A CRADLE TO CRADLE (C2C) DECISION SUPPORT MODEL FOR THE DEVELOPMENT OF MIXED FUNCTIONAL AREAS

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Abstract
Designers and engineers are facing a challenge in their roles: to integrate the new Cradle To Cradle Philosophy in their practice, to develop C2C plans and to justify that the plan is C2C. In this paper the focus is on energy production and -consumption. Secondly, the focus is on urban area development, including the following functions: houses, offices, industry and greenhouses. There is a trend towards this type of functional mixture because they allow interesting new energy combinations. Traditionally energy systems are chosen after the main design decisions are made. Instead a model has been developed that can support the decision making process including the energy aspects at the start of the project. The model calculates what the total remaining energy demand is (if there is any) and it gives suggestions on how to resolve this energy shortage. The model utilizes reference data on energy consumption/production for buildings and energy systems. The model supports easy manipulation of the entered building function division, C2C ambition levels, the energy performance level and so on. With this model one can check if C2C goals can actually be realized within the plan area. An application of the model is illustrated by a Case Study. Finally some preliminary experiences are discussed.

Keywords: Cradle to Cradle philosophy, decision support model, integration of mixed functions, sustainable urban development, green energy supply.

INTRODUCTION

The global environment is becoming more important every day, the climate is changing dramatically, caused by pollution. In the 1960s, the fact that pollution is a problem was identified. In the 1970s en 1980s, it became more visual and tangible, due to the discovery of the hole in the Arctic ozone. In 1987 the World Commission on Environment and Development published a report called ´Our common future´ also known as Brundtland-report. Many publications use the following definition for sustainable development from the Brundtland-report namely; “Sustainable development is development that meets the need for the present generation without compromising the ability of future generations to meet their own needs.” Since then a lot of research has been done in sustainable development, nevertheless more research has been done in other industries than in the construction industry. The role of all participants in the construction industry must be changed, by integrating more sustainable technologies into the processes. Nowadays the construction

industry starts to put more effort in sustainable development. Especially on the development of sustainable green energy supply and on better isolated buildings that improves the energy performance of buildings, is a lot of progress made.

The Cradle to Cradle is a concept, developed by W. McDonough and M. Braungart, that considers the whole industrial system and gives a new vision on sustainable design (further details are described in the literature study paragraph). According to Van Den Dobbelsteen and Van Den Grinten (2008) the main difference between C2C and another sustainable development theory is that C2C has a chemical basic principle. Another difference is the link between ecology and economy. C2C states that the concept saves money for the industry and that you can make profit with C2C. However, sustainable projects are known, but C2C project are unknown. There is no exact definition of a C2C building project. Developers and consultants give projects the name C2C to get more media attention, though the title C2C to the projects is misplaced. This is a problem that needs to be answered to take the theory of C2C to the next level in the construction industry.

Energy is a very important factor in the C2C concept. Energy usage takes care of 80% of the carbon dioxide exhaust in the world. A C2C working landscape with the focus on energy would never be possible when the C2C concept is considered literally. The laws of thermodynamic states that there will always be a decrease in energy quality, so this does not fit the C2C thought of up cycling. However, the definition of C2C within this research makes it possible to realize a C2C working landscape. There is a trend towards this type of functional mixture because it allows interesting combinations for new energy supply systems. An energy supplying working landscape creates value (energy) for the environment so it fits in the C2C concept from this point of view. The New Step Strategy is the modified (C2C) version of the traditional trias energetica and can be used to create a C2C situation. Within each of the New Step Strategy there are possibilities for creating C2C solutions.

Cradle To Cradle as new trend in Building and Construction, changes the role of the developers and consultants: they have to integrate a new philosophy and its implications. There are examples of C2C in practice, but these are all examples on a product scale. When C2C is applied on large building projects or urban development, it is not known which problems can occur and what to do to solve them. The problems within the development of C2C projects have to be taken away or reduced to realize those projects. However, the C2C concept is so large that one research cannot solve all the problems. Dennie Collas, the main researcher on this topic, focused in his paper on the energetic view of C2C within working landscape with the following functions: houses, offices, industry and greenhouses. The aim of this research is to improve the utilization of C2C in a working landscape, from an energetic point of view, by analyzing what the problems are in current C2C projects and recommend solutions for these problems.

