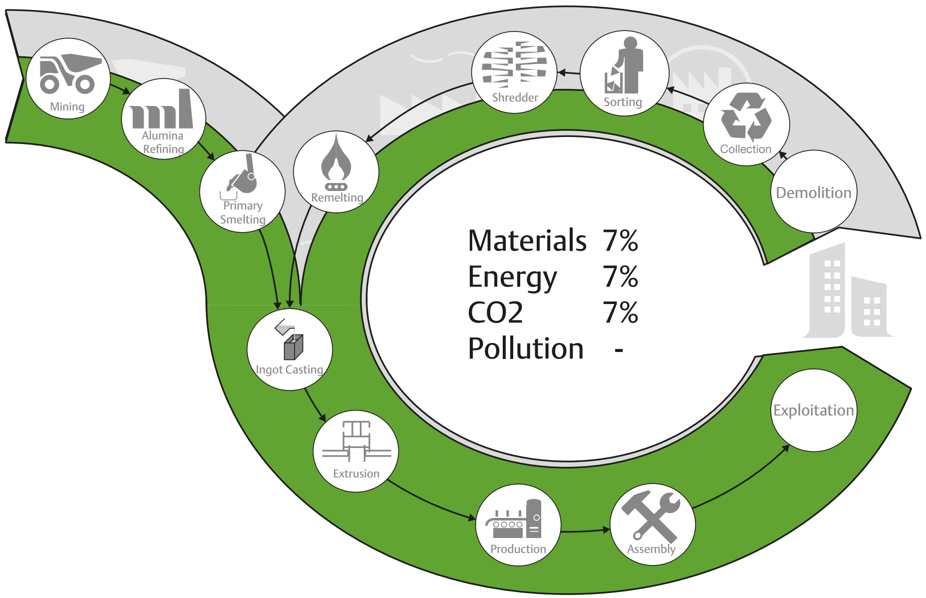



**Figure 5 - 16**: 7% reduction

#### *5.2.5 Step 5: Supply chain integration*

These scenarios form the bases for the fifth step in the plan. The scenarios with be discussed by all the actors in the supply chain. In this case in the form of an expert meeting, with all the actors of the aluminum supply chain. For different elements under investigation like materials, processes and methods the group assembled, is different, therefore this step is the most complex due to its unknown outcome.

Sustainable construction is a combination of all three scenarios together. The integration of the supply chains is to assess the technical and economical feasibility of these scenarios. This step will form the core in achieving sustainable construction. The expert meeting, however, had two goals, the second goal being to see how this meeting should be designed and whether it can direct the stakeholders in the chain towards durable solutions using the scenarios and construction models.

This method (expert meeting) has been assessed for the aluminum case and the results of this meeting will provide insights on the validation of this step and the validation of the method used previously. The method did however involve a session of one and a half hours, therefore only one scenario is chosen for the feasibility. This is due to the time limitations of this research. In practice this step should however involve more time needed to solve all three scenarios.

**Supply chain meeting setup**

The initiator of this meeting is responsible for achieving the goal of the meeting, which is discussing the technical and financial feasibility of scenarios. The person that needs to initiate this meeting, according to the experts, is the contractor. First, the group argued the government, but after discussion they said the contractor should be the initiator. Sustainability is currently linked to public imaging. Public imaging is of importance for all organizations and that thus they though initiation should come from an actor within the supply chain that puts forward the whole chain. The contractor, as mentioned in the problem analysis, is also the person that deals with the most actors in the chain directly (also viewable in the sustainable construction process model). In this case the meeting was set up by myself in order to investigate the use-fullness of the step.

The expert meeting was set up by using four questions and statements to help achieve the goal of the meeting. The experts in the aluminum supply chain involve the recycling specialists, the production and assembly specialists and manufacturers. In this case the manufacturer did not have the time to join the expert meeting - something that does impact the result - however the outcome for the aluminum was not the main objective. The main objective was to test the manner of working in this step. The table below shows the experts from the aluminum supply chain.

The full report results of this meeting can be found in appendix 8.

| EXPERT | FIRM | PERSPECTIVE |
|---|---|---|
| Gooike van Sloten | Struijk Group | Demolition |
| Frank van Delft | Jansen Recycling | Recycling & Collection |
| Tim Wolbrink | HKS Metals | Recycling & Collection |
| Kees Sterrenburg | De Groot & Visser | Supplier & Sub-contractor |
| Danny Burgstede | BAM Utiliteitsbouw | Contractor (Site manager) |
| John Loendersloot | BAM Advise & Engineering | Technical maintenance |
| Jitske van Helden | BAM regio Utrecht | Environmental specialist |
| Jan Prins | BAM KAM | Quality, Health&Safety, Environment |

**Reflection different scenarios**

What do you (as part of the supply chain) need to do (in each of the scenarios) to achieve the following result (in these scenarios)? Asking them this question assessed the reflection of the interviews on the different scenarios:

The working method used here, was based on the fact that everyone could address the question individually. The three scenarios were put on the wall in poster format. By putting their thoughts on sticky notes and posters, people could suggest initiatives for the feasibility of each of the scenarios. This way ensures that everyone reflects on his/her own process. Through communication with other actors, suggestions for other initiatives were also put forward.

