DEVELOPMENT OF A DECISION SUPPORT MODEL FOR DETERMINING BUILDING LIFE-CYCLE STRATEGIES IN THE NETHERLANDS

S. Binnemars[1], J.I.M. Halman[1], E. Durmisevic[1]

[1]Department of Construction Management and Engineering, University of Twente, Enschede, Overijssel, The Netherlands,

s.binnemars@utwente.nl, j.i.m.halman@utwente.nl, e.durmisevic@utwente.nl

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Abstract

Over recent years, it has become increasingly apparent that there is a growing need for so-called green buildings with a lower environmental impact over the whole building life-cycle. The construction industry demands strategies that support a drastic change of the way we develop, construct and maintain buildings. However, new building concepts represent too much of an evolution of traditional building systems, which does not necessarily lead to the intended shift towards green transformable buildings. The research aims to acquire knowledge about the impact of specific design characteristics on the complete building lifecycle, develop possible scenarios to create green transformable buildings, determine how the various strategies relate to the building lifecycle and to create knowledge about how to measure the effectiveness of the chosen strategies. The expected result of this research is a decision support model for building concepts. The model should lead towards a better understanding of innovative green solutions for buildings and therefore provide a better opportunity to create innovative new building concepts. This paper describes the research design, which will address the goals.

Theme: *Green Buildings and Architecture*

Keywords: *Conceptual Building, Building Lifecycle, Life-cycle Strategy, Measurement, Decision Support Model*

1 INTRODUCTION

There is a need for more sustainable building. This paper describes the research framework of a PhD project at the University of Twente about the development of a decision support model for determining the most effective building life-cycle strategies to apply in the Netherlands.

The main question of the research described in this paper is: How best to design, construct and maintain green buildings throughout the complete building life-cycle? This question does not have a simple answer; it does not even have a single solution, as the result is dependent on factors such as the function of a building, the way the building is used and the location.

Over the last 25 years, it has become increasingly clear that sustainability is necessary if we want to maintain our current level of civilization. Humanity is polluting and destroying the earth at an increasing rate.

Since the need for sustainability became more widely accepted, the greatest contributors to pollution also started becoming visible. It is widely considered that the construction industry in combination with the built environment have a very high impact.

To cope with this high impact, many studies have been performed to address a range of specific questions. This has resulted in much unstructured knowledge about design approaches, production efficiency, better building lifecycle performance, and reducing material wastage. Now it is time to combine the knowledge to make a leap in the development of the construction industry by better guiding the decision-making process. To achieve this, the scientific knowledge must be understandable for the construction industry. Therefore, it is necessary to combine and translate the acquired knowledge into terms of goals, strategies to achieve those goals and insight in the effects of those strategies on the goals.

The first part of this paper – Sections 2 and 3 – explains the key driving factors of innovation and problems in the construction industry. The second part – Sections 4 and 5 – provides an overview about which attempts are already made and what theories might provide new directions. In the final part – Sections 6, 7, 8, 9 and 10 – the opportunities, objectives, research design, goals, benefits and deliverables of the research are described.

2 WHAT MAKES OUR WORLD UNSUSTAINABLE

2.1 Resources

We live in a world with roughly two kinds of materials: regenerative and non-regenerative. Sometimes regenerative materials are used at a rate faster than the regeneration rate. In that way, even the regenerative materials will not last. For materials, which are perceived as non-regenerative, there is a Peak Oil theory (Hubbert 1956) about the extraction of such materials. There are roughly three phases in the extraction of natural resources. First, exponential growth of output, then a phase of stabilization of output and finally a decline in output. (Figure 1) This theory is also applicable to other types of materials. Currently, we live in the first phase of material extraction, where new deposits continue to be found and output continue to increase. However, once we pass the peak the extraction of material becomes both harder and more expensive. Eventually the material will be depleted or be too expensive for practical use.

