Design for Disassembly - a way to minimize building waste
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research part I
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MSc thesis Delft University of Technology

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Design for Disassembly - a way to minimize building waste

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Preface

Before you lies the research report on the topic of ‘design for disassembly’, focusing on how to minimize building waste in building design.

This research is part of a cross-disciplinary research for obtaining a degree in ‘Architecture, Urbanism and Building Sciences’ at the Faculty of Architecture and ‘Construction, Management and Engineering’ (CME) at the Faculty of Civil Engineering and Geosciences.

This research report has been written to fulfill the requirements of the MSc ‘Architecture, Urbanism, and Building Sciences’ program. This research has been conducted in the Explore Lab studio under supervision of Hielkje Zijlstra and Roel van de Pas. I have worked on this report from February to June of 2018.

Ditte Gerding,
June 2018
Fig. 1. A traditional Dutch landscape as an example of a waste-free material system? Painting by Paul Joseph Constantin Gabriël called ‘Een molen bij de poldervaart bij Abcoude’ (1888) and modified by author.
Since the industrial revolution production and consumption rates have accelerated. The invention of mechanical production has facilitated mass production. Consumers were supplied with more and better goods and have demanded so subsequently. The production and consumption process is aimed towards gaining ‘more, more, and more’. To facilitate this ‘need’, the extraction of raw materials has increased.

From the 1960s already, warnings have been sounded, by for example the Club of Rome and by Rachel Carson in her book *Silent Spring*, to create awareness of the consequences of human activity to the environment.\textsuperscript{1,2} The increased production and consumption rates put a burden on the environment. The current extraction rates of resources will lead to depletion. The consequences of this unsustainable resource extraction and material use are omnipresent, these cause deforestation, mining deconstruction, and increased CO\textsubscript{2} emissions. These emissions affect the living quality of the environment – in terms of contamination of the biosphere, soil and ocean pollution, and loss of species diversity. The need for a different way of dealing with materials and resources is evident.

Strangely, besides these increased production and consumption levels, the way we deal with products and materials also detrments depletion. Products
“take, make, waste”

Leonard, Annie. (2010), The Story of Stuff: The Impact of Overconsumption on the Planet, Our Communities, and Our Health—And How We Can Make It Better, Free Press, New York City, USA

Fig. 2. A bunch of waste in a landfill
and materials are dealt with in a linear way. After its ‘useful’ life time the product or material is regarded as waste. Even more, products are designed to be thrown away. After the useful life time oftentimes reuse or recycling is difficult. Waste landfills are growing. And on top of that, even if the waste is being processed, the amount of waste produced during this step is significant.

The building sector is responsible for a large share of the total waste production in the Netherlands. This is partly due to the organization of the building process, which follows a principle of constant production and consumption of (raw) materials. The linear production of buildings entails the stages of design, construction, consumption and demolition. This process opts for constant utilization of raw materials, since a building is not designed to be reusable. In the Netherlands, at the end of a building’s lifetime, only a small amount of the building materials and parts are reclaimed, a large amount is regarded as waste.

Currently, the design of buildings does not take into account the possibility to take them apart. At the end of a building life it is extremely difficult to reuse or recycle materials. The current pressing scarcity of resources and polluting influence of waste, requires a more circular building approach to support the need for sustainable building.

The past years, circularity has become a popular term in the built environment. Several ways to reshape the linearity of the building process towards a more circular process have been invented and applied in successful or less successful ways. Some approaches have focused on cutting down production and consumption rates. Other approaches have focused on building with waste. But why not try to prevent waste in the first place? So that building with waste is not necessary. Instead of reducing or reusing waste, why not create less waste?

Currently, reuse of building materials and parts is mainly an afterwards activity and requires innovative design thinking. The change towards a circular building process requires a different way of thinking. This study focusses on minimizing or (even more) preventing waste by designing buildings and building parts in such a way that, after used, it can easily be disassembled and reused. Thereby, the concept of waste would need to be redefined, since the waste created from these kind of buildings is no longer useless. The concept ‘design for disassembly’ aims to support this different way of thinking, and intends to anticipate the reuse of building materials and parts from the start on in the building process – from the design stage onwards. The building is perceived as something temporary, design for disassembly
intends to build for change. Thereby, the benefits of design for disassembly
are: reduction of waste, reduction of energy consumption and reduction of
resource consumption (in the material extraction, processing, manufacturing,
assembly, and demolition phase)\(^5\).

Although a lot of initiatives, databases and projects have arisen which focus
on design for disassembly, proper execution of the concept has mainly been
restricted to industrial products and product design – for example, the car
industry. The implementation of the concept in the built environment, and
specifically in building design, could be improved. Design guidance could
help to facilitate this implementation.

In relation to this problem, the objective of this thesis is to demonstrate how
the concept of ‘design for disassembly’ can be applied today. Its relevance is
to provide design guidance, based on certain aspects, on how to implement
design for disassembly. Therefore, the following research question is posed:

“How can design for disassembly successfully be implemented in the building design in order
to minimize waste at the ‘end of life’?”

In order to answer this question, some concepts need to be defined. It is
important: to define ‘design for disassembly’, to define when it is implemented
‘successfully’, to define ‘building design’, to define ‘waste’, and to define ‘end
of life’. Therefore, the following sub questions are posed to define these
concepts and thereby answer the main question. These sub questions are:

“What is a workable definition of the concept ‘design for disassembly’?”;

“What is the position of design for disassembly within the architecture discourse?”;

“What aspects should a design for disassembly building implement?”;

“To what extent have preceding buildings been able to implement design for disassembly?”;

This thesis will proceed as follows. The first chapter presents a theoretical
frame to position design for disassembly within the architectural discourse.
This is based on a literature study. The second chapter provides a workable
definition of design for disassembly and addresses important aspects that
building projects should implement or take into account. After this theory
building, three projects, based on a selection of projects, that have aimed to
implement design for disassembly (to a certain extent) are analyzed. Before
this analysis starts, the method for this case study research is presented. These
projects will be analyzed on the basis of predetermined criteria, besides by use
of interviews the vision of the architect is taken into account. This analysis
of preceding projects will provide the basis for design guidance that will help
to implement design for disassembly in the design phase even better today.

Fig. 4. Waste production in the Netherlands, extracted from Rijkswaterstaat Leefomgeving, (2017). Vrijkomen en verwerking uit de doelgroep Bouw, 1990-2014

Fig. 5. Waste production per sector in the Netherlands, extracted from Rijkswaterstaat Leefomgeving, (2017). Vrijkomen en verwerking uit de doelgroep Bouw, 1990-2014
Fig. 6. The treadmill of production: mutual economic striving keeps us always struggling to increase production, often with little regard for social and environmental consequences. Extracted from Bell, M. (2012). An Invitation to Environmental Sociology. London: Pine Forge Press, p. 71.
This thesis is part of the graduation process for the master ‘Architecture, Urbanism, and Building Sciences’ at the Faculty of Architecture and will provide input for the other part of the graduation process; the design. Additionally, follow-up research will be done into this topic from a more construction management perspective, as part of the graduation for the master ‘Construction, Management, and Engineering’ (CME) at the Faculty of Civil Engineering and Geosciences.
“But because we don’t design buildings to be taken apart, they usually face the wrecking ball method of demolition, which makes it extremely difficult to reclaim or recycle materials.”