The results for this question are discussed in two steps. First of all the thoughts that apply to all scenarios are examined. Secondly the findings per scenarios are discussed.

Firstly the remarks that are applicable for all scenarios. These involve quotes like; “Awareness of all euros (cash flows) in the chain”, according to Danny Burgstede. The whole group mentioned, “more transparency in the supply chain regarding: $CO_2$ emissions, energy usage, material losses and financial data”. Both remarks have already been mentioned in step three and step four. This transparency will prove to have an impact on the outcome of the different steps in the entire analysis. Experts often brought to light, initiatives used within their organization (where they work). Danny Burgstede talks about "Lean" and "Computational engineering", John Loendersloot mentioned "LCC". All these methods are focus areas within the BAM Group (where these experts work). This could also apply to other initiatives from other actors. More interesting is that these initiatives are combined with new ideas. For example, John Loendersloot says "new methods of demolition should be included in the LCC calculations". Part of his working field and a contribution to the chain. "Lean commitment in pre-construction phases connected with the assembly process" according to Danny Burgstede. This shows that expert do not only put forward tools in their own process, but change the process and put forward additions in an attempt to innovate. There were various thoughts related to the design and some do not have to be influence by the architect like the “assembling in a manner that is dismountable”, according to the group. Gooike van Sloten adds, “Currently dismantlers have different requirements than is expected from contractors”. These quotes indicate that all experts believe that the current system can still improve in terms of quality and better alignment of the processes to one another; however, these thoughts need to become more concrete.

Secondly, the individual scenarios put forward interesting findings. These will be discussed in-depth separately.

Scenario one involve the extra 10% recycling. Tim Wolbrink and Frank van Delft together mentioned “that better separation of waste materials can contribute to extra recycling”. Better waste seperation would lead to a better recycling cycle and more recycled materials. Jan Prins mentions: “A better mentality, behavior and discipline during sorting on-site in all processes of the supply chain will contribute to more recycled materials”. The demolition company found an element that would improve his volumes of work mentioning “more demolition”. This indicates that this scenario will involve forms of urban mining thereby becoming competition for the mineral miners.

Scenario two involves the reuse at element level by 50%. Tim Wolbrink and Gooike van Sloten talk about current processes that need to improve and new processes introduced: “Supply and demand should be more closely aligned, the waste product or scrapping product should be cleaned and a market should be created for these new materials”. The recycling specialist indicate: “A new market will need to be created with supply and demand for the aluminum elements”. Both recycling specialist indicate that this role could be for them, because they already manage the market at component level. This scenario with however be discussed in detail in the technical and financial feasibility.

Scenario three involve the reduction of wastage within the process. Kees Sterrenburg makes the observation that “an optimization of the extrusion profile used will reduce the amount of materials needed”. This indicates reduction on the usage of material, but this scenario also involve reduction in the processes on the output side. Danny Burgstede mentions, “concurrent engineering application: this reduces failure costs, wastage”. This is closely related to the lean management and expert agree on this. However, this scenario was not clear to all experts.

All scenarios can be looked at in depth, however in the time span of the meeting, one scenario was chosen based on the initial feasibility assessment of the scenarios, in this manner the aluminum industry focuses on one scenario. Thereby testing the supply chain and its ability to solve the difficult scenario. The group in this case was asked the following: Which scenario would be the best option for aluminum?

The second scenario was chosen (reuse), the reasoning for this was mainly that the reduce scenario involved too many aspects that are related to the design, “which was excluded in this process according to Mr. Baartmans”, the group mentioned. This reduction aspect is also the most difficult to achieve due to the fact that it is the highest step in the ladder of Lansink. The recycling scenario was not chosen due to the fact this is already "optimizing itself", according to the group. This is an interesting thought, because they mentioned earlier that there is room for improvement. This is motivated by quotes: "better quality in separating materials", mentioned by Frank van Delft and "A better mentality and behavior could also contribute towards more recycled aluminum", followed by Jan Prins. Fact is, that this would not lead to the desirable 10% extra amount of recycled materials and that this is the reason this scenario has not been chosen. Reuse was chosen due to the high-reduced impact on the environment and "aluminum is more interesting to reuse at a higher level", the group argued.

Additional observations in the meeting put forward aspects of the meeting that can prove to be of importance for the outcome. Changing the mindset of the experts in the meeting is crucial for the results. This is proven by the manner the meeting was set up. The presentation on the sustainable construction process and the way of thinking put forward was the basis of changing the way of thinking (cyclic and not linear). Before the first question was asked the circle of blame was explained. The only rule in the meeting was not to point fingers towards others but be self-critical. Interesting was the first thing that people mentioned after the first question was "the need to change the mindset of the architect", Gooike van Sloten. Taking this as an example of wrong behavior and explaining this to the group is the role of the meeting facilitator. This helped to change the mindset of the experts and helped them to innovate instantly, this also indicates that one of the obstacles mentioned in chapter four had been surpassed.