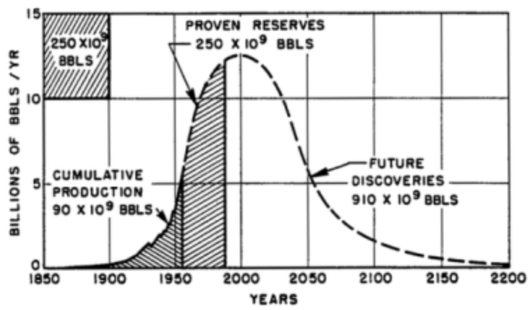

Figure 1, Peak Oil Graph (Hubbert 1956)

In ‘Limits to growth’ (Meadows, Randers et al. 1972), the rapidly growing world population is linked to the finite supply of resources. Examples are the limits to food production and problems induced by industrialization such as pollution, and resource depletion. In ‘Cannibals with Forks’ (Elkington 1997), ‘Collapse’ (Diamond 2005), and ‘A New Green History of the World’ (Ponting 2007), the authors state that society is able to choose to be sustainable or unsustainable. If they choose to be unsustainable this will eventually mean humanity’s downfall. Scarcity of materials would create huge problems in the construction industry.

2.2 Environment

The Brundtland report “Our Common Future” pleads for sustainable development. The report warns of:

- acidification of forests and lakes
- depletion of ground water
- desertification of productive dry lands
- destruction of forests
- energy shortages
- environmental degradation
- erosion
- increase of poverty
- global warming
- lack of food security
- loss of species and generic resources
- new chemicals and new forms of waste
- overpopulation
- ozone layer depletion
- pollution of air and water
- proliferation of toxic chemicals and hazardous wastes
- toxic substances into human food chain and underground water tablets.

The authors of the report claim that these factors taken together will cause problems in the future. (World Commission on Environment and Development. 1987)

In ‘Small is beautiful’, Schumacher (1973) criticises western economics. He claims that the modern economy is unsustainable because natural resources are treated as expendable income. The problem is that most resources are not renewable and so will eventual be depleted. In addition, he claims that nature’s resistance to pollution is limited.

Rockstom et al.(2009) published their first article about what they call planetary boundaries, aiming to quantify these boundaries (Figure 2). These boundaries can, they say, not be crossed without danger of losing the stable and ideal living conditions that have been present on earth since the start of the Holocene. However, the problem is that we have already crossed four boundaries, namely: Climate Change, Ozone Layer Depletion, the Nitrogen Cycle and the Rate of Biodiversity loss. Fortunately through regulation and political action Ozone Layer Depletion has been brought back within the threshold and the Ozone Layer is recovering. The problem is that once a boundary is crossed too far or for too long, the climate on the planet can change drastically. This means that every human development should be evaluated against these nine boundaries.

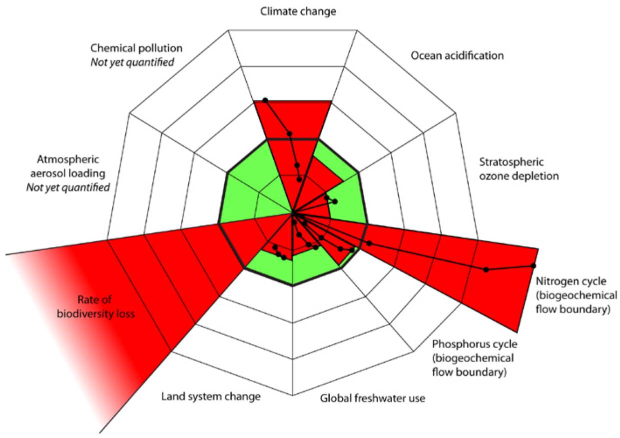

Figure 2, Nine pillars of the stability of the environment (Rockström 2009)

Given the severity of the problems discussed in this section, the construction industry has to aim for prevention of those potential problems in their actions and developments.

2.3 Economy

From 1990 to 2008, the total number of building permits issued in the Netherlands slowly declined from 37,845 to 34,735. In this period, the number of permits for new buildings dropped from 28,058 to 18,320 and the licenses for other reasons, such as renovation, grew from 9,787 to 16,415. The financial crisis that started in 2008 had a serious impact on the building industry. The total number of licenses has since dropped from 34,735 to 22,717 of which 12,205 are for new buildings and 10,512 are for other reasons (CBS 2012). The weak state of economy put additional pressure on an already declining market. Competition in the construction industry has become fierce and price driven. Good positioning in this market is important for survival.