RESEARCH METHODOLOGY

In this research an orientating literature study is done which gives understanding of the current developments and definitions within the building industry on Cradle to Cradle. For this orientating literature study four terms were used namely; Cradle to Cradle, sustainable area development, energetic interaction between buildings and energy usage of buildings. The literature study is used to get understanding of these terms used in this research and forms the base for the rest of the research. The method which is used to perform this study is

a desk research. Online databases where consulted to find papers and researches on the subjects given above. Finally a selection was made for the most important papers by using a content analysis. Also a practical field research is conducted with use of interviews. In this way the problems which come with putting C2C into practice are analyzed. Several internal and external interviews are held to get an answer on the research questions. The external interviews are taken of actors which are involved with C2C projects. From these interviews the problems are obtained and used for further research. The problems are categorized and analyzed with the Porras method to find the primary and most important problems. Based on the information that is obtained in the literature and problem analysis a model is developed that can help C2C developers or consultants with their C2C projects. The literature study forms the base for the model. The problem analysis focuses the model on a specific problem.

ANALYSES

The analysis that is conducted in this research consists of 2 parts: the theoretical literature study and the practical field research with interviews.

Literature Study
The literature study is held to get understanding of the definition of the terms that are important in this research. Online databases where consulted to find papers and researches on the subjects given above. The following terms are important to get understanding of the C2C concept:

A possible concept to develop sustainable is the triple bottom line, developed by John Elkington (1998). The triple bottom line reflects the organizational success of a company. It is based on values for measuring organizational success. These values are People (social), Planet (environment) and Profit (economic). When there is a balance between all values, a sustainable situation is reached (McDonough, Braungart 2002). The constant pursuit of the goal zero within the triple bottom line forms an unhappy marriage between financial and ecological objectives (Braungart et al, 2007). The triple top line is a theory that focuses on 100% good products instead of minimizing the environmental impact. The goal is not to balance economy, ecology and social equity thought to optimize and maximize all values through intelligent design (MBDC, EPEA 2002). The motto of the Eco efficiency theory is to do more with less. Instead of true recycling this is actually down cycling since the material is downgraded in quality. Eco effectivity is an approach that takes the position that the quantity of the emissions is not the problem; it is the quality of the outputs that must be addressed by making the emissions healthy (Braungart et al, 2007).

The Cradle to Cradle concept
Since the building industry is characterized by a ‘throw away’ culture, with construction and demolition waste comprising about 50 percent of solid waste in landfill this can be called a cradle to grave approach because the after-life of a product is not considered. C2C reconsiders the whole industrial system and gives a new vision on sustainable design. It’s being developed by William McDonough and Michael Braungart. The C2C concept embodies the triple top line and the eco effectivity concept. C2C design is characterized by three main principles: Waste equals Food, Use solar income and Celebrate diversity (Ness, Field, 2003). The C2C concept can be translated into a number of practical approaches. The most important approach within this research is that buildings produce more energy than they use and clean their own waste water. Focusing on energy, all the different definitions of C2C

can be combined to one definition for a C2C project: "A C2C building or project is one that is energy neutral or even one that makes energy for its environment" (Dobbelsteen, Grinten, 2008; Fraanje, 2008; McDonough et al. 2003).

Trias Energetica
The first step to develop sustainable buildings is to use the trias energetica theory. The paper of Dobbelsteen and van der Grinten (2008) states that the trias energetica consists out of three steps:

1. Minimize the demand for energy
2. Use sustainable sources
3. Fill the remaining demand in a clean and efficient way

This concept is a good tool for lowering the energy usage of buildings, but has not reached a turnaround in the building industry.