Notes


Theoretical frame

This chapter describes the position of ‘design for disassembly’ in the architectural discourse. Therefore, architectural-historical context is provided. This includes a description of examples of historical temporal and movable buildings (such as the tipi), futuristic adaptable buildings (such as the Walkable city by Archigram), flexible buildings, industrial buildings, and the current relevant circular buildings. These examples are addressed in regards to their relation with design for disassembly. The aim of this chapter is to provide context for this concept and embed it into the architectural discourse. This chapter answers the sub question:

“What is the position of design for disassembly within the architectural discourse?”

As already discussed in the introduction, the follow-up of this research (the design) incorporates the perspective of design for disassembly by aiming to minimize waste at the ending of a building’s life time. The examples, concepts, and developments discussed below will be perceived with this basic thought in mind.
First steps in disassembly
Since the past decades, the term ‘design for disassembly’ has been in use according to its current meaning in relation to sustainability. Generally, ‘design for disassembly’ is defined as a strategy or management approach to deal with construction waste. Instead of demolishing a building, disassembly is provided as a better option to deal sustainably with materials and waste. Nevertheless, in the past the term design for disassembly has already been applied. As argued by Crowther, the term design for disassembly was applied to buildings that incorporated the possibility to be disassembled in order to be moved or transported to another location. An example of this kind of building is the American tipi. This vernacular temporary house offered the possibility for quick and easy disassembly. The use of lightweight materials supported easy transportation of the structure. The tipi could be rebuild on another location (fig. 1). Other examples of these kind of houses; a temporary, lightweight and dismantlable tent structure; are the Northern African tent and Central Asian yurt. The contemporary variant of this type is the tent used for recreational purposes at camp sites.

Later, a more advanced example of a dismantlable building is the Nissen Hut, which functioned as a temporary building in military situations where movability (i.e. transportation) is crucial. Another example which is discussed by Crowther in this context, is the colonial cottage by John Manning (this is a closed system). This cottage suited oversea transportation to serve the colonial housing demands in the oversee areas. It must be noted that these examples are all a form of a closed building system. In contrast to an open building system, which has a flexible layout that can be adjusted according to the user’s needs. This building type will be elaborated on later in this chapter.

Although these examples can be considered as forerunners of the current approach to design for disassembly, it is important to be aware of the differences in nature of these buildings. These early examples are all designed to be able to be rebuilt somewhere else. So the design is location independent. In these cases disassembly is considered as a reversed building process; after disassembly the project can be rebuilt elsewhere. So, its objective is not to minimize waste, since the design itself is considered permanent to some extent; it can be transported to different locations but will remain the same. It is not considered as a possibility to reconfigure the building parts or divide them over different locations and new projects. Anyhow, the design is still perishable, and will within a certain amount of time be outdated, resulting in non-usefulness, or obsolescence.
Fig. 1. Traditional yurt from Central Asia (top), colonial cottage by John Manning circa 1833 (middle), traditional tipi from Northern America (bottom).
Fig. 2. Conventional building process depicting the steps after disassembly, this mainly results in demolition.
Relation with site

If a building is considered obsolete, or useless, this is usually followed by (partial) demolition. Valuable materials and parts are extracted and the remaining parts face the wrecking ball or shredder. The remaining rubble is dumped into the ground or in a landfill. Otherwise it is combusted or degraded to asphalt. See fig. 2.

According to Crowther, five types of obsolescence can be distinguished, these are: locational, functional, technical, physical, and fashionable obsolescence. The previous discussed examples – Tipi, Nissen Hut, and colonial cottage – are all projects that could help to overcome locational obsolescence. Locational obsolescence occurs when a building’s function is not required (anymore) at its current location. Functional obsolescence happens when the function for which the building can be used is no longer needed. Technical obsolescence arises when the building cannot fulfil certain structural or service related performances. In the case of declination of the structure, the building is considered physical obsolete. And lastly, fashionable obsolescence occurs when a building does not fit current trends and taste of style.

Usually, a building is considered useless or obsolete due to a combination of these types of obsolescence. All of these five forms result in demolition, and subsequently generate waste. Remarkably, these types have in common that they all dependent (somewhat) on human or social preferences. For instance, in case a building is technically still usable, it could be considered (based on human preferences) as unfashionable, and thus outdated.

Past examples that aimed to reduce waste or obsolescence of a building focused on extending its life time by providing possibilities for reuse and replacement of parts to support maintenance. The underlying principle of these buildings is not to design for disassembly, as in to reuse its parts after the building’s useful life time, but to keep the building in good condition and prevent obsolescence by providing the possibility to alter and maintain parts of the building. These examples are aimed at partial disruption of the building by disconnecting parts of the building for replacement or adaptation. Well-known and imaginative examples, as experiments in building systems and replacement, are the Dymaxion House by Buckminster Fuller, the Takara Pavilion at the 1970 Expo in Japan (as an example of Japanese metabolism architecture), and the Walkable City by Archigram (fig. 3). This last example also prevents locational obsolescence. Additionally, the work of Archigram was a critical note on the high ‘disposability content’ of architecture and urban design.
Fig. 3. Buckminster Fuller, Dymaxion House, 1964 (top left), Expo 1970, Japan, Takara Pavilion (top right), the Fun Palace, Cedric Price, 1964 (middle), Walkable City, Archigram, 1964 (bottom right)
Archigram drew inspiration from the work of Cedric Price. The work of Cedric Price questions, the then current, conventions on how a program is translated into a spatial design. This is in particular visible in the Fun Palace design. The Fun Palace was a design for a leisure center, focused on theater and entertainment. Although this building has a predetermined function (a leisure center) the design offered room for adaptations to the function and structure. At that time, it was considered a very unconventional building design. Price did not design a building but rather a framework, that could adapt to different functions.

A neutral or specific building?

The need to design for disassembly, i.e. to reduce waste, is inherently related to the function of a building. Often, the (pre-)determined function of a building leads to certain spatial requirements. For instance, requirements in heights, layout, and services. Perhaps this is especially the case in the Netherlands and Germany. These countries have spatial planning procedures that regulate functions of (future) buildings. So during the design phase one has to adhere to this predetermined function and its necessary spatial (and technical) requirements. This is also the case for the life span of a building. This is normally determined to be either 15 or 50 years.

So, the function of the building (or ways in which it can be used) determines its usefulness. This careful predetermination of functions (in the Netherlands and Germany, amongst others) is done to prevent non-/un-usefulness or squandering in the public space to deal efficiently with space. Thereby, wastage of space is minimized. However, this only holds if the specific use for which the space is designed it still up-to-date. Yet, a certain function or its spatial dimensions is subject to change and changes over time.

This dilemma regarding the functionality of a building – with on the one hand predetermining a specific function and on the other hand aiming to extend the life time of a building – poses the question of how to deal with the function in relation to usefulness of a building. With this in mind, architects have aimed to design a building with a neutral function – or put differently a building that can adhere to different functions simultaneously or over time. Thereby, this building type could adapt to change. The building is designed with a certain degree of flexibility in mind.
So we need to design flexible?

It can be argued that designing flexible buildings responds to this need to extend the life time of a building by designing a building in such a way that it is less dependent on one function. A flexible building can respond to changing (functional) needs over time. This line of reasoning approaches a building as an object that can fulfill several functions or provides room to change its function. For example, the Dom-ino system by Le Corbusier is an example of an object that is capable to respond to changes in use (also to benefit mass-production). This object only determines the (load-bearing) structure of a building and makes the precise infill flexible and open to interpretation by the user. The structure is independent from the layout.