2.4 Society

Properties of Society

Society is always in flux, as can be observed by the population breakdown of the Netherlands (CBS 2012) shown in Figure 3. In addition, the average household size has dropped from 3.93 persons per household in 1950 to 2.22 in 2010. (CBS 2012) Therefore, housing needs have clearly changed over the past 60 years.

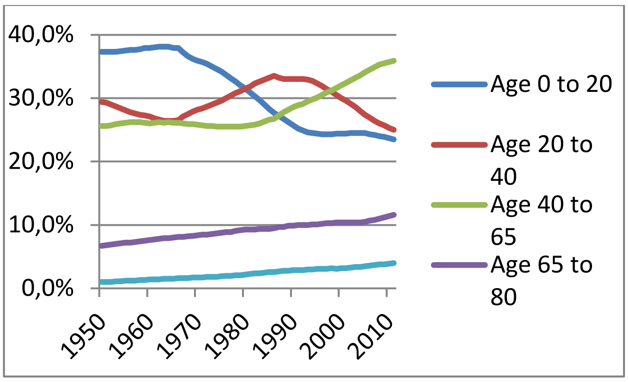

Figure 3, Population Breakdown by Age for the Netherlands (CBS 2012)

Needs of Society

Maslow’s Pyramid (Maslow 1982), which in the western world the physiological and safety level were always taken for granted and people’s struggles were at the love/belonging, esteem or even self-actualization levels. However, nowadays problems are starting to arise at the safety level. One can think about security of employment, property, and resources. If we continue to deplete the world's resources, we might even end up struggling to fulfil the physiological needs for food and fresh water security.

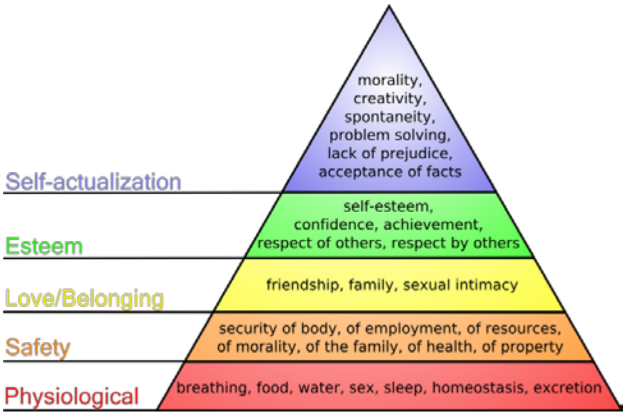

Figure 4, Maslow's hierarchy of needs (Finkelstein 2006)

The construction industry is directly affected by the people living in and using the buildings. When the needs of people for a living environment change this is likely to have an impact on the construction industry.

3 THE CONSTRUCTION INDUSTRY AND THE BUILT ENVIRONMENT

3.1 Current impact of the Construction Industry and the Built Environment

In the Official Journal of the European Communities, it is stated that:

> "The residential and tertiary sector, the major part of which is buildings, accounts for more than 40% of final energy consumption in the Community and is expanding, a trend which is bound to increase its energy consumption and hence also its carbon dioxide emissions" (European 2003)

This lead to the conclusion that the construction industry has to lower its footprint of energy usage and CO_2 production.

3.2 The Construction Industry and the Economy

Since the start of the economic crisis in 2008 charts show a clear drop in the number of building permits. In addition, the housing market shows a drop in bought and sold houses as well as increased periods in which the houses are for sale. There are even more offices empty and for sale. All in all this reduces the need for new buildings, which puts stress on the market.

3.3 The inherent inflexibility creates a balancing problem

The inability of buildings to adapt to new functions, which is a common attribute of buildings, currently creates a problem. There are too many office buildings, which are no longer used; on the other hand, there are too few houses for first-time buyers.