**Technical feasibility**

This part involves the question: What needs to happen to make this technically feasible and who should take the lead? The method used here, was the division of the group into 2 groups of 4. The small groups will devise solutions from different perspectives. The findings of the groups are presented to one another. Put together this gives the list of conditions where the scenario should meet. The other group is given the space to respond and supplement.

The result of this round was a list of issues that this scenario would have to meet each other in order to make it technically feasible:

- Standardization of aluminum elements. It must be designed by new norms and concepts, take an example from housing concepts
- There should be an incentive for the government
- The behavior of the materials (material technical characteristics) must be developed so that quality can be improved
- Laws and regulations persist for periods of 5-10 years
- Detachable concepts make less adhesives and sealants and more dry joints
- Accessibility of the materials in exploitation phase -> for disassembly
- Only use reusable materials
- Recognition of materials (what is what and what is in it) after a longer period, possibly with the use of BIM (Building Information Modeling) models
- Database for supply and demand, new trader, role seems reserved for Recyclers -> market
- Easy to assemble elements
- Translation towards the investor through leasing concepts. (Producers want like this so they are guaranteed of raw materials in the future)
- New conservation methods of aluminum, so they are easier to separate in subsequent processes of component reuse. (Currently only coating and anodizing)

These results put forward are far more specific than in the first rounds of the expert meeting and involve issues that can be translated to points of action. This is the result that was sought in this part. This result also shows us that the whole chain believes that the technical feasibility is solvable within the own supply chain. The list above only includes two points (out of eleven in total) that are about external influences of the government, points that are not solvable within the chain. This means the supply chain is innovative enough to solve the list above internally and together as part of the supply chain integration.

The feasibility list mentioned also involves aspects that are applicable for other materials and processes. The 'detachable joints' for instance are also applicable for concrete prefab elements, or synthetic materials. This means that the results of this session are applicable to a broader perspective involving other processes and materials. This tells use two things: firstly it tells us that during this session the actors looked at influence able factors within the supply chain, showing that the mindset was cyclic and not linear and towards the circle of blame. Secondly, the right question was asked to retrieve the results needed in this step.

**Financial feasibility**

This part of the meeting was set up so the experts were able to react on the following statement: This scenario is going to deliver me money! The method used was an open discussion.

All the experts were resolute in their verdict, but they said the statement should be changed towards: This will not cost me money! All the experts in the meeting agreed, even the recycling actors, which will need to change their main process, but still believe that they are able to do so. Therefore this scenario is financially feasible. Meaning that another main obstacle is overcome and that this step can prove to overcome this obstacle in the future.

Having analyzed the profit in a different manner by looking at the cost and selling prices of the parties, shows that some will make a profit but others will not. The decision was made to assess the profitability in the supply chain; the extra thought was that together the supply chain can also assess the technical feasibility of the scenarios. This method used in the expert meeting shows the result that does not cost any money. In addition, a second major obstacle to sustainable construction is overcome. This indicates that for the obstacles argued, this step can ensure that sustainable construction can become reality.

The goal of the step was to achieve the technical and financial feasibility of the scenarios provided in step four. The list of technical improvements and the unanimous opinion of the financial feasibility thereby indicate that the goal of the meeting has been met. Furthermore, the obstacles profitability and cyclical thinking have been dealt with during this step, which shows that a sustainable process could take place.

### *5.2.6 Step 6: Plan of approach and CPI's*

The organization of step five as part of the research has put forward the two main goals of the tool. The expert panel has put forward the question on what the next step must be in order to change towards sustainable construction. Step five has provided the answer, indicating the strength of an expert meeting. This is, however, more of an introductory meeting and that the need to make the abstract points defined in the meeting into practical points of focus. This step is all about translating step five into a plan of approach.

The points addressed in the previous meeting should form the bases for a new expert meeting where the entire supply chain is represented, for the specific element under investigation. This means that this step is a new expert meeting that would involve more time than an afternoon. The goal of this meeting is to translate the technical points into critical performance indicators (CPI's) and a plan of approach. This plan of approach would involve the detailed description of points of action. These point of action involve: what are the changes in the entire process and most importantly who can be held responsible for the changes within the different processes. By discussing this with the entire chain, processes can be optimized. As the model of the model is cyclic, meaning all processes effect the other. Therefor, in order to change one process the correct input is needed from the previous. Knowledge about the cyclic nature of the model will prevent that these actors do not take the other actors into consideration. This involve solving element like between Danny Burgstede (contractor) and Gooike van Sloten (demolition specialist). The assembly is the last process before the demolition company come, considerations about the dismount ability of the building.

The plan of approach would also need to be approved by all actors in the supply chain, with a clear time line in which the processes are changed and optimized. The expert meeting organized in step five has already put forward that innovation can take place and that the actors are able to implement sustainable construction and overcome the obstacles mentioned in chapter four.