Several architects have aimed at designing flexible buildings to extend the life time of a building. In this sense, flexibility is interpreted in different ways. The work of Leupen et al. distinguishes different types of flexibility. In order to deal with time and uncertainty a flexible building could be obtained in three ways: by designing a polyvalent building, a partly permanent and partly temporal building, or a semi-permanent building. According to Hertzberger the idea of polyvalency is “that you can make forms that are in themselves lucid and permanent, but can change in the sense that you can interpret them differently.” In other words, this would result in a neutral, or multipurpose building, a building that can adhere to different functions. In addition, the work states that flexibility could be obtained by means of flexibility in latitude, subdivision, load, services, expansion, or function. These types of flexibility relate to spatial flexibility – expansion of a room or adding a floor, for example thanks to surplus in construction load – or relate to flexibility in services and installations.

One could argue that this shows similarities with the concept of design for disassembly. Design for disassembly also tries to respond to change to prevent demolition and waste. However, it must be noted that the work of Leupen et al. serves a different purpose, which is to extend the life time or usefulness of buildings by means of incorporating flexibility, instead of minimizing waste.

Flexible building usually considers a part of the building to be permanent. In general the permanent part is the structure of the building. This is designed to last for, for instance, 100 years. Within this frame flexibility and temporality is offered. Already a few decades ago, architects made a distinction between a permanent and a more temporal part of the building. The open building principle by John N. Habraken presented a novel way of thinking about the usefulness of a building. In 1961, he published his work *De dragers en de mensen*...
Fig. 4. *Maison Dom-Ino* system, Le Corbusier, 1914 (top). *John N. Habraken* system, the principle of support and infill, 1963 (bottom).
Fig. 5. Konrad Wachsmann, space-frame structure for aircraft hangar, 1953 (top), Frei Otto, German pavilion in Montreal, 1967 (bottom)
(Supports: An Alternative to Mass Housing). Here he proposes a division between structure and form. Its aim was to support the need for mass housing by cheap and fast production realized by means of standardization. While on the other hand providing a comfortable and private dwelling for the user. The main idea was to separate the building into two layers; the support and infill. The support provides the (permanent) structure of the building, while the infill was flexible and temporal and to be arranged and furnished by the user. It must be noted that John N. Habraken had a different system in mind than Le Corbusier’s Maison Dom-ino’s system. The division that Habraken opts for is based on responsibility of and control by: the user, architect, manufacturer, etc.

Interestingly, the work of Konrad Wachsmann, and similarly in the work of Frei Otto, also focuses on the relationship between consumer (user) and producer (architect). The architecture, or actually space structures, designed by Konrad Wachsmann, perceives space as subject to change. The space structures do not have fixed dimensions and can change according to the user’s needs. The architect (only) provides the basic need, which is providing shelter.

This approach requires a distinction in different life times, and subsequently a separation in building parts according to their rate of change. Generally, the support has a (much) longer life time than the infill. This concept of layers of change was defined by Stewart Brand (fig. 6). The work of Brand and his notion on layers of change critically touches upon the notion of buildings as permanent. He argues that a building is subject to changing demands and needs. He studies buildings, or actually the use of buildings, over time, and demonstrates the spatial changes that it experiences to prevent obsolescence. Brand identifies layers to support this state of change. Each layer – site, structure, skin, services, space plan, stuff – comprises of materials or parts with the same speed regarding maintenance and technical life time. This results in a hierarchy of layers based on time. However, this necessity to separate these layers, does not implicate dismantlability of the whole building. The structure of a building, for instance, could be designed to be ‘permanent’, i.e. last for 200 years, whereas the infill can be disassembled and adjusted on in a short time frame. In this respect, Brand considers site as eternal; the site “outlasts generations of ephemeral building”. In this study and in relation to design for disassembly, site is interpreted as independent (and in that sense temporal) from the building is case of proper implementation of design for disassembly.
The work of Superuse also identifies certain layers based on scale. They identify six layers: building, building part, component, element, material, raw materials. The design for disassembly strategy can be aimed at each of these layers. In relation to larger scales, such as building and building part, disassembly can be perceived as modular building; large parts of the building can be disassembled and reused (or recycled) as a whole.

A decade ago the word ‘solid’ has come into being to depict buildings that are not designed with a specific program in mind and therefore open to accommodate different functions. In this sense, the building itself is considered permanent (or monumental), it is preserved over the long term, but also contains a large degree of freedom in term of use. See fig. 6. for an example.

Flexibility, as an approach to extend the useful life time of a building, is a means to reduce waste. Yet, a critical note is required here in relation to design for disassembly. Design for disassembly could be perceived as a means to increase flexibility, in terms of structure and installations. Easy disassembly of building parts, components, and elements, could benefit the value of a building. Since it allows for changes, substitution, and dismantling in the future. This enhances the possibility to respond to changing demands and extend the functional life of a building. However, it must be noted that design for disassembly can also impede flexible use, in terms of flexibility in lay out, of a building. Since, easily dismantlable and highly reusable components could restrict the measurements of spaces that allow for multiple functions or neutrality in use. In general, flexible building design leads to surplus or over-dimensioning of the buildings size and spaces. Since the spaces should be interpretable to multiple functions or types of usage.

Minimizing waste can be done in two ways: by designing the building for disassembly or by prolonging the functional or economic life time of the building. The potential for either of those two can be judged on the basis of the following: by judging the reuse and recycle potential to facilitate disassembly of the building or by determining the type of obsolescence that is prevented by extending the life time (locational, functional, technical, physical, fashionable). Extending the life time generally results in a flexible building. In relation to waste, however, in order to minimize waste that is generated by a building, the building should be useful at all times. Otherwise, demolition is the way to go. Nevertheless, in the ‘end’ the building is considered obsolete. So flexible building does extend the life time, and thereby prevents obsolescence for some time, but in the end waste still occurs. So waste is not minimized, but waste is postponed.
Fig. 6. Steward Brand, layers of change (top), example of a solid, Tony Fretton, Amsterdam the Netherlands. Solid Oud-West, binnenplaats, by Alex Schröder (bottom)
The tension between life time and usefulness of a building is also present in the case of monumental buildings. If a building is determined as a monument, perceptions towards time and value of the building change. Generally, a monumental building is preserved for as long as possible, its lifetime is extended and demolition is prevented at all times. Usually, this also brings along a more conscious consideration towards materials. The used materials are dealt with carefully and renovations or alterations to the building are executed with care. Van Hinte, et al., however, argue that long life time is not an argument for defining a building as sustainable.\textsuperscript{12}

The time factor
As described, generally, a building is considered obsolete after a certain amount of time. The time frame after which a building is considered obsolete differs. A building can last for a specific amount of time before it is considered obsolete. Generally, this amount of time is dependent on the technical (ability of the building and its parts to perform), functional (usefulness of the building’s function and spatial configuration), and economic (feasibility) usefulness of a building. If one of these three expires, the building is obsolete. As argued, flexible building is an approach that aims to extend the economic and functional life time of a building to meets its technical life, and secure usefulness.

Another way to deal with this misfit, is to acknowledge the different life times that a building is subject to. As argued by Klomp, Post & Dullemen the technical and economic life time of a building should be equal to eachother.\textsuperscript{12} Yet, the technical life time of a building is usually much longer than its economic and functional life time. If the technical life time of a building is matched to its (while this life expectancy is even becoming shorter and shorter) economic life time, obsolescence of materials and building parts is prevented. At the end of the economic life time (and technical life time) the materials will either degrade biologically or can easily be dismantled and reused (or recycled).\textsuperscript{12} Thereby, the technical life time is shortened and can be optimized to relate to the economic life time, see fig. 7.