The New Step Strategy
This theory is a modification of the trias energetica and it fits the C2C concept. The major difference with the trias energetica theory is that the usage of any waste flows is included in the steps of the New Step Strategy (Dobbelsteen, Grinten, 2008):

0. The non sustainable situation
1. Minimize the demand
2. Re-use waste flows (within the same cycle)
3. A) Fill the remaining demand in a sustainable way
   B) Let waste be food

C2C is a new way of thinking which goes further than current sustainable approaches. Traditional views on building sustainable didn't have this focus. A C2C working landscape with the focus on energy is not possible when the C2C concept is considered literally. The laws of thermodynamic states that there will always be a decrease in energy quality; this doesn't fit the C2C thought of up cycling. However, the definition of C2C within this research makes it possible to realize a C2C working landscape.

Practical Field Research
After the theoretical literature study that has been conducted the following question rises: "What are the problems of putting C2C into practice?" To find these problems interviews are used. Several external and internal interviews are held. The interviewed actors are involved in the 'C2C-projects' in the Netherlands. The actors have experience with putting C2C into practice so they know what problems can occur. The interview is divided in four parts. The first part contains questions about C2C in general, the second contains C2C project related questions, the third part contains questions about the energy concept of the projects and the fourth part contains several theses where subjective opinions about C2C can be given. From the interviews 20 problems can be identified:

- Lack of experience with C2C projects
- Developers ask more money
- Traditional way of thinking
- Not willing to 'pay more'
- C2C is product focused
- Higher risks
- Actors think C2C is too expensive
- No ambition for C2C
- Many unknown factors
- Not enough C2C building materials
- Focus on initial investment
- Traditional solutions in C2C projects
- The C2C concept is new
- Traditional government
- Advantages not visible
- Traditional partnership contracts
- 100 % C2C is not yet possible
- Less value to C2C projects

