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Cradle-to-Cradle in Building Services

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Abstract. While the concept of Cradle to Cradle (C2C) is reasonably covered in building construction and finishes, it is rather 'uncharted area' in the building services – MEP engineers struggle to define what a C2C design for their discipline could look like, and only a few manufacturers have ventured into offering C2C-certified or -inspired products. The authors set out to change this by providing a comprehensive guidance for MEP engineers on how to design a C2C building in their discipline; they cover design criteria, system selection, system sizing, design for de-construction, and material / product selection for all of the main MEP disciplines (water and drainage, heating, cooling, ventilation, electrical installations, IT & data, vertical transport, fire protection, controls). In addition, the document sets out a number of criteria by which the 'C2C aptness' of a design can be measured, providing minimum criteria and a specific 'C2C vision' for each discipline; these criteria could form the basis for a future assessment tool for C2C buildings.

Keywords: C2C, guideline, criteria, MEP, building services

1. Introduction

The construction sector is a resource-intensive industry, with a significant effect on the environment [1] – apart from taking up land and impacting on ecosystems, buildings use materials that are not safe for humans and the environment, consume significant amounts of energy in construction and use, and are usually not being built in a way that allows recycling their components.

To provide some context, in Germany, approx. 60% of the total amount of waste by weight originates from the building industry [2]; most of it ends up in landfills. When it comes to embodied energy, building services account for 7 to 15% of the total embodied energy of buildings [3]; the impact will be significantly higher over the lifetime of a building, as buildings services have a shorter lifecycle than the building structure [4] and will be replaced where other elements remain.

Building services also have a significant contribution to energy use (36 % of the final energy consumption in Germany [5]), water pollution, and air quality over the entire life cycle of the building; in these areas, building services will have the highest impact of all building components.

An often-discussed solution is to apply the “Cradle to Cradle” (C2C) design concept to buildings [6]. Its principles are reasonably well-understood and researched for building structures and finishes, where guidelines and C2C-certified products exist, but little is available in the area of building services.

To address this, the authors set out to analyse the effect of C2C thinking on building services, and translated the results into a first attempt of a design guideline for C2C-inspired design for the corresponding systems. This paper is a (condensed) summary of the resulting guidance document for Cradle-to-Cradle inspired design in Building Services; it provides an overview of the approach taken to develop the guidance, and describes the criteria (“ultimate vision”, “minimum criteria”, “no-go criteria”) proposed for each discipline, as well as the main findings of a market research and evaluation of available products and materials.

2. Objectives and methodology

2.1. Objectives

The objectives of the research were to identify how the design of building services had to be adapted to comply with the C2C concept, and to define criteria the engineers could use in the design process; at the same time, engineers should be provided with sufficient information to be able to carry out a ‘C2C-inspired’ design.

2.2. Methodology

To establish criteria, the team started by defining an “ultimate vision” for implementing C2C in each of the building services disciplines; based on the “criteria for the built environment” for Cradle to Cradle formulated by Mulhall and Braungart [7], the main criteria were:

- Improving air quality
- Improving water quality
- Using renewable energy
- Producing biomass / nutrients
- Improving wellbeing of users
- Avoiding banned materials & ensuring materials can enter techno- or biosphere after use

It soon became apparent that the “ultimate vision” could not be used as a guidance for a ‘real-life’ design, as the requirements were too onerous for most commercial developments, and in some cases the requirements in one discipline would contradict those of others; to address this, the team added “minimum criteria” and “no-go criteria” to provide ‘stretch targets’ that would require some efforts over and above normal design standards, but would still be achievable in a commercial project.

For each discipline, the main systems were then evaluated to assess their feasibility for meeting the minimum and ‘no-go’ C2C criteria for the corresponding discipline.

For the evaluation of the main products and materials used in the construction of each discipline, materials were evaluated for containing banned materials and for their recyclability; products were evaluated for materials they contained and for de-constructability, and a market research was carried out to identify certified products. Again, this was carried out discipline by discipline, covering all systems that had been identified in the first step.