XX architects demonstrated this principle in an office building that houses their agency, the XX office. This building is designed to last for twenty years. The technical life time was adjusted to this period by acknowledging certain design principles. The building materials should, in order of preference, after 20 years degradable biologically or be developed into raw materials, be easily reusable without modifications, be easy reusable with slight modifications, or
Fig. 7. Life time optimization of a building based on work of Klomp, Post & Dullemen (top), XX office, XX architects, 1998 (bottom)
be easily recycled by considering separation into homogenous parts. These principles were not realized to their fullest potential, nevertheless, the XX office is a very promising example. For example, the choice of construction type and materials, a combination of demountable wooden columns and steel cables and parts that are connected by use of screws, is designed to be easily reusable.\textsuperscript{12}

**Time is money, efficient disassembly**

Another approach, related to design for disassembly, is Industrial, Flexible and Demountable (IFD) building. Here the primary supporting structure functions as the component that is subject to many modifications. The secondary structure is the skin. The tertiary structure consists of the finish and the fit-out kit.\textsuperscript{13} Industrialized building was popular in the Netherlands around 1940 and became popular again around 2000 as an initiative from the ‘Rijksbouwmeester’. This approach focused on industrialized, flexible, and demountable buildings. Its aim was to build more efficiently and to improve building quality by industrializing the building process. ‘Industrializing’ refers to the production of buildings and building parts in a factory according to an industrialized process, in order to minimize the work that needs to be done on site. In 1940 this approach towards flexibility mainly focused on obtaining a plan that can be used as efficient as possible in several ways.

Around the year 2000 this approach towards flexibility mainly focused on obtaining a ‘neutral’ plan, a plan that gives freedom to the user to provide it with a certain function, dictated by the changing lifestyles of people and the unpredictable configuration of households. In the Netherlands the IFD-programme has stimulated the production of buildings, building parts, and products in accordance with the IFD-ideology. As turned out, the concept was not taken up as much as expected. It is argued that this approach required more time and thinking in the planning phase of the building process.\textsuperscript{13}

Internationally, several architects have experimented with the concept of industrialized, standardized and modular building. For instance, Konrad Wachsmann has done several studies into prefab building. His design for a steel prefab house shows standardization of the elements and prefab fabrication.\textsuperscript{7}

The work of Jean Prouvé also focuses on these aspects. He has designed a demountable house (fig. 8). In relation to this study, the house cannot be considered a design for disassembly example, since it is an example of a reverse building process. The design (only) considers demountability and rebuilding of the same building configuration (on another location), possibilities for reuse
and recycling are not considered extensively. Its use, however, of standardized and prefab parts is interesting. Especially, considering the historical context. The work of Elma Durmisevic contains an extensive overview of principles of design for disassembly. The work relates design for disassembly to industrialized and prefab building. Durmisevic argues that the building process should be further industrialized to serve design for disassembly. A systematic approach is required to implement disassembly. Unfortunately, this work limits itself to the spatial and technical aspects and does not provide architectural implications or more in depth consequences for the building design. Durmisevic provides several examples in relation to design for disassembly. One example is Renzo Piano’s Centre Pompidou. The Centre Pompidou shows a clear distinction in layers of the building according to their rate of change. The structures and services are flipped towards the outside. By positioning these parts to the outer side of the façade, the plan becomes free from restrictions and provides flexibility. Moreover, the building design evidently focuses on assembly by relating the building elements to a grid and by use of demountable connections. Brand questions the success of the Centre Pompidou, the exposure of services (and also the structure) is a “maintenance nightmare”. Adding the perspective of sustainability

The IFD-approach mainly incorporated the aim to build efficiently, and to reduce dissipation or waste to secure a feasible building time. It’s aim to reduce waste and be more efficient was not dictated by ecological or sustainable principles. Later, ecological and sustainable awareness in terms of materials and energy use become more and more important. The past decades ecological awareness has increased. Several reports (Silent Spring, 1962; Operating Manual for Spaceship Earth, 1969; Limits to Growth, 1972) have increased conscious on the depleting utilization of resources and have warned for pollution of the environment. It was argued that if we continue to contaminate the earth and deplete its resources, we cannot secure a safe and liveable future. Several approaches have aimed to deal with these problems. For instance by cutting back our current production and consumption rate. More optimistic approaches have argued to not lower our current comfort standard, but to transform the system itself.

In relation to the built environment, an industry that contributes (largely) to (global) material use and waste production, sustainable building has achieved a more prominent role the past decades. Currently, the term ‘circular
“Recycling is an aspirin, alleviating a rather large collective hangover ... overconsumption.” [...]

Roben Lilienfeld and William Rathje (1998) Use Less Stuff: Environmental Solutions for Who We Really Are. (extracted from Cradle to Cradle ...
Fig. 9. A temple carpenter’s timetable

The entire process as a single continuum

Life of trees in new construction

Yakushiji temple

Moved 718

First built ca. 690

Life of trees in original construction

Human lifespan

Sakamun
building’ is a popular approach towards sustainable building. The work of Mcdonough and Braungart, an architect and a chemical scientist, is a central piece of literature for understanding the need for a circular building and building process. Their philosophy called ‘cradle to cradle’ presents a new way of thinking and dealing with the issue of sustainability. The philosophy of cradle to cradle even goes a step further than ‘sustainability’ – which means to maintain or endure. According to them sustainability is the “minimum”; it gives nothing back. Instead of being sustainable in a way of cutting energy and resource use, they argue that comfort does not have to be sacrificed to be sustainable, however, the system must be designed differently. This mainly incorporates building (and designing) in such a way that a building is healthy (in terms of emissions, materials: non PVC, cadmium, lead, and mercury, amongst others, and requirements like daylight, clean air and water) and that no waste is produced. This last principle is put into practice by dividing materials into technical and biological nutrients. The technical nutrients should be designed for disassembly and the biological nutrients should be able to degrade in nature. It is of importance to separate these two types of nutrients. Otherwise, “monstrous hybrid” are created, which cannot or hardly be reused, recycled or dissipate naturally. These principles have been translated into criteria for the built environment, these are described in the book *Cradle to Cradle Criteria for the Built Environment*. An interesting, historical example of a building (type) that already integrated these closing of materials cycles, or circularity, is the traditional Japanese temple. The design of this building is highly focused on the building process from extraction of resources to dissipation, rebuilding or dismantling. Yet, it must be noted that this is motivated by religious ends. The life time of the temple, twenty years, is in line with the time needed to grow the wood that is used as the main building material. In relation to design for disassembly, a Japanese temple is perceived as continuous through time. Although parts need to be replaced the temple remains, see fig. 9.

Circular building relies or incorporates certain aspects from the cradle to cradle philosophy, especially the principle on how to deal with waste and obtain a circular material use. This philosophy proposes a durable way to deal with the earth’s resources on the one hand and providing a healthy and diverse living environment on the other hand. As already described, the concept of design for disassembly is dictated by the means to minimize waste at the end of a building’s life time, in order to deal sustainably with resources and materials. These ecological aspects of design for disassembly clearly relate to the currently popular approach towards sustainable building.
called circular building. Behind this principle is the need to build more sustainably. Although a wide accepted definition for circular building has not yet been established, it usually incorporates aspects like ‘closing material cycles’, conscious use of resources and materials and use of healthy materials. In relation to this research, the interpretation of this term will be based on the work of Braungart & McDonough. This work identifies principles in relation to circularity, with the aim to obtain closed material cycles. Circular building is, usually, defined as incorporating reuse and recycling in the building process to close technical and biological materials loop. Circular building uses building products and parts that can be reused at the end of the buildings lifetime without reducing its quality. The used materials and their processing should not be detrimental to the environment. In relation to design for disassembly, this concept can be considered an aspect of ‘circular building’. Though, design for disassembly has a different basis. Instead of utilizing waste, design for disassembly is aimed at preventing waste.