3.4 Innovation in the Construction Industry

Until the 20th century, improvements in house building were mostly based on the use of new materials or expanding the capacity of houses. Since the second half of the 20th century, there has been a constant drive towards the improvement of the performance of the building. Developments such as: sound insulation, fire protection, reduction of energy consumption for heating, communication technologies, and home automation all added to the performance of the building, but they all did so by adding materials or subsystems. However, these innovations did not lead towards a fundamentally new building methodology. Instead, only lots of new technology was added. This is called 'innovation by addition' (Lichtenberg 2004). Innovation through addition has led to enormous complexity in buildings. So reducing their adaptability.

4 DEVELOPMENTS IN THE CONSTRUCTION INDUSTRY IN THE NETHERLANDS

Although much appears to be dysfunctional in the construction industry, there are also positives. Several attempts have been made to deal with the problems described above. This section briefly introduces Green Architecture, Industrial Production, Sustainable Construction, Flexible and Adaptable Buildings, RGVO and Design for Disassembly.

4.1 Green Architecture

Green Architecture, aims to achieve sustainable buildings, but although becoming increasingly important is nowhere close to being a standard. Green Architecture improves Energy & Water Efficiency and applies Renewable Energy into buildings. Furthermore, Green Architecture makes use of Environmentally Preferable Building Materials and Specifications, reduces waste generation and reduces the use of toxic materials. Other key factors are a focus on high Indoor Air Quality, Smart Growth and Sustainable Development.(EPA 2012)

In short, Green Architectures aims to reduce stress on the environment and resources while creating buildings with a healthy indoor climate.

4.2 Industrial Production

Industrial production of buildings has been practiced on a large scale since the Second World War. The major benefits of Industrial Production are economies of scale, higher efficiency, reduced stress on resources, and higher quality because of the controlled production environment. However, it did face some problems, especially the standardized designs. They were so boring people did not like those buildings at all. (Scheublin 2006)

4.3 Sustainable Construction

Sustainable Construction aims to increase the performance of the construction process by reducing the CO_2 output, energy use and waste generation. This approach improves the quality of the buildings and at the same time reduces the impact on environment. However, although promising, Sustainable Construction is still quite new and under development.

4.4 Flexible and Adaptable Buildings

Improving adaptability and flexibility increases the value of the building and of its components and elements. In addition, the increase in adaptability creates freedom of expression for owners. The combination of these two ensures a longer lifetime for the applied materials, which reduces stress on natural resources.

4.5 RGVO (Dutch Acronym for Result Aimed Property Maintenance)

RGVO is the proactive maintenance of buildings based on minimum and maximum quality levels. The application of RGVO prevents unexpected high costs during the use period. This is done by measuring and acting in time. Also, this ensures a certain quality level throughout the life of the building. (Sprong 2009)

4.6 Design for Disassembly

Design for Disassembly improves the ease of both assembly and disassembly, which increases the reusability of components (Durmisevic 2010). Therefore, the value of components and elements will increase and the end-of-life waste generation will be reduced. The ability to disassemble a building enables the reuse of components – which reduces the stress on natural resources – and allows adaptation to the changing needs of society.

5 HOW TO PROCEED WITH THE DEVELOPMENT OF SUSTAINABLE BUILDING

Current developments in the Netherlands are focused on reducing, reusing and recycling. Whether this is the optimum approach is debatable. We can learn a lot from the Cradle to Cradle approach (Braungart and McDonough 2002), and aim for a positive footprint. Cradle to Cradle aims for a cyclic economy in which the output of one process is at the same time the input for another process. A positive footprint means producing abundance of useful materials, which are used as input for other processes. Two examples of a positive footprint are: the cleaning of fine dust from the air and using CO_2 in the production process. This does not only apply to CO_2, fine dust and energy, but to all aspects: environmental, economic, societal (Binnemars 2011)