The completed guideline was then peer-reviewed for usability, applicability, and completeness by engineers of the various disciplines, as well as materials specialists.

3. Approach – structure of the guideline

The guideline starts by giving a general introduction to the C2C principle; it is assumed that readers are experienced Building Services Designers, but not necessarily familiar with the Cradle-to-Cradle concept.

The guideline itself is then structured into chapters for each of the main Building Services disciplines; this reflects the reality of Building Services design, which is delivered by specialists for the different disciplines (ie HVAC engineer, electrical engineer, PH engineer, etc.).

The chapters are

- Water and waste water
- Gasses and fuels
- Heating
- Ventilation
- Cooling
- Electrical installations
- Data and ELV installations
- Vertical transport
- Specialist systems (eg fire protection, kitchens, swimming pools)
- Building Management Systems (BMS)

Each chapter is made up of a section on

- Aims and evaluation criteria
- Design criteria and boundary conditions
- System selection
- System sizing
- Material selection
- Construction methods

This reflects the design stages that a building services design would typically follow; in each section, the guideline indicates what the engineers need to consider and would want to know at the corresponding stage. In addition, chapters on materials and construction were included at the end of the document, to explain the corresponding principles applied in the individual chapters.

4. Proposed C2C evaluation criteria

The following chapters describe the proposed criteria for the main disciplines (water and waste water, gasses and fuels, heating, ventilation, electrical installations). The remaining disciplines do not have own criteria, but rather depend on other disciplines to supply them with electrical energy and have to comply with requirements regarding material use; they are covered in the full guideline, but could not be covered here due to restrictions to the length of the text.

4.1. Water and waste water

For water and waste water, the "ultimate vision" would be to be water- and nutrient-positive, ie improving the water quality on the site, including the water supplied to the site; figure 1 indicates which material streams need to be considered in this evaluation.

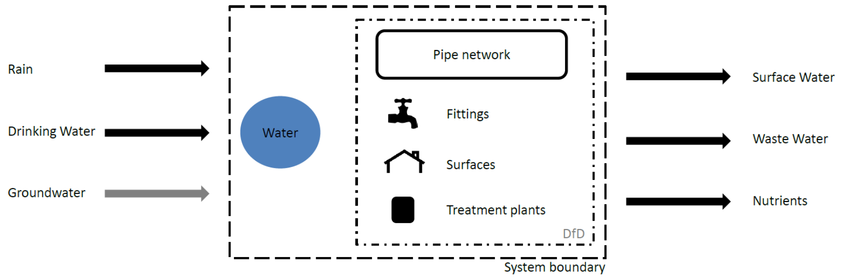

Figure 1. Overview of water and waste water streams in a building

In most cases it will be unrealistic to meet these criteria, as technology is not readily available, and the generated nutrients cannot be used; as minimum C2C criteria the team established

- establishing a water balance for the water entering and leaving the site (incl. precipitation)
- providing water treatment for water leaving the building
- providing means for water metering
- providing means for measuring waste water quality

In addition, a No-Go criterion of water pollution was established, with an indication of limits for harmful materials that could typically be found in a building environment.

The following steps were identified as a possible route towards a ‘C2C building’:

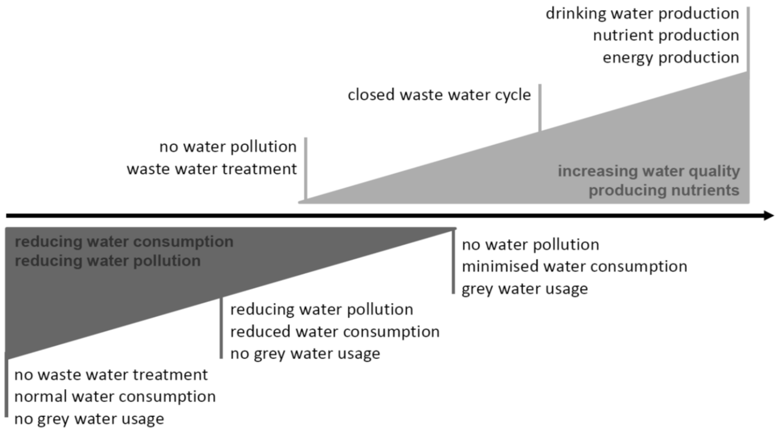

Figure 2. Roadmap for water and waste water

4.2. Gasses and fuels

For gasses and fuels, the “ultimate vision” would be to only use fuels produced on site, and converting them into usable energy without hot combustion; figure 3 indicates which material streams and energy flows need to be considered in this evaluation.

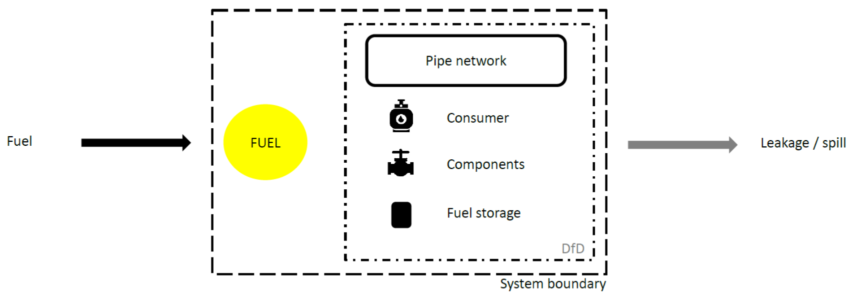

Figure 3. Overview of gas and fuel streams in a building

In most cases it will be unrealistic to meet these criteria, as the use of most buildings will not allow producing sufficient fuels to provide for the building’s corresponding energy use, and technology has not advanced enough to completely avoid hot combustion in a commercially viable way; as minimum criterion the team established

- Providing exhaust gas filtration to avoid air pollution

In addition, a No-Go criterion of usage of fossil fuels or fuels from 'energy crops' (ie only planted to generate fuels) was established, with an indication of which fuels could be used and which not.

The following steps were identified as a possible route towards a 'C2C building':

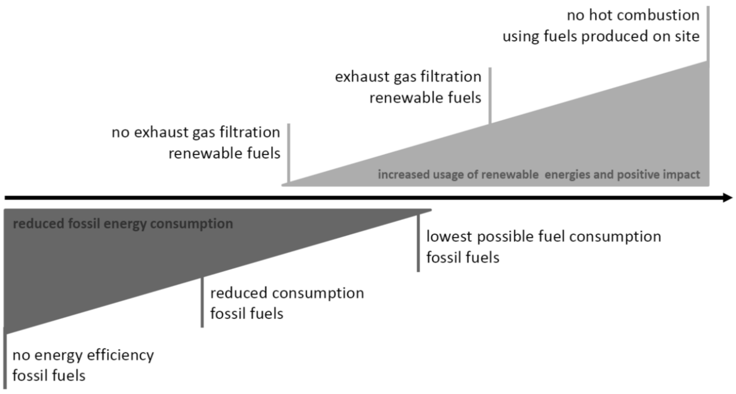

Figure 4. Roadmap for gasses and fuels

4.3. Ventilation

For ventilation, the "ultimate vision" would be for the building to have a positive effect on the air quality both outside (= generate oxygen) and inside (= provide indoor air conditions that contribute positively to the occupants' health) of the building's envelope; figure 7 indicates the air transfers that need to be considered in this evaluation, as well as some measures and criteria.