The design of this expert meeting would then involve:

- Translation of the technical and financial feasibility, towards a detailed plan
- Translate the detailed measures into CPI's
- Make a detailed plan of approach with timetable
- Make actors responsible for different CPI's

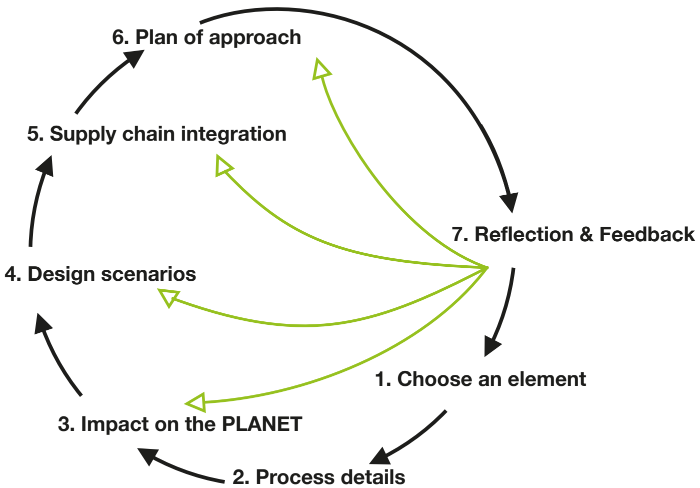
#### *5.2.7 Step 7: Evaluation*

The last step in the step-by-step plan is the evaluation of the previous steps made, the plan of approach and to evaluate if the CPI's are met. In this manner de designs of the scenarios can become more ambitious and new steps can be taken towards the goal of sustainable construction. Thereby optimizing the construction process and transforming the process into a sustainable construction process.

This step would also provide the room for improvement in the methodology of the step-by-step plan. Discussion, findings can be addressed. The step-by-step plan is flexible and able to change. New insights brought to light in the experiences of the experts can compliment steps. This would then optimize the step-by-step plan. The main evaluation, however, is to reflect upon the question: Is the supply chain more sustainable? and Is sustainable construction achieved?

## 5.3 Step-by-step plan (Manual)

The sub-research questions answered is: *What are the elements of the analysis tool and how are these elements related?* This all has shown us that various steps taken in an analysis tool, in order make the step-by-step plan with the bases of the definition of sustainable construction; construction with no impact on the environment, while making a profit. The analysis method, in order to understand the supply chain and also influence it in a manner that impact the environment in positive manner, includes 7 main steps:




## 5.4 Findings

The main question for this chapter was: *How can you implement the construction process model as a tool, in order to achieve sustainable construction?* This question can be answered by saying the abstract model - talked about in this question - needs to be used in the first step to indicate the element for analysis and then translated it into a new detailed model for the remainder of the step-by-step plan. Therefore the model, its symbols and the theory behind the models are useful achieving sustainable construction.

Additional conclusions about the method (step-by-step plan) are those in order to retrieve the information needed in step five (the expert meeting). Steering the group is of importance, this is illustrated by the example of the experts mentioning the architect as person to blame while they were told not to blame others, but reflect on themselves. This shows that changing from a linear towards a cyclic process involves behavioral change and a facilitator could prove to be of importance.

The organized expert panel has proven to be a tool/step that is essential in achieving sustainable construction; this can be illustrated by the fact that profitability can be achieved in this step by assessing financial feasibility. Furthermore, the experts understood the sustainable construction process model and the manner of thinking. The change needed to achieve this however, still proves to be a problem because the experts often fall back into old habits.

# 06 Conclusions & Recommendations

This chapter focuses on the conclusions and recommendations. The first section - conclusion - provides answers to the main and sub research questions. After the conclusions are discussed, recommendations are made for contractors, suppliers, manufacturers, labels and the construction industry.

## 6.1 Conclusions

The main research question for this research is: *How can a sustainable construction process be defined and how can the sustainable construction process be achieved?* This research question contains three main subjects: defining sustainable construction, assessing obstacles and achieving sustainable construction. Achieving sustainable construction involves an analysis in overcoming the obstacles and the implementation of a tool in order to actually achieve sustainable construction. All subjects will be discussed separately in order to chronologically formulate the main conclusions about the different research aspects.

### Defining

Defining sustainable construction involves a number of elements that have led to the definition of a sustainable construction process with an illustrative model. The elements are discussed separately in order to provide reasoning for the conclusions made in the following part. Elements involve; the history, current manner of contracting, current construction process and sustainable construction process. This order is a result of the research into the sub-research question: *What are the elements of a sustainable construction process, and how are these elements related?*

The historical development, first of all, has provided insights into the construction process that needs to be understood before designing a current construction process; the first part of the research (chapter two). The industrial revolution has moved towards unlimited usage of our natural resources and energy sources because the products developed are bigger and better. The possibilities that arose from this development changed the construction industry, which is not so much the manner of working but the possibilities of the technology. This brought forward the bad hygiene circumstances in and around factories and cities; this was the first moment that sustainability counterbalanced the industrial movement with the hygiene improvement in cities. The second point, where the counter-balancing surfaced was when the Club of Rome stated limitation growth and that resources are endless. Thirdly the well-known Brundtland report states that sustainability is thinking in a different manner and more about the future generations. History, therefore, shows us that sustainability is actually a counter movement to industrialisation.