The terms ‘reuse’ and ‘recycling’ have been addressed in the previous paragraphs. In order to benefit from reuse and recycling after disassembly, one could learn from the cradle to cradle philosophy by McDonough and Braungart. This philosophy encompasses the slogan ‘reduce, reuse, recycle’. Important to note is the difference between reuse and recycle. Reuse is the process of reusing a material without reprocessing it, it can immediately be reused in its current form. The process of recycling comprises reprocessing of an existing material into a new material. In this process the existing material can be considered a raw material that is manufactured into a new material. Oftentimes, recycling results in a material or product that is of lower quality that the original material or product. Therefore, some consider recycling as unfavorable to sustainable building, since it could result in lower quality. It must be noted, that one material is easier to recycle than the other, the same applies for building materials. This is dependent, amongst others, on the level of mixture with other materials and on the energy needed to extract or transform the material. If disassembly of buildings is anticipated in the design stage, provisions can be made to reuse or recycle its parts if the building is considered obsolete. Designing for disassembly could ensure the reuse and recycling of building parts, components, and materials. This is a problem that needs input from the ecological as well as the industrial perspective.

In this respect, the term ‘urban mining’ should also be covered. Urban mining seeks for ‘existing’ materials, parts, and components in the urban sphere. Usually this involves existing products or materials that have been used and are now (at the end of their functional or economic life time)
Fig. 10. Superuse, WORM, Rotterdam the Netherlands, 2012, picture by Allard van der Hoek (top), Liander office, RAU, Duiven the Netherlands (bottom)
considered as waste. Urban mining revalues these materials – which are considered as waste, reused, or second hand – and finds a new use for them. The architecture firm Superuse utilizes this principle in their designs. This results in use of unconventional building materials. For instance, they designed a temporary music club in Rotterdam called Worm. For this design that they waste materials and parts for the interior and small building interventions, such as the entrance. This included, amongst others, a bench made of tyres, entrance walls made of air fans and wall finishing made of air plan interior panels. Another example by Superuse is the use of windmill blades – which are difficult to recycle due to their hybrid composition – as objects in public space. These blades are depreciated, but still of good quality.

This approach does not involve the principle to prevent waste by designing for disassembly, but to reduce waste by reusing it; it uses existing parts and components, that are regarded as waste to create buildings. An advantage of this approach is that even monstrous hybrids can obtain a new use. However, the quality of these parts and components is uncertain, this bears risks for the building performance.

One could question the need for the ‘Superuse approach’. Its origin lies in the utilization of waste materials. This could be perceived as an approach that afterwards tries to solve the waste problem, because waste has already been generated. The book Materials Matter by Rau and Obenhuber focuses on tackling the cause instead of the consequence. They argue that the ‘system’ should be transformed in such a way that it prevents generation of valueless product and materials or waste in the first place. They do so, by taking out the ‘throw away’-step in the traditional (building) material process, by means of uniting production and responsibility. This means that a carpet manufacturer, for example, who provides flooring will remain responsible for the carpet at the end of the building’s life time. This will shift incentives, the carpet manufacturer will now be incentivized to take back a high quality or highly reusable or recycle product at the end of the building’s life time. Especially the incentive to design a highly reusable or easy recyclable product could benefit design for disassembly. Furthermore, this approach will incentivize the owner to perform proper maintenance. The architectural office RAU has put this principle into practice for the design of the town hall in Brummen. This building functions as a material depot and material bank. All materials are documented and monitored, and responsibilities for certain parts of the building, i.e. wooden structural columns and beams and vegetation roof, are located at the manufacturer. Thereby, materials and products become a service, instead of an owned product. This is also applied to the Liander office in Duiven, the Netherlands.
Fig. 11. Toasters by Agency of Design, from top to bottom: the Optimist, Pragmatist, and Realist.
And then? What after disassembly?

According to Crowther four types of disassembly of buildings can be identified. These four types relate to different levels of scales of the building. These are: 1) relocation and reuse of an entire building; 2) reuse of components in a new building or elsewhere in the same building; 3) repossessing of components and materials into new components; 4) recycling of materials into new materials. 3 Based on the previous discussion and development in relation to design for disassembly, it can be argued that the first approach – relocation – (only) requires rebuilding or transportation of an entire building. In other words, disassembly is not a necessity. The other three approaches can be considered as design for disassembly. Reuse or recycling of parts and components is possible. Further, the parts and components can afterwards be used in another building or configuration.

An interesting example of an industrial product that demonstrates different approaches that could be chosen after disassembly, is the design of three different toasters by ’Agency of Design’. Each toaster shows a different approach to deal consciously with materials and resources. The toasters are designed out of waste. On top of that, the parts that the toaster consist of are reusable at the ‘end’ of its lifetime. This is especially the case for the ‘Pragmatist’. The Pragmatist secures easy maintenance and reuse of its parts by providing easy disassembly. In contrast, the ‘Optimist’ is more in line with the flexible approach towards building, it is designed to “last for generations”. 25 The third toaster, the ‘Realist’, shares similarities with the cradle-to-cradle approach: different kind of materials are separated into technical nutrients – that can be reused or recycled – and biological nutrients – that can decompose. The joints are designed to be disassembled quickly without defecting its parts. These three approaches could provide inspiration for ways to deal with buildings after disassembly. Depending on the intended life time of a building one could opt for easy maintenance disassembly, like the ‘Pragmatist’, or one could opt for a very temporal life time and no waste because of reusable and degradable parts, like the ‘Realist’.

In sum, in general terms three approaches in relation to design for disassembly could be distinguished. First, the approach that preached flexibility resulting in ‘permanent’ buildings that could adopt several functions. This approach was partly dictated by the need for mass production and resulted in building with a separation of support and infill. The second approach could be depicted as the standardized or Industrial, Flexible and Demountable (IFD) approach, resulting in industrialized, modular and prefab buildings aimed at building efficiently. Demountability and dismantlability of
Fig 12. Optimal building process according to design for disassembly. At the end of life materials can be disassembled and be reused or recycled.
buildings supported a quick and easy building process. The third approach, which demonstrates the meaning of design for disassembly by means of its ecological implications. This resulted in building based on circular principles, where waste is utilized as a resource. This ecological perspective supports design for disassembly and its goal to minimize waste, and focuses on reuse and recycling of building parts and materials.
Notes


This chapter provides a helpful definition of the concept ‘design for disassembly’. This definition includes important notions that influence or determine design for disassembly. These notions will function as aspects that a design for disassembly project should meet. This chapter relies on the previous chapter – the theoretical frame; defining design for disassembly is (obviously) related to exposing its historical context. This chapter answers the following two sub questions:

“What is a workable definition of the concept ‘design for disassembly’?";

“What aspects should a design for disassembly project implement?”

To be able to adequately define ‘design for disassembly’, a lot of literature has been studied. This ranges from the work of McDonough & Braungart, to the work of Rau & Oberhuber, and the work of Crowther, amongst others. Based on the literature study in the previous chapter, the following notions came to light that typify design for disassembly (for the building and its context): temporality, reuse and recycle, life time, and obsolescence. And the following aspects appeared to be important in relation to the building: separability, homogeneity, flexibility, standardization, and prefab. These notions will shortly be discussed below.
Defining

In this study, the word ‘design for disassembly’ has an underlying principle or objective to minimize waste. This principle will also be reflected in the follow-up of this research, which is the design. As already discussed in the introduction the follow-up of this research, the design, incorporates the perspective of design for disassembly by aiming to minimize waste at the ending of a building’s life time.