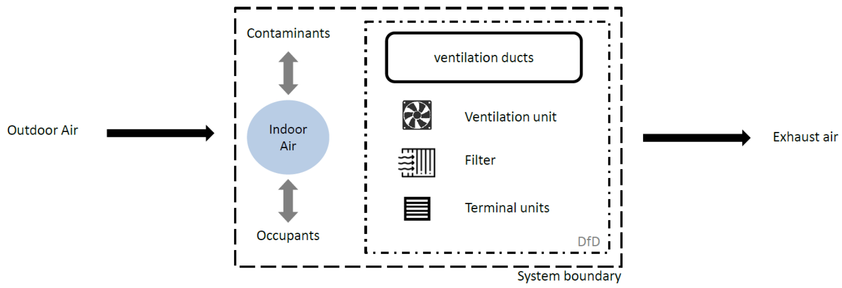

Figure 7. Overview of air transfers in a building

In most cases it will be unrealistic to meet the above criteria, as the generation of oxygen would depend on greening the building – which is not within the MEP engineer's scope – and it cannot even be quantified which indoor air conditions would contribute positively to the occupants' health (this would be a result of the combination of many factors); as minimum C2C criteria the team established

- healthy indoor air (measurement of indoor air quality during operation)
- neutral exhaust air (measurement of outdoor air quality before construction, measurement of exhaust air quality during operation)

In addition, two No-Go criteria, 1. harmful exhaust air and 2. unhealthy indoor air were established, with an indication of conditions for both.

The following steps were identified as a possible route towards a 'C2C building':

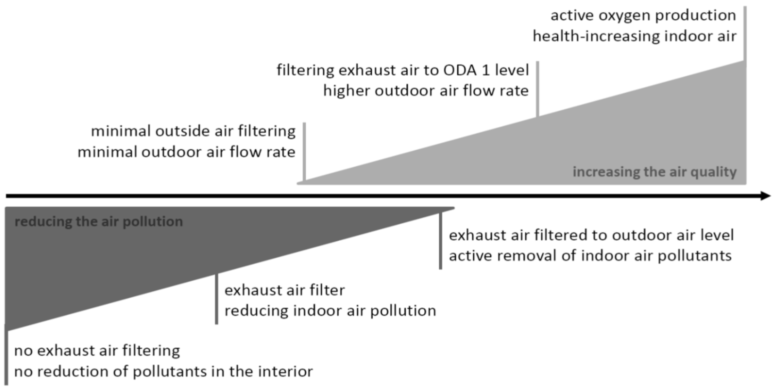

Figure 8. Roadmap for ventilation

4.4. Energy

For Energy (electrical and heat), the "ultimate vision" would be to be 'energy-positive', ie producing more energy from renewable sources over the course of a year than the building requires; figure 9 indicates which consumers of energy need to be considered in this evaluation in the case of electrical energy.

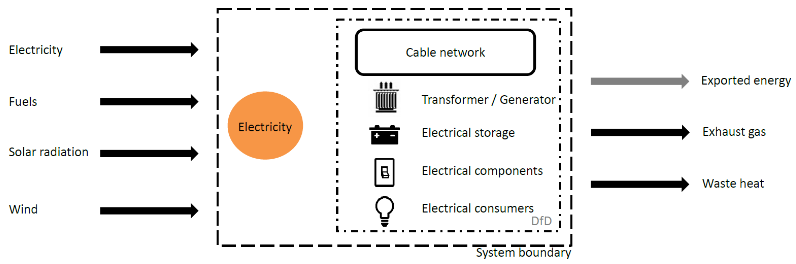

Figure 9. Overview of electrical energy consumers and sources in a building

In most cases it will be unrealistic to meet the above criteria, as the use and space availability of most buildings will not allow generating sufficient energy to provide for the building's corresponding energy use; as minimum C2C criteria the team established

- own renewable energy generation (without setting a minimum coverage).

In addition, a No-Go criterion of using energy generated from fossil sources or fuels from energy plants was established, with an indication of which energy sources could be used and which not.