Construction, in general, is also different from other industrial processes like agriculture and production processes. Take the example of the phone, the need for mobile phones came from the market. The production industry (product development) always takes the need from the market and explores it within the limitations of the industry, in order to meet the needs of the market. This conversion towards a product often involves a creative

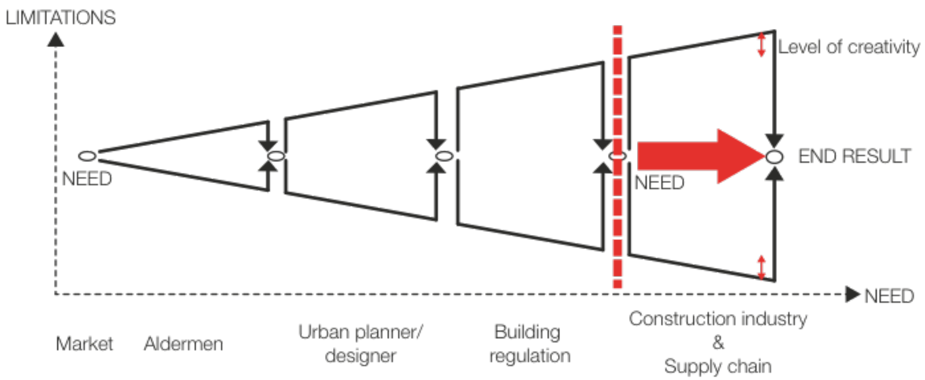



**Figure 6 - 1**: Manner working nowadays

process where the supply chain is involved. In a manner that the supply chain helps in the innovative development of the product; take for example the supply chain integration at Toyota. In construction this works differently. The limitations are explored and the need formulated by the aldermen (of the municipality) or spatial planners. Then this demand is formulated in specifications; these are tested by the building regulations before it finally comes to the market, often through tenders. In this manner, the need for housing, offices or infrastructure is not defined by the end user (only indirectly). The market therefore, has less room for creativity in developing a product. This is explained in figure 6-1. The freedom to utilise the potential of the market is not possible in this manner. The market then produces the product that is often not fulfilling enough for the end user and therefore/thus the product does not achieve the result. This is illustrated in the example of the I-phone. This way the construction industry has less space for creativity.

The construction process and the level of creativity that can be achieved during the first three stages of figure 6-1 are tremendous, however, they are difficult to influence by contractors due to the position in the market, the tender or contract the work. Towards the supplier feeder industry, the contractor has more influence and is able to achieve more, because of its unique position in the supply chain. The contractor gets the contract or tender and then involves the whole supply chain; he is the actor with the cash. So, on both ends of the process in figure 6-1 there is a need for improvement. This research has focussed on the second step with integration of the supply chain in order to achieve a better (innovative and creative) result in relation to sustainability.

The current construction process is based on the problem analysis, the history and manner of contracting mentioned previously. The different elements and their relationship to one another were defined in a process flow diagram. The definition used was “Construction technology is the application of applied sciences in order to enhance productivity and quality of its products. The nature of the construction **activities** (performed by **labour**) involves the **place** where construction work is to be carried out and the **time** available for construction work. These are the four factors that determine the effective construction process”. This formed the basis for the flow diagram in figure 6-2, where the numbers indicate the different elements mentioned in the definition. Chapter two goes in-depth on the different elements of the construction process, it can however be said that the figure

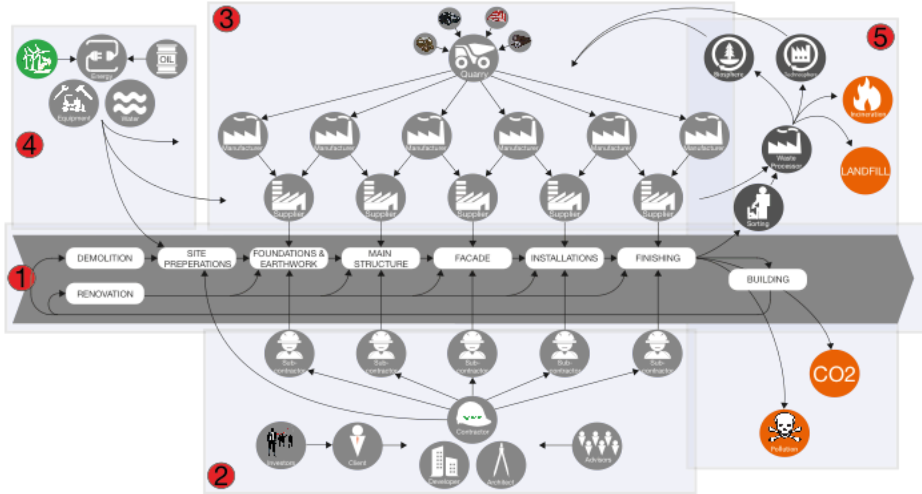



**Figure 6 - 2**: Current construction process

is a visualisation of the definition and forms the basis for defining the initial elements used in the sustainable construction process.