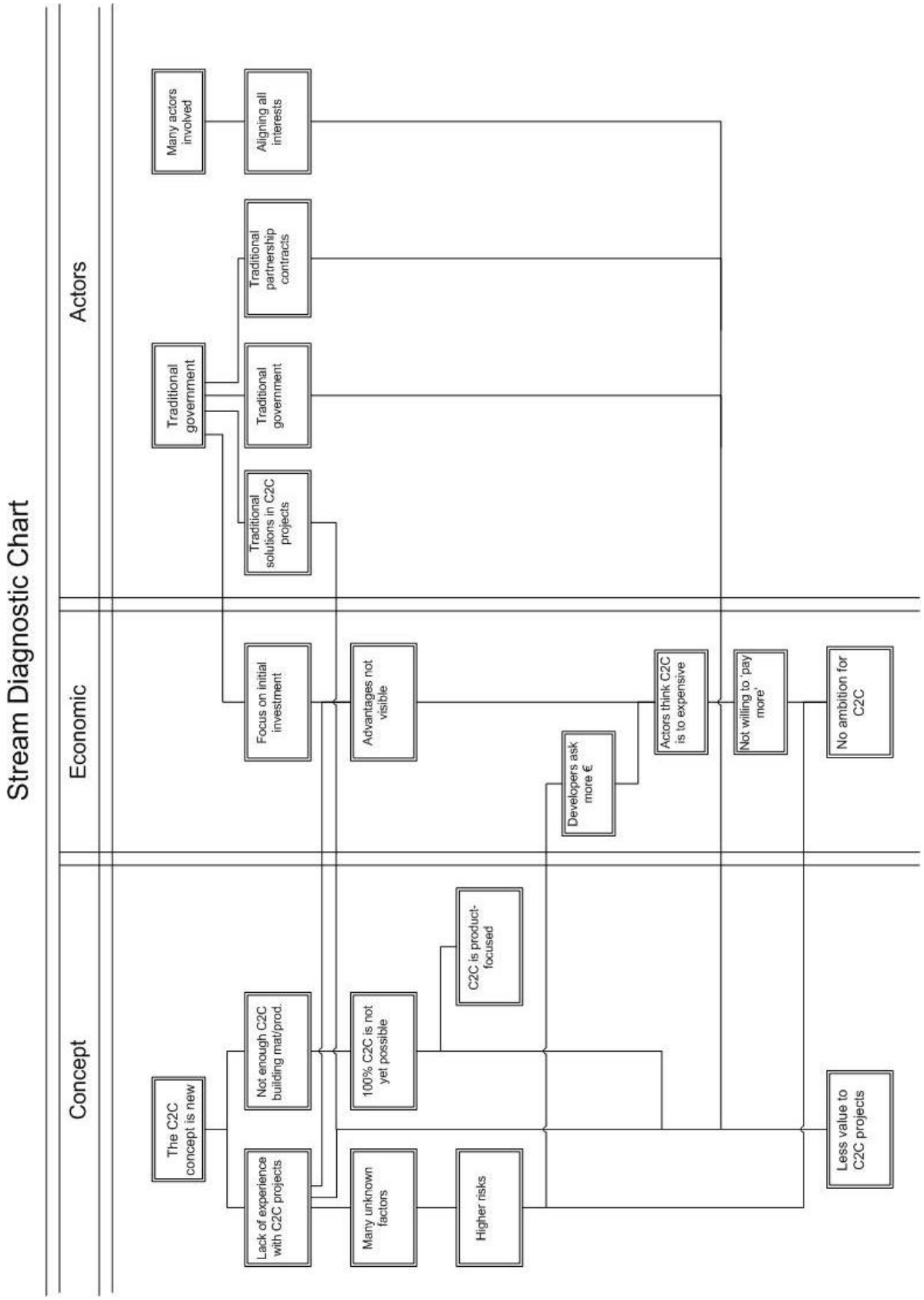

Figure 1: *The Porras stream diagnostic chart*

PROBLEM ANALYSIS

Interviews are used for analyzing the problems which come with putting C2C into practice. With the method of Porras (1987) the problems are categorized and the primary and most important problems are found. The Porras method will lead to a stream diagnostic chart, showing in figure 1. In this chart the core problems and the problem relations can be tracked.
The Porras method is build up in several steps, these steps will be used to find the core problems. According to the Porras method the steps are:

1. Collecting data
2. Categorizing Problems
3. Identifying interconnections
4. Analyzing the problem chart

The problems can be categorized into three groups: problems related to the C2C concept, economical factors within a C2C project and problems related to how the actors in a C2C project think and act. The core problems within these groups are the problems which cause every other problem in a direct or indirect way. Three core problems have been found:

1. The C2C concept is new
2. A traditional way of thinking
3. Many actors involved in C2C processes

When literature and practice are compared with each other a few conclusions can be made. Literature and practice both state that a 100% C2C situation is not (yet) possible. In the literature can be found that there are not enough materials available to build C2C. Literature and practical research conflicts on the aspect of certification. Literature states that a C2C certification is necessary. Practice analysis shows that there is actually no need for C2C certification. Finally the C2C concept should not be taken literally, since this is not yet possible in the current industry.

DESIGNING THE MODEL

As an answer to the problems given in this paper a solution can be developed: a model. To develop a model which offers a solution, the model has to be developed for a specific problem. This model focuses on the core problem ‘The C2C concept is new’ and within that core problem there is a sub focus on ‘Lack of experience’. The model will give project developers more experience and understanding of how to develop a C2C working landscape.