The following steps were identified as a possible route towards a 'C2C building':

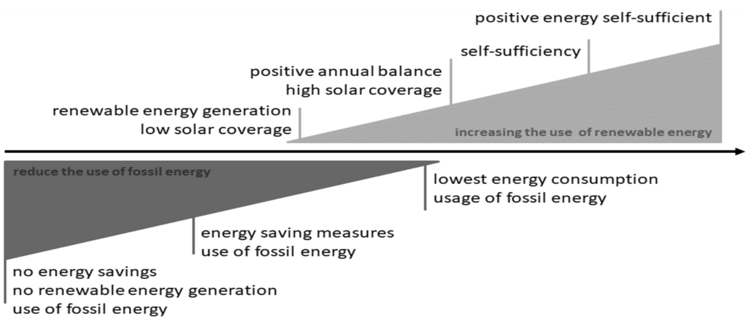

Figure 10. Roadmap for energy systems

4.5. Materials and construction

For each discipline, a generic criterion of using C2C-compliant materials and construction methods was set; each chapter then provides an evaluation of typically used materials and components, as well as construction methods.

5. Main findings

The research was not so much carried out to answer a single question, but to provide guidance on what a 'C2C design' for Building Services should look like; the findings are included in the full guideline. However, the team took away the following thoughts from its work:

- C2C design is not equivalent to applying the principles of sustainability certifications – in some areas the focus is quite different, and will lead to different results.
- It does not require a dramatic change in approach in building services design to comply with the C2C concept; a main factor is awareness of the criteria and their application to system and material choices.
- Manufacturers are currently not very active in the field of C2C (or even aware of the issues); there are not many C2C-certified or -inspired products for building services.
- Some areas (eg painting / coating of metal surfaces, components of healthy indoor air, new refrigerants, impact of plants, material / system passes) warrant further investigation.

6. Discussion and conclusions

With their work, the authors would like to contribute to a more widespread adoption of C2C principles for building services. The guideline can play an important role in this process, as it overcomes some of the obstacles by providing design criteria and evaluating system and material choices.

To really achieve this objective, the guideline has to be brought to the attention of and made available to designers and engineers in the sector. The authors started by sharing it with engineers across the globe within their firm, and presenting it at industry events; feedback was that the guide is ready to use and a good base for a C2C-inspired design. A publication via the author's firm's website (www.arup.com) is being considered, which would make the publication available to a much wider audience.

An important factor will be the adoption of C2C principles by manufacturers of the components of building services. An application of the guideline in the building design could provide some 'market pressure', ie when designers enquire with manufacturers about material use and product certifications; it is hoped that this will lead to further C2C-certified products becoming available.

A further factor is the acceptance of and demand for C2C-inspired buildings in the market. Following C2C principles will have an impact on the user experience of a building; depending on the approach taken, C2C-inspired buildings can also cost more than traditional buildings – although current research by an Arup team in the UK showed that this does not necessarily have to be the case.

To be able to deliver a C2C-inspired building, the whole project team – from investors and developers over designers and engineers to contractors – must buy into and apply the principle. While designers and engineers are interested in applying the principle and now have some guidance available, and some developers see the concept as a possible differentiator, investors yet need to be convinced of the benefits.

A next step would therefore have to be to investigate how a C2C-inspired design increases the value of a building, be it in lettability / rent, or in market price; contact has been sought to real estate agents and investors to obtain first feedback on this issue, but is hampered by the relatively small number of completed buildings – currently it is rather based on 'informed guesses'.

Potentially, the positioning in the market could be helped by linking C2C principles with well-established sustainability rating systems like LEED, BREEAM or DGNB; the criteria established in this paper could form a basis for the corresponding rating. The team also saw a potential to link WELL certifications to the benefits of C2C-inspired buildings on health and productivity of the building users.

It should be noted that the guideline is still considered ‘work in progress’ – some points will still have to be researched further to give a full picture of all possible applications for a C2C-inspired design of building services. Feedback on the evaluation criteria, as well as findings from further research, would be appreciated.

7. References

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