Based on this information, the following definition of design for disassembly is provided:

“Anticipating the temporality of a building by means of designing a building to be demountable, to be able to reuse or recycle parts and materials, thereby reducing the need for raw materials and minimizing the generation of waste.”

This first aspect that this definition includes is temporality. In regards to ‘design for disassembly’, a building is assumed temporal. Since a building is subject to an economic life which spans a certain duration. This duration is determined by (capricious) forces outside of the scope of building design, such as investments and social preferences. This temporality intrinsically includes the end of a building’s life time. Design for disassembly goes along with this idea, by providing a (future) use of the building’s part at the end of life. In this study temporality, and thereby the existence of an end of life, is considered as a given for the building. It must be kept in mind that the end of life of a building, does not imply end of life for its parts and materials.

The point in time at which the life of a building ends, is determined by its useful life time. As concluded from the theoretical frame, a functional, technical, and economic life time can be distinguished. By matching these different kinds of life times, obsolescence can be prevented or postponed.

As explained in the theoretical frame, a flexible building can be seen as a form of postponing obsolescence. This obsolescence can occur due to several factors, as determined by Crowther these are: locational, functional, technical, physical, and fashionable obsolescence. The types of flexibility that Leupen et al. define can be related to flexibility in use, structure or services. Especially for flexibility in use and structure, the building is generally over-dimensioned, because it should be able to bear the loads of later added extensions. This leads to perhaps more than necessary use of materials. Besides, a flexible building can still become outdated. And if the building is not designed to be taken apart, a lot of material is wasted. This seems not a preferable approach if one aims to minimize waste. Therefore, in relation to the approach of this study and in relation to design for disassembly, this aspect ‘flexibility’
will presumably not be a critical factor in determining successful design for disassembly.

It must be noted, that the previous mentioned considerations do not imply that a monumental (or long enduring) building is of no value. Designing a building for disassembly does not mean that the building itself should be of no value – since it will anyway be disassembled in the end. A building that is designed for disassembly could exist for a long life time and become a monumental building – as long as the quality of the used materials allow this. Design for disassembly and monumental buildings are not incompatible. As mentioned earlier, a monumental building could minimize waste to some extent, mainly by prolonging the building’s life time. Besides, a pre-determined life time can sometimes turn out to be highly uncertain in practice. As quoted from Leupen et al.: “Buildings designed to a ‘best-by date’ may well last for centuries”.4 (p.129)

In order to investigate possibilities for reuse, separability of building layers is important. As described in the theoretical frame, the work of Stewart Brand defines a building as a configuration of layers, of which each layer has a certain rate of change.5 A design for disassembly should consists of layers – site, skin, structure, services, space plan, and stuff – that are each easily separable. The rate of change of each layer can be different, as long as each layers can effortlessly be accessed and maintained. The application of the work of Stewart Brand on a conventional, permanent building and a temporal, design for disassembly building can be seen in Fig. 2. Additionally the type of joints and connectors also influence the potential for reuse. Therefore, a joint should be reversible: it can be unconnected and again connected without incurring damages. This can be obtained by use of demountable, stacked, nailed and screwed connections. Stapled, glued and fixed connections do not provide for disassembly without difficulty.6

Standardization can aid reusability. Standardization can be seen in terms of use of standard components. These are components that are common in the building industry. This relates to the building products of which the components consist and the applicability in practice. Besides, standardization also relates to whether the building is subject to a grid based on standard measurements. The standard components can be straightforwardly integrated in the standard grid. Later on, the components can fit easily in other configurations and buildings thanks to their functional measurements.

Standard elements can be fabricated on site or prefab. Prefab elements ease disassembly, because it generally involves ‘dry’ connections, in contrast
Fig. 1. The functional, economic, and technical life time of a building. Conventionally, the technical life time of a building is much longer than its functional and economic life time (top). A flexible building, generally, aims to extend the functional and economic life time (middle). A building designed for disassembly aims to match the different life times by reducing the technical life time by means of easy reuse and recycling of the building parts and materials (bottom).
Fig. 2. Configuration of permanent and temporal layers for a conventional building (left), and design for disassembly building: structure and skin are a bit more permanent because they should endure generally for a longer period of time (right). Adapted from Steward Brand.
to ‘wet’ connections. In relation to the scope of this study and the (only) indirect relation between prefab and design for disassembly, it is decided to not take into account aspect ‘prefab’.

In the case of parts that cannot be very easily reused – this is, for example, the case when the form hampers reuse – one can look into possibilities for recycling. Recycling normally involves reprocessing of an existing component, element or building part. For this study it is not relevant to discuss the recycling process in detail – i.e. physical or chemical recycling. In relation to the scope of this study, recycling potential will be considered in terms of ‘the possibility to reprocess the material with as little energy as possible while preserving a good quality’. This means that downcycling is not seen as a favorable option. Some important notions that facilitate recycling are the following. Recycling is easier when use is made of homogenous materials. This means that hybrid materials, for instance a combination of steel and concrete should be avoided, unless they can be separated. Furthermore, materials should remain in their corresponding cycle: technical or biological nutrient cycle. The potential for recycling is based on research by Verfago & Avellaneda (see Appendix I). This research determines possibilities at the end of life for some main construction materials. The work of Knaack, Klein & Bilow also has identified the recycling potential of construction materials, based on embodied energy and quality of the recycled product. It is assumed that production energy positive linearly relates to recycling energy. So, materials that need a large amount of energy to produce them, also need a large amount of energy to recycle them into the original substance.

It must be noted that a building can make use of ‘new’ materials, existing materials that are recycled, or existing materials that are downcycled. One could argue that the second possibility is the best option in relation to sustainable use of raw materials and resources. But, these aspects do not influence design for disassembly potential. As long as high quality reuse or recycling of the used parts and materials is possible, new materials could be used for the building design. Since new materials will not become lost or disappeared in a building designed for disassembly.

The process of disassembly requires time and labor. The above described aspects can enhance the efficiency of this process. Based on Crowther four possibilities after disassembly can be identified. These are: relocation and rebuilding of the entire building, reuse of parts and components in a new or the same building, recycling of components into new components, recycling of materials into new materials. The steps after disassembly can be related to different scales. It can comprise the building, building part, component,
element, material or raw material level. It is difficult to draw a clear line between these different levels.

**Focus**

The proceeding of this study focuses on these aspects to investigate disassembly of buildings. Based on the above mentioned considerations, these are the following aspects: level of disassembly, separability, homogeneity, standardization, life time, and process. While investigating three buildings, the temporality of the building will be kept in mind. At the end of life obsolescence can occur due to a combination or mixture of the different types of obsolescence.
Notes


This chapter describes the method for the case study research. This includes information on how cases were found, how cases were selected, and how the case study research will be executed. Besides, some limitations regarding the case study research that should be kept in mind will be described.

**Finding cases**

Before selecting three interesting case studies, an extensive list of projects has been set up. This list has been compiled based on projects that suffice certain criteria. These criteria relate to the domain of interest for this study. The domain is defined by (all) the cases that relate to the phenomenon of this study. That is, in this case, building projects that implemented the principle of design for disassembly (to a certain extent) or projects that have used this approach as a certain point for the design. The phenomenon to study is the implementation of design for disassembly in the built environment (from the perspective of architecture). However, the boundaries of this domain were explored beforehand and during the search for suitable cases further refined. In relation to the provided theoretical frame, some related concepts were also included, such as open building, flexible building, and adaptable building.