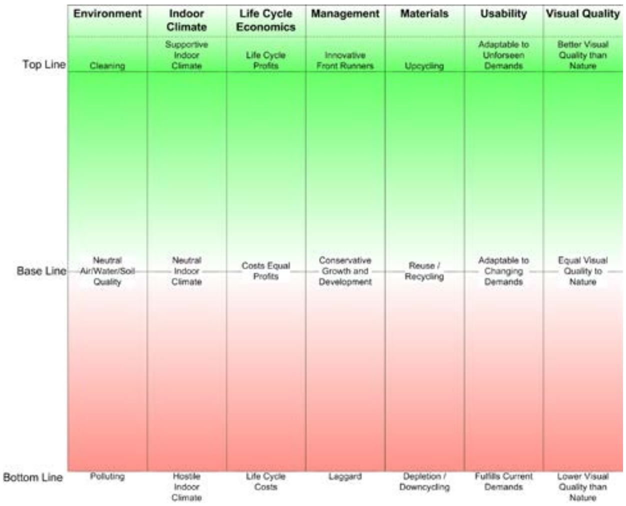

Figure 5, Example of a Conceptual New Sustainability Perspective (Binnemars 2011)

A broader perspective about green buildings, such as that shown in Figure 5, could help in determining directions for further development, innovation and research. The diagram depicts a space from the bottom line, via the base line to the top line. The bottom line can be seen as "bad", for instance: polluting, poor climate and poor visual quality. The base line is currently seen as sustainable, aiming for CO_2-neutral, energy neutral and economically neutral. The top line suggests a positive impact, such as CO_2 absorption, creation of a healthy environment, economically beneficial and upcycling.

6 OPPORTUNITIES TO MAKE A LEAP TOWARDS GREEN BUILDINGS

Although there are many challenges, there are also many initiatives and opportunities to learn. For this research a lot can be learned from the experiences with existing innovative building methodologies. Furthermore, other industries that are technologically ahead of the construction industry can provide inspiration. Moreover, this research can use previous studies which tested theoretical methodologies in practice and use the results as arguments for or against the use of those methodologies.

6.1 Learning from existing innovative building methodologies

A lot can be learned from existing building methodologies and their successes and failures, such as: Open Systems Building (Habraken 1972), Wilde Wonen (Weeber and Vanstiphout 1998), IFD(SEV 2001), Slimbouwen (Lichtenberg 2009), IDF (Binnemars 2011) and Living Buildings(de Ridder 2011).

6.2 Technomimicry

Also, a lot can be learned from more industrialized high tech sectors such as the automotive industry, the industry for household appliances and the computer industry. One of the most commonly used strategies is development following the Product Platform Development principle, e.g. (Veenstra 2006). Another important development is the adaptation of the Cradle to Cradle Concept (Braungart and McDonough 2002) in both products and production processes.

6.3 Scientific researches

Finally, a lot can be learned from studies performed in the field of construction, but also from research in other fields. This knowledge can then be combined to generate knowledge applicable to the construction industry.

7 THE OBJECTIVE OF THIS RESEARCH

The objective of this research is to develop a decision support model for sustainable building concepts. This will require knowledge of existing strategies and measurement techniques. To reach the objective a clear overview about which additional research has to be done in relation to missing strategies or measurement techniques is necessary. This result in four sub-objectives: (1) develop a model for the building lifecycle, (2) create a matrix of possible strategies, (3) determine the relations between strategies and the building lifecycle phases, and finally (4) determine the options for measuring the effectiveness of the strategies on the building lifecycle.

8 WHO WILL BENEFIT FORM SUCH RESEARCH?

Besides the goal, the beneficiaries are also very important since they are the reason for the research. This research aims to place specific knowledge in an overview which is helpful for science, the decision support model is supposed to be a useful tool for the construction industry, and a healthy construction industry will help the society.

8.1 Science

Science will benefit from this research. Considering the combining of previous specialized research projects, tapping into other pools of knowledge, which are not directly related to building and construction, and revealing missing strategies and missing measurement techniques.

8.2 Construction Industry

The construction industry will also benefit from this research. There will be a clear overview from the current state of development and a broader perspective to be able to decide which direction for innovation is preferable to pursue. Furthermore, the model can be used to reflect upon and improve the current business strategies.

8.3 Society

Society will benefit from a healthy construction industry by less pollution, more jobs, better job security, higher quality buildings with higher quality architecture and better indoor climate quality.