Content of the model

Based on the information that is obtained in the literature and problem analysis a model is developed that can help C2C developers or consultants with their C2C projects. The literature study leads to a thought which finally forms the base for the model. When a model is used to review the energetic quality of a C2C project it is important that the energetic definition of C2C project is clear. As seen in the theoretical chapter of this research the energetic C2C definition is: “when a project is energy neutral or supplying” it is C2C from an energetic point of view. The model needs to be able to calculate the energy demand of several buildings from the available date and must give an understanding of what can be done to minimize this demand.
The problem analysis focuses the model on a specific problem. It is necessary that the model can be used in several ways:

- The output of the model gives understanding of developing a C2C project. The model gives recommendations what to do or what not to do.
- A trial and error method will give the users understanding of what goes wrong when and what the consequences are of a wrong choice early in the process.
- The model tests a specific input and judges if the situation is a C2C situation.
- The model gives recommendations what to do when a C2C situation cannot be achieved for a specific project.

Choice of the instrument

The model is developed for C2C project developers and their consultants. The model is developed within the range of their knowledge. The model can be used in the planning phase of a C2C project, so the actors must be able to use the model with the project-information which is available in that phase. It is also important that the model can be used by only one person, so it does not requires more persons to operate it. Within these requirements the research concludes that the only instrument which is applicable is a computer tool. In a computer tool it is easy and clear to use a lot of variables and numbers.

A "Seven steps model to a C2C working landscape"

The considered working landscape has four functions: houses, offices, industry and greenhouses. In the literature chapter of this paper the New Step Strategy is (NSS) explained. Step 3b (let waste be food) of the New Step Strategy (NSS) is not included in the model because this step refers to materialistic subjects. Step 3a (fill remaining demand in a sustainable way) refers to energy and is included in the model. The model must have an input part where the project demands can be selected and an output part where the calculations and recommendations are given. In the input part demands must be included which refer to the subjects named in the sustainable way. There are a number of demands which can have an influence on the project outcome. The demands payback time (sustainable techniques), project environment, division within the project and the energetic C2C project goal have a big influence on the project outcome and are included in the model. With all data given above the steps of the model are developed. The steps given below summarize the total concept of the model and show the input part of the model. The model is based on the seven step plan which is derived for the NSS of the research of Van Den Dobbelsteen and Van Der Grinten (2008) the model is called a "Seven step model to a C2C working landscape".

1. Select a good area for the development of a working landscape.
2. How large is the area and what is the division of the functions?
3. Select a variant per function.
4. Select the project goal.
5. Select the payback time of the sustainable techniques.
6. Select if energy-exchange is applied in the project.
7. Fill in the remaining energy demand.

The model is set up in Excel. In total the model has 11 sheets of those 11 sheets the first three are most important; they represent the part 1-3 as given above. To fully explain the use of the model a manual is set up which guides the user through the model. The model is a product of a totally different view on urban development. Normally area's are developed and the energetic aspects are a result of choices made early in the building process. Within this view the project choices are made based on an energetic view on urban development. The energetic point of view is the starting point for urban development.

VALIDATION OF THE MODEL

The developed "Seven step model to a C2C working landscape" is tested and validated in this Paragraph. The model is validated on user experiences and an internal validation is done with a test case. If the test case works, the model is proven to be correct and useful in practice.
In cooperation with the company DGMR this area has been chosen and the division of the function has been made. The division of the functions is as follows; 5,28ha is the surface for the function of greenhouses. 16,65ha is the surface of houses and the surface for the functions industry and office is 13,92ha. In the selected area's 500 houses, 50.000m2 greenhouse, 41000m2 industry and 75.000m2 offices are developed.

The selected test case is a fictitious development of a working landscape. The location of a project is very important because it can have an influence on how the energy is generated sustainably. For doing a test run of the model three tests are regarded:
1. A test where the goal is 0%
2. A test where the goal is 50%
3. A test where the goal is 100%

The three goals are selected and will give a different output of the model. The other input stays the same. By comparing the output of these three tests this will give an internal validation if the output of the different tests can be justified.

For the three tests the following input is used, which is the same for each test only the project goal is different each time:
- The number and surfaces of the functions that are being developed are given above.
- Variant 3 is used for all functions.
- The selected pay-back time "8-20 years".
- Energy exchange is used.