This resulted in a list comprising of about 40 projects, including
international, historical and contemporary examples, see Appendix II. During the assembly of this list with projects, it became clear that a project that has implemented all the aspects of design for disassembly, as defined in the chapter ‘criteria’ – does not exist, or in the sense that I was not able to find it.

**Selection of cases**

From this list three projects have been selected for further investigation. This choice is based on the objective after disassembly, for each of the three cases this is different – after disassembly the project is rebuilt, dismantled, or returned. Further, the cases have a different life time duration. In order to establish sufficient ground for comparison, the building requirements (in terms of comfort and technical capabilities) are the same: all three are indoor spaces. However, the functions and programme of the cases are different. Hopefully, this will result in different approaches towards and different implementations of design for disassembly. In relation to the design assignment, of which the objective is to minimize building waste at the end of life, this choice enlarges the possibility to explore as much inspiration as possible for the design in relation to designing a building for disassembly.

The selected projects are: ABT office in Delft by BiermanHenket built in 2001, The Green House in Utrecht by cepezed built in 2018, and the Townhall in Brummen by RAU built in 2013. These projects are all contemporary cases located in the Netherlands. The Townhall in Brummen consists of an older building and a new built extension based on design for disassembly principles. The other two buildings are new.

**Research design**

This case study research is of exploratory nature. This means that the case study research will not provide an exhaustive list with requirements to design a building for disassembly. The aim of the case study research is to provide design guidance on how to best implement design for disassembly. In order to analyze these cases data will be collected, such as drawings, photos, presentations. Besides a site visit will be done and an interview with the architect will be conducted.

Each case study will be studied on certain aspects. These aspects are as follows: context, object, and vision. The context provides a short description on the general facts and figures of the case: scale, function, life time, urban context. The object provides a more in depth analysis of the case in relation
to design for disassembly. In order to do so certain aspects will be assessed. These aspects are based on the output of the theoretical frame and the criteria chapter. This analysis will be backed up with an interview with the architect to provide some background on the vision or concept behind the project. Usually, the final project or design is (slightly) different from the vision or concept behind the project, due to a range of circumstances inherent to the nature of the building process. It could be that the ambitions of the project are not that clearly expressed in the end. It would be a pity if this is excluded from the analysis. The case study ends with (intermediate) conclusion on Design for disassembly potential: to what extent is waste minimized? (in terms of reusability of materials and extension of life time).

The follow-up research, that will be done to graduate for ‘Construction, Management, And Engineering’ at the Faculty of Civil Engineering and Geosciences, will focus on the process in terms of collaboration between actors to implement design for disassembly. This research could take the same case studies to study these aspects in terms of realizing the circular or design for disassembly ambitions.

**Limitations**

From this analysis conclusions will be drawn on the level of waste minimization by use of implementing the principle of design for disassembly. One must be aware that the criteria or design guidelines that will, hopefully, follow from these case studies are not exhaustive. The selected cases are (only) a fraction of the projects that have dealt with implementing design for disassembly and do certainly not include all possibilities to deal with this matter. It is highly possible that alternative or more criteria and design guidelines will suit. Nevertheless, the aim of this case study research is not to provide generalizable information, but to provide design guidance, based on informative and representative cases, that could function as design starting points.
Fig. 1. Townhall in Brummen by RAU built in 2013 (top), ABT office in Delft by BiermanHenket built in 2001 (middle), The Green House in Utrecht by cepezed built in 2018 (bottom)
### Table 1. Overview of aspects for case study research

| **Context** | Brief general context of the case: general facts, scale, (pre-)determined function, life time, urban scale |
| **Object** | Analysis according to (pre-)defined aspects. These aspects are based their relation with facilitating reuse and recycling, and thereby minimize waste. |
| | • Level of disassembly |
| | What level of the building is designed for disassembly? Building, building part, component, element, material, raw materials based on the work of Superuse.³ |
| | • Separability |
| | What layers are permanent? What layers are temporal? What is the rate of change? Layers are based on the work of Steward Brand.⁴ What types of joints? Is the joint reversible? Type of joints: fixed, glued, stapled, screwed, nailed, stacked, demountable based on the work of Superuse.³ |
| | • Homogeneity |
| | What kind of materials are used? To what extent are there mixed materials? To which cycle (biological or technical) do they belong? |
| | • Standardization |
| | To what extent are standardized building parts and components used? To what extent is the building subject to a systematical grid? Based on the work of Durmisevic.⁵ |
| | • Life time |
| | Are the functional and economic life time matched to the technical life time? Based on the work of Klomp et al.⁶ |
| | • Process |
| | What after disassembly? What kind of disassembly process? Reversed building? Based on Crowther.⁷ |
| **Interviews** | In-depth information about the vision of the project, by conducting a semi-structured interview directly posing the research question of this study. Besides some specific questions in relation to the particular building and in relation to other work of the office are asked. |
Notes


5. **Durmisevic, E.** (2010). *Green design and assembly of buildings and systems: Design for disassembly a key to life cycle design of buildings and building products.* Saarbrücken: VDM.


“Long life, loose fit, low energy, low waste”

Yvonne Segers - van Wilderen, BiermanHenket, 15th of May 2018
ABT Office

Context

In 1999 BiermanHenket architects (at that time Henket architects) started with the design of the ABT Office at the Delftech campus. The function of the building, an office (around 2000 m$^2$), was pre-determined, but the design offered flexibility in terms of configuration of spaces and later changes in use.\(^1\) The required programme for the building comprised working spaces, meeting rooms, and parking space. The building design consists of two parts with office spaces. In between an atrium and central (inflexible) core are positioned. The building consists of three floors. The ground floor is used for car parking.

The building process is characterized by an interesting relationship between the client and architect. The client, ABT, provided the architect with some clear and extensive spatial and technical requirements. They demanded the building to be demountable, as a whole, so that it could be rebuilt on another location or that the configuration could be changed. For instance, the ground floor that is now meant for parking could be used as office space in the future by placing façade panels.\(^2\) Besides, demountability should result in lower demolition and maintenance costs.\(^3\)

In contrast to the XX office by XX architects, also located at the Delftech...
campus, this building is designed for a long life time. Generally, office buildings should endure a life time of 50 years. This long life time gives the building a permanent status. Though, at the end of life the building can be demounted and rebuilt elsewhere. Remarkably, since the building was finished in 2000, the building structure and spatial configuration have not been altered.

Object

Level of disassembly

The building is designed with the principle “long life, loose fit, low energy, less waste” in mind. This principle relates to the, at that time popular, Industrial, Flexible and Demountable (IFD) building approach. ‘Less waste’ is translated into “efficient industrial production and demountable building parts”. ‘Loose fit’ refers to flexibility. ‘Low energy’ relates to low energy use and demand. And ‘long life’ refers synchronizing the functional, technical, and economic life time of the building.

These principles resulted in use of building components with a high durability, in terms of quality and endurance. Building components have been combined into building parts. The façade panels, for example, consist of standard wooden frames with openings and closed parts made of exterior plastic cladding and interior plywood panels.

Demountability of the building is perceived in terms of dismantling building parts (façade panels, second skin parts) and building components (columns, ceiling components, floor tiles). Disassembly of building parts and components is taken into account in order to replace them or reconfigure or rebuild the building.

Separability

Fig. 4 visualizes the permanent and temporal layers of the building. Additionally, it shows the separability of layers. The site layer is considered as temporal, because it was intended that the building could be rebuilt on another location in the future. Thus, the building is independent form the current site.