The sustainable construction process was defined using the definition provided by the twelve experts interviewed. These experts together with an in-depth research in sustainable construction in chapter 3 provided the following definition: ”Sustainable construction is construction that does not impact the environment (**planet**) and **people**, while making a **profit**”. This definition is based on the famous definitions of Elkington and Brundtland.

These definitions, however, did not provide the insight needed for a new flow diagram, visualised in figure 6-2. The tool of Lansink - the ladder - was used to structure the sustainable construction process model in steps. The basis of the whole diagram and definition can be found in the Cradle-2-cradle philosophy and industrial ecology. These are based on a cyclic nature of elements, like in all nature’s processes. The sustainable construction process model (figure 6-3) is the translation of the definition, different tools and philosophies into a flow diagram and thus defining sustainable construction, the first part of the main research question in this research. This definition proves to be a definition for the construction process including all elements defined and related to one another, thereby answering the first part of the research question.

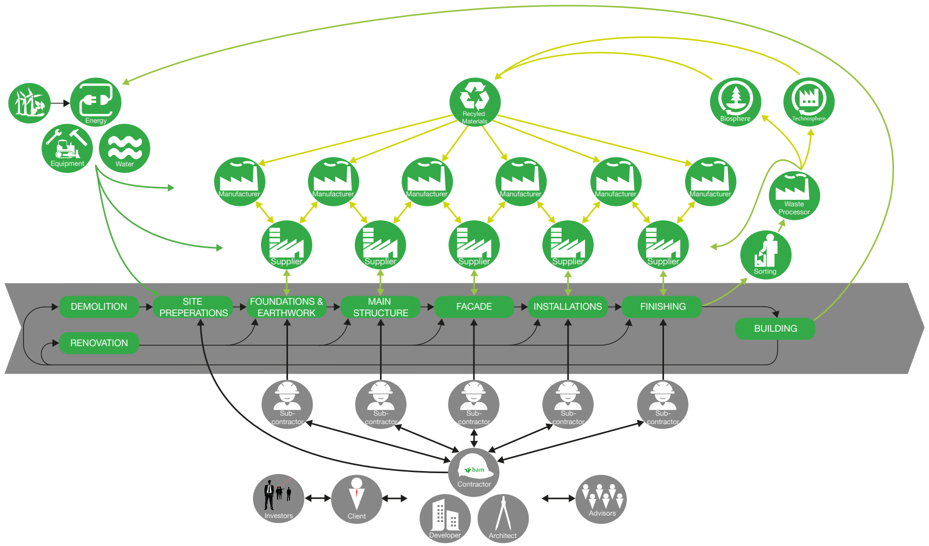



**Figure 6 - 3**: Sustainable construction process

### Obstacles

Defining sustainable construction has already brought to light a number of elements that tell us something about achievement of sustainable construction and the obstacles currently preventing sustainable construction from taking place. Various actors and experts also indicate that they believe certain obstacles exist, but no research really provided the insight into the different obstacles. This part of the research - achieving - involves two main elements, namely obstacles preventing achievement and a plan of approach based on the knowledge conducted in developing a plan of approach.

This research, analysing the interviews with twelve reputed experts, has provided insights on the achievement factors of sustainable construction. Together with defining sustainable construction and the comparison to the current construction process, it has formed the basis for answering the questions about how to achieving sustainable construction. In the exploration of this answer, the obstacles for success (achieving sustainable construction) are sought to provide insights on achieving the result.

The first obstacle for sustainable construction is the difference between linear and circular nature of the models. For sustainable construction (circular) to take place in the current, linear manner of thinking must be let loose. This is retraceable in the lines showed in the models. The models of the current construction process show orange rest product, while the sustainable construction process is fully self-sustaining (cyclic). Important to understand in this model is that it involves a new manner of thinking, a new mind-set. This implies that a behavioural change will need to take place.

The second obstacle in achieving sustainable construction is the commitment needed from management or initiators, in order to ensure the success of a new manner of thinking. This obstacle is closely related to the first obstacle and in this manner it can be dealt with. Commitment and persuasion will be necessary in order to overcome this obstacle.

The third obstacle is that sustainable labels are currently often used as the definition for sustainable construction. The goal of labels is to assess the sustainability, and create an extra value for the product, through a certificate. This is a noble and good cause, however, various market parties and clients use these labels as a definition for sustainability and because the labels are still evolving they do not incorporate everything related to sustainability and sustainable construction. This makes it hard for real sustainable initiative to settle, because certain labels do not support them and organisations want the credits related to the labels, for commercial reasons. Furthermore the assessment of a process is often not of interest to the client, because the actors involved in the process often only profit from the added value of the process. This means that the labels also contribute as an obstacle in achieving sustainable construction.