For the quick scan the following data/assumptions are used:
- According the manual, geothermic heat generation cannot be used.
- Heat/cold storage is applicable.
- Bio-wkk is applicable
- The project developer does not want a Pv field.
- Large wind turbines cannot be used, because there are problems with the licenses.
- Solar collectors are applicable.
- Pv panels are applicable.
- Wind turbines on building level can be used.

Results of the test case
When 0% C2C is selected for the project goal a traditional working landscape is developed where all energy demand is generated with energy form the public gas or electric net.
Because the goal is to reduce 0%, the goals will always be achieved. The model gives an understanding of the energy demand of the functions.
If the goal is to make the working landscape for 50% C2C it can be seen in the model can be seen that the goal is already achieved after step 1-6. The model shows that direct heat exchange does not contribute much to achieve the goal about 1/10. Heat exchange in combination with a heat/cold storage system does contribute a lot. This combination is enough to achieve the project goal.
100% C2C is a lot harder to achieve. The model shows that after using heat exchange with a heat/cold storage system that the energy demand is reduced with approximately 50%. When

this output is compared with the test before, the model calculates the same output of step 1-6 independent of the goal. This is right according the practice situation because the amount of energy is not related to the selected goal but related to the number of functions.

The model shows in step 7 that there are 4 sustainable techniques available to generate the remaining energy demand: these are heat/cold storage system (already used to lower the demand in step); bio wkk; solar collectors; pv panels.

The models used the bio wkk because it has the shortest payback time. The model also shows how much energy bio wkk must deliver. This amount of energy shows how big the installation needs to be and if this is applicable in the working landscape. DGMR has reviewed the model and had several remarks on the user friendliness of the model and the accompanying manual.

CONCLUSION & DISCUSSION

As new emerging trend, Cradle To Cradle leads to Changing Roles in Building and Construction: In lack of a programmatic brief with performance requirements in Clients and (local) Governments points of view, the vague C2C Philosophy has to be implemented and specified by Designers, Engineers and Consultants.
The described model takes away the problem and the consequences of the problem: 'lack of experience with C2C'.
The steps of the model are translated into a digital tool. The importance of the model is that the approach for urban development is totally different than normally. The model considers the energetic approach as a starting point for urban development. The model is an indication whether or not the usage of the C2C concept with the energetic view is realistic on a new to develop urban area.

From the research 20 problems are found. Through the Porras method these problems can be divided into three groups: conceptual problems, economical problems and actor problems. Within these groups there is a hierarchical distinction in the importance of the problems. The core problems are:

1. The C2C concept is new
2. A traditional way of thinking
3. Many actors involved in C2C processes

The research focuses on energetic processes in working landscapes. Within this focus part of core problem 1 can be solved. By offering an understanding of the energetic processes within C2C working landscapes actors gain insight and can develop a C2C working landscape. Within the energetic C2C definition of this research it is possible to realize a 100% C2C situation.
To realize a 100% C2C energetic situation in a working landscape a concept must be used which is based on eco-effectivity and the principles of C2C. The New Step Strategy of Van Den Dobbelsteen and Van der Grinten (2008) satisfy to these demands.
The validation shows that the model works and choices can be justified. From the test case and user experiences some points of improvement are found:

- The number of sustainable techniques must be related to the number of buildings. This can influence the output.
- Step 5 and 6 of the "Seven steps model to a C2C working landscape" must be switched.

Future research

From this research some recommendations for future studies arise. The main recommendation is to expand the model. Examples of limitations because of the given time period: the model considers only 4 functions; the model considers only 8 sustainable techniques; the model considers only the payback times of the techniques and not the costs of the constructional measures in the variants.

Also recommended is further testing of the developed model to reach a higher quality. The model has been validated by a single company. Although it is hard to find people who can validate such models, it would give a broader validation if more companies tested the model.

Form the three core problems this research solve only core problem one: 'the novelty of the C2C concept'. So, two other core problems to go: 'the traditional way of thinking' and 'many actors involved in C2C processes'. Therefore, future research is needed!

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