9 RESEARCH DESIGN

9.1 The Research Design

The researched is designed in such a way that knowledge is gathered in a specific order. Each phase provides input for the next phase. (Figure 6) This makes it crucial to follow the steps in this order. Also, the phases are specific enough to have a clear start and finish which allows a modular project approach for each phase. The phases are designed as a pyramid; each phase must provide a good foundation for the next layer. (Figure 7)

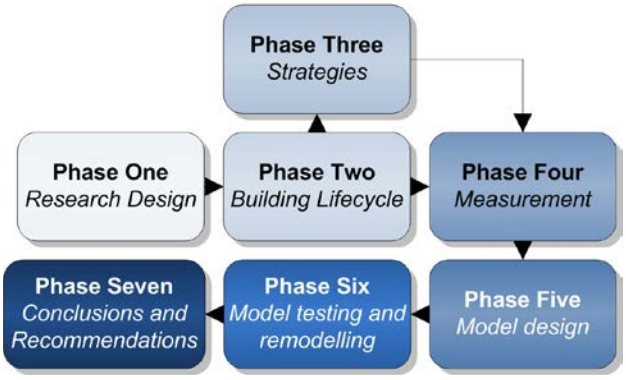

Figure 6, Research Design route

Phases two, three, four and five will consist of the following steps:

- Set the goals for the phase
- Describe how to reach the goals
- Develop a planning with deadlines for the goals
- Gather the necessary data
- Interpret the data
- Develop a model
- Write a paper about the findings

9.2 Phase One

Phase One is all about the research design. The expected result is this paper and a more detailed phase-to-phase description of the research. The focus of the research design is developing a clear overview about what knowledge is needed and at what point in the research.

9.3 Phase Two

The purpose of phase two is to create knowledge about the complete building lifecycle. This knowledge will be presented in a model including material, money flows and actors. This is necessary to determine the influences of existing strategies on the building lifecycle (phase three).

9.4 Phase Three

In this phase, research will be performed into possible strategies for different parts of the building lifecycle. Existing strategies will be identified and related to the lifecycle model.

9.5 Phase Four

After creating knowledge about the lifecycle, strategies and the relations between those two, this phase will involve searching for methods of measurement to rate the effectiveness of those strategies.

9.6 Phase Five

Once all information about the lifecycle, strategies and measurement techniques has been collected this will finally be incorporated into a model which supports design decisions for conceptual building.

9.7 Phase Six

After the model creation, this phase consists of the testing and validation of the model followed by any necessary remodelling.

9.8 Phase Seven

Finally, conclusions will be drawn and recommendations made about the process and the results.

10 EXPECTED RESULTS

There will be three major outcomes of this research. The first will be the pyramid of knowledge about strategies for sustainable buildings, which is created over several phases. The second result will be a matrix of sustainable building strategies, which categorizes strategies based on attributes and identifies which are missing. The final result will be the decision support model for determining which lifecycle strategy is the most sustainable for a specific situation and which can be used by the construction industry.

10.1 Pyramid of knowledge

The pyramid is symbolic for the knowledge created in this research. To achieve the best results in each layer, a thorough knowledge about the layers below that layer is necessary. The first level aims for a complete understanding of the building life-cycle; the second level aims for an understanding of the applicable strategies; and the third level aims for understanding of the relations between strategies and the building life-cycle. The fourth layer aims to measure the effectiveness of the strategies and the top layer aims for understanding about which strategy reaches the best result for a certain desire.

Figure 7, Knowledge Pyramid

10.2 Strategy matrix

The strategy matrix will be developed during phase three and completed in phase four. One axis of the matrix will list the different life-cycle phases and the other axis of the matrix will list the effects on these phases. The matrix will be populated with strategies. In this way, it will be easy to observe which effects have not yet been addressed by a strategy. This information can be used for directing further research.

10.3 Decision Support Model

The final outcome will be the decision support model itself. This model must be easy to use. The aim for the model is to calculate which strategy is most suitable considering the input parameters. The output of the model is a generated list of the most suitable strategies and justification for the choice. Figure 8 shows a flowchart of the model.

Figure 8, Graphical representation of the model

11 ACKNOWLEDGMENTS

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