The fourth obstacle in achieving sustainable construction is the profitability of sustainability. In the current situation all sustainable initiatives are dependent on the profitability. Take for example waste that is cheaper when sorted and energy bills that compensate the larger investment costs. This proves that when a sustainable initiative can be translated into an economic return on investment it can become successful, and therefore it is an important obstacle for several sustainable initiatives to take place (not enough gain or reduction in costs). However, if sustainable initiatives do not cost extra and do provide a good image for the organisation, this value can be exploited to the benefit of the process actors. In order deal with the profitability, two things are possible; reduce the costs and add value for sustainability, which is hard to make insightful. In creating more value, various labels (more the 50) have emerged to make the value of sustainability insightful. Within the construction process the added value is only worth something for the contractor and the supply chain. They will need to be willing to pay for this added value or translate this towards the product they deliver. Therefore, sustainable construction initiatives within the process, that reduce the costs or do not cost more, are useful and have a chance for success.

These obstacles show that in order to achieve sustainable construction the new system will need to incorporate strengths it can deal with. These obstacles are a combination of the weaknesses& opportunities and threats& weaknesses, not utilised in the current systems. These provide insights into the achievement and implementation of the model as tool to achieve sustainable construction.

**Implementing**

In order to achieve sustainable construction and overcome the obstacles previously mentioned, a plan of approach or tool needs to be developed. Chapter five discusses this tool and its development in-depth. The main question for this part is: *How can you implement the construction process model as a tool, in order to achieve sustainable construction?* and *What are the elements of the analysis tool and how are these elements related?* The second question is answered first. Preforming the analysis into a specific element, aluminium has provided insight on how sustainable construction and the implementation of the model provide the best possible results, in this case a sustainable construction process. The steps taken in the step-by-step plan involve two main goals; analysis and solutions.

The first step in the plan already indicates the possibilities within the model designed and its ability to analyse various processes, materials and new initiatives. This step forms the basis for the first choice that needs to be made by the person using the model. The possibilities of the model are reasons why people react enthusiastic about the model. It provides clear reduced visualization of the reality, makes the process insightful and shows added value.

The second step involves a creative process were a new model is designed, based on the processes and elements used in the previous step. The model used for aluminium, shows the manner in which this model could be designed, but could be different in various other elements investigated.

Step three involved the quantification of the impacts on the environment related to the detailed processes that are assessed. This step provides the insight into the process under investigation with its related impact on the environment. Take for example the transportation aspect, where BREEAM focuses on the last transportation step between a supplier and construction site. The material has often already travelled a hundred times the amount of kilometres monitored in BREEAM. This means that changes that are discussed in later steps can be assessed on their impact on the environment of the entire process and allow for optimization.

The reduce reuse and recycling designed scenarios are introduced as part of the Trias Ecologica, showing that sustainability can be solved in a different manner than recycling components in construction. Reusing can really impact the industry a lot more effectively. For instance the reuse of aluminium facades can prove to be harder due to the fusiform corrosion that occurs on the element of the facade that has been cut. The quality that is needed for the elements when reused is therefor of great importance for the feasibility. It reduces the impact tremendously (41%) when reusing 50% of the facade as elements and not as components.

The expert panel design (in step five) has proven to be a crucial step in the step-by-step plan. The reason for this is that all obstacles related to the achievement of sustainable construction are dealt with in this meeting. The meeting, set up for the aluminium case, provided answers useful for the task at hand, but is dependent on the experts involved in and the facilitator of the meeting. In order to retrieve the information needed, steering the group is of importance. This is illustrated by the example of the experts mentioning the architect as person to blame while they were told not to blame others but reflect on themselves. This shows that changing from a linear towards a cyclic process involves behavioural change and a facilitator could prove to be of importance. This step in the tool is strong and enables the supply chain to overcome the obstacles.

The next step would be to make a plan of approach and translate the output from the first session towards a concrete solution. This step would prove its worth in a project although it has not been tested, but based on the knowledge retrieved by this research it should prove to be the final step in the achievement of sustainable construction.

The first question can be answered by saying the abstract model needs to be used in the first step to indicate the element for analysis and then be translated towards a new detailed model for the remainder of the step-by-step plan.

**Achieving**

The last sub-research question based on the information above can now be answered: *How can we achieve sustainable construction?*

The achievement of sustainable construction involves a step-by-step plan where the current situation changes towards the desirable situation. In order to achieve sustainable construction, at least the obstacles mentioned in the previous part will need to be overcome.

The tool developed looks at the obstacle of profitability; the other obstacles however have also been looked at. In order to achieve sustainable construction, with the defined model and definition, it must be accessible and easy to understand. This has to do with the mind-set that needs to be changed with a cyclic manner of thinking and not a linear one. The expert panel organized in chapter five put forward that the experts in the industry, discussing the achievement, understood the model and new manner of thinking easily. This indicates that this manner of thinking is understandable, but in order to achieve it, a behaviour change within the mind-set of the actors is needed.

For this plan the commitment of management of employees is needed during the process of change. Commitment is necessary because the proof for profitability is not (yet) there; people still need to be convinced. If the profit aspect had been proven, commitment would most likely not be necessary. Still the commitment is an aspect that no tool or model can solve, it needs to be there. Therefore, the persuasion of people is needed in order for them to commit towards a new process. The assessment of the profitability and its feasibility are curtail in the success of the step-by-step plan used, however the supply chain assembled in this case was able to achieve this result, providing the first indications that this obstacle can be dealt with.

The last obstacle is that labels are used as unjustifiable definition for sustainable construction; de definition provided in this research is far more broad and flexible, allowing for new interpretations and possibilities. The defined sustainable construction model is far more broad and focussed on the process that labels can focus on the product at hand, the building. The labels can assess this, but the process is an aspect that should be optimised internally and the only actors that profit from this are the actors within the process.

The implementation through the step-by-step plan provides insights on how to achieve sustainable construction and how to deal with this change. The steps mentioned form the basis for the change that is needed to achieve the desirable situation. These steps involve a lot of methods that are known, but put together in a manner that the practical situations can be solved. The steps form the basis of the knowledge retrieved during the entire research.

The research consisted of three parts in the research questions mentioned in the first chapter:

1. Defining a relationship between elements in a sustainable construction process
2. Assessing obstacle in achieving sustainable construction in practice
3. Designing an analysis model for optimizing sustainable construction

All the aspects have been dealt with and provided with conclusions that the construction industry can use to their benefit. The recommendations in the next part will provide a manner in which the industry can deal with the conclusion put forward in this research.

The strength of this manner of approaching sustainable construction is that there is room for creativity. If the mind-set of the actors were the same this would lead to more sustainable processes. Sustainability is a movement that counterbalances the industrialization and has the goal to make people aware of the decisions we make and the processes we chose in order to achieve a product or service have an impact on the environment. Labels always have the weakness of being bound, the same counts for legislation. Thinking in a sustainable manner that works, with the powerful foundations (economic state of mind) of the old system, while adding aspects that compliment this will, prove to be the basis for success, along with changing several foundation of the current system.

## 6.2 Recommendations

This research has put forward a definition of a sustainable construction process and a tool to help achieve this process. However, conducting this research has also brought to light, the imperfections, as well as limitations of the scope of the research. These aspects are discussed below, together with recommendations for new research.

First off, my recommendation would be to relate the defined sustainable construction process to the product produced by this process. Various experts have mentioned that scenarios - like the *reduce scenario* - within processes have a strong connection to the design and the product made from the design. This means that optimizing the process will affect the product and the other way around. Research into these effects could compliment this research.

Secondly, the research scope did not involve the product and the result of the new process on the product. This lack of involvement caused the question to arise what effect the sustainable construction process has on the sustainability of the product. This question is of interest because this would create a certain value for the new process. In conclusion, new research into sustainable construction could involve the exploitation phase and therefore the product.

The third element of recommendation is about the step-by-step tool developed in this research. Time limitations in the graduation project have confided the ability to test all the steps in this tool. The tool, includes a new expert meeting were the concrete plan of approach is designed by the supply chain actors and translated to a plan of approach and CPI's. Therefore, this is a recommendation to the people wanting to use the tool; test the last step first, in order to see the results it might deliver.

The achievement of sustainable construction deals with a series of obstacles, four of which have been addressed in this report. One of these obstacles is commitment, the obstacle that is not needed once people believe its added value (profitability). However, convincing these people will involve determination. In the most ideal situation, it will involve a pilot project which is used to prove the step-by-step plans value in practice. The last recommendation would be to use the tool in practice in the form of a pilot, then monitor the process and gather information to prove its worth to the rest of the world.

If the previous recommendation for the construction industry would be done, it is best to integrate sustainable construction through the CSR platform. The reason for this is that this parts of the organization has the theoretical background on this model. This however, will need to be put forward in the whole organization in order for all projects and management layers to believe and adopt this perspective.

Alongside the recommendations for the construction companies, there are also some recommendations for the supplier industries and the labels that assess the sustainability of the project.

The labels need to become more flexible in the manner of assessment; the evidence needed in the BREEAM project is often so large that this does not allow room or time for creative solutions. The introduction of innovation points should be expanded to at least 33% of the points in credits. Furthermore, BREEAM involves a lot evidence needed for a certificate. Every time a contractors delivers a building this evidence must be collected, making it a long process and costly process. BREEAM is the assessment for the product and not for the process, the process is dealt with in this research.

The recommendation that can be made for the supply feeder industries would be to dare to think alongside a contractor and come forward with innovative and creative solutions for a problem. Together with assessing their own process and organizing this in a more sustainable manner, this would contribute to the impact on the environment as a whole. There are so many supplier industries for the construction industry that depend on the construction process. This means that when improvement starts with the construction process on site, this would also have to take place in other parts of the chain. Together they can genuinely reduce their impact.

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# Appendix

## Appendix 1: Interview scheme

## Appendix 2: Construction process models

***2.1 Sustainable construction model***

***2.2 Current construction model***

***2.3 Detailed construction process aluminum***

- •Current status
- •Recycle
- •Reuse
- •Reduce

## Appendix 3: Interview analysis

***3.1 Interview analysis model***

***3.2 Atlas output***

## Appendix 4: Interviews

## Appendix 5: SWOT excel model

## Appendix 6: Evidence quantification of model

***6.1 Pricing aluminum facade De Groot & Visser***

***6.2 Amount of recycled aluminum***

## Appendix 7: Aluminum optimization model

## Appendix 8: Expert meeting report