The structure is considered more permanent compared to the site. Although the beams and columns, a combination of prefab steel and concrete with screwed connections, can be disassembled, the foundation is permanent. The foundation is made of prefab concrete piles. It is designed to bear a higher load, so that expansions in the future can be foreseen. Disassembly
Fig 1. Sketch of section (top), sketch of floor plan of first floor (bottom) by BiermanHenket
Fig. 2. Picture of the ABT office building, made by the author
Fig. 3. Picture of the interior of the ABT office building, made by the author
of the foundation is not taken into account. Leupen et al. states that those concrete piles are almost “impossible to remove”. Additionally, the floor composition also hampers disassembly, and thereby temporality, due to the substrate that is bound to the floor construction. An anhydrite floor was necessary to comply with the spatial requirements. To provide some detachment of this layer, the floor was placed on a foil so that it could not stick to the construction floor. However, in case of disassembly, the quality of this material cannot be maintained and therefore reuse is not possible.

If necessary, the floor construction can be strengthened by use of steel strips and fiber composite laminates, these will be glued to the structural flooring elements. By use of glue this layers becomes attached, this impedes disassembly.

The services (ducts, electricity, lightning) are clearly visible in the building as a separate layer, attached to the ceiling or to the ground. Arrangements have been made to integrate the installations in a demountable and easy accessible way into the structure, for example, prefabricated holes in the beams provide room for installations. The heating and cooling is provided via ducts that deliver pre-heated or -cooled air from the cavity between the first and second skin. This layer is considered temporal, because it is accessible and its configuration can be changed. This benefits disassembly of this layer, the services can be altered and removed. For instance, in the floor the services are located beneath textile tiles on top of stacked steel tiles and a heightened prefab floor, these tiles can simply be lifted. Thereby, maintenance, reconfiguration, and removal of services is possible.

Originally, the floor plan was designed as a traditional office space – several closed office spaces defined by flexible interior walls. After completion, the space plan has been adjusted in accordance with the changing way of working of ABT – towards a more open lay out: almost all interior walls have been removed. The design of the interior walls as a separate, easy adjustable system provide freedom to arrange the space plan according to the current working needs, and is therefore considered temporal.

Investments were made to obtain a proper surface quality of the structural elements, so that another layer of finishing is not required. Thus, parts of the structure layer also function as skin. Besides, some building parts can be identified as skin, for example, the façade panels, and second skin made of greenhouse components. These components can be removed for maintenance or can be reconfigured. The façade panels can be removed and altered from the outside, by use of a crane. To do so, the second greenhouse skin needs to be removed.
Fig. 4. Layers of change, thick lines show permanent layers, thin lines show temporary layers extracted from Steward Brand and edited by author (top), sketch by Bierman Henket of facade panel (bottom)
Fig. 5. Pictures of the interior of the ABT office building, showing work places and services, made by the author
Fig. 6. Picture of the second skin facade of the ABT office building, made by the author.
The stuff layer, including mainly office furniture, is highly temporal. It is mostly detached from other layers or can be removed with little labor – the original cabinets for storage space can be demounted from the interior walls.

By separating in layers according to different functions, demountability is facilitated. For instance, the skin consists of two layers. The outer second skin, consisting of greenhouse elements and glass, functions as wind and water tight layer. The inner skin, consisting of a timber frame construction and demountable panels, functions as a thermal barrier. Since the inner skin does not need to be made water and air tight (normally by use of glue) screwed and nailed connections are sufficient, these connections are demountable.¹²

As can be seen in fig. 7, the building can be reduced to its building components by disassembly. This figure provides a vertical detail of the connection of the façade to structure. The beams and columns, a combination of steel and steel-concrete beams and concrete and steel-concrete columns, are screwed.³ A cone-shaped (thus self-unloading) concrete connector is used to connect the floor slab to the beam. This connection was required for safety reasons. The connector can be detached from the slab after disassembly. The connector will, after disassembly, be of no value, because it is destroyed.² The shape of the ribs of the floor slabs are curved. This is specially designed for this building to provide room for ducts positioned perpendicular to the ribs.¹⁰

As can be seen in fig. 7, the interior wall panels of the façade are nailed. The exterior wall panels are stacked into wooden profiles. By use of consoles, the second skin façade is connected to the structure. These consoles or screwed on the structural beams.

Homogeneity

At the time of construction, around 2000, use of existing, already used materials or use of recycled materials, was not considered. Also, the origin of materials and future use of materials was not considered to a great extent. The design focused on use of demountable connections and products that could endure a long life time.¹²

Appendix III depicts the materials that have been used. This table provides an overview of the origin of these materials as well as possibilities for reuse and recycling. Recycling of materials is based on Vefago et al.¹³ The main materials that have been used are: concrete, steel, concrete-steel hybrid, aluminum, wood, glass, bituminous materials, and synthetic materials, see fig. 10. For each material the recyclability potential has been determined. As can be seen, especially the bituminous materials (mainly present in the roof) and hybrid materials are difficult to recycle. The hybrid materials, especially
Fig. 7. Exploded vertical detail of connection of facade to structure, extracted from ABT and adapted by author (no scale)
Fig. 8. Picture of the ABT office building, showing the first floor and structural elements, made by the author.
Fig. 9. Picture of the ABT office building, showing the facade and ceiling connection, made by the author.
Fig 10. Recyclability potential, depicting the main materials used in the ABT office building; based on quality of the material after reprocessing and its embedded energy.
those part of the structure, can be reused thanks to their connection types. The reuse potential in practice, especially in another building or configuration is dependent on the fitness of the shape and measurements.

The construction consists of a combination of concrete columns and beams and steel columns and beams. Besides, a hybrid of steel and concrete is used for the main beams and columns, see fig. 8. The choice for a hybrid steel-concrete construction was made because of its fire retarding capacities. If the construction would have been made of steel, which is generally more easy to demount, this would have required a lot of fire retarded cladding. This would have impeded disassembly and recyclability of this component. Based on these arguments the choice was made for concrete. However, usually prefab concrete parts are connected on site by use of ‘wet’ connections. In this case, this is not desirable. In order to overcome this, the concrete prefab elements were connected using steel and demountable connections.²

Despite these advantages, the use of a hybrid or mixed building part of concrete and steel impedes recyclability. In order to recycle these parts properly, separability of the steel and concrete is required. Yet, the concrete columns that are attached to a steel connector or foot cannot efficiently be separated. The concrete column is casted with the steel connection. The connection is further strengthened by use of steel pins.² On site, the concrete columns with a steel foot and top are screwed to other columns and beams.

For the foundation, which consists of reinforced concrete piles (at a depth of 1 meter), separability of the steel reinforcement is impossible without destroying the concrete. Recycling of the concrete leftover will, with the current method of recycling, lead to quality degradation. On top of that, the foundation piles cannot be removed with destruction.

Standardization
The objective to design a demountable building, necessitates the building to be very systematical and subject to a grid. This grid was based on the requirement to integrate parking spaces in the building design. Additionally, the office spaces should also fit this grid. This resulted in a column distance of 5,40 meter, this could fit two parking places of each 2,70 (or 2,55 between the columns).¹² These measurements could be translated in a working place of 1,80 meter wide. The measurements for these floor components (1,8 meter in width and 9,0 meter in length) also fit the grid measurements.⁷ The façade panels, of which the smallest panel is 0,90 meter wide, likewise fit into the grid.
The services are also subject to the grid. The services are attached to the ceiling by use of plastic blocks. These blocks are casted into the concrete floor beams. The spacing of those blocks results in a certain fixed grid for the installations. All types of installations have to match this grid. This required out-of-the-box thinking from the different installation workers. Normally, they all have their own sizing and measurement system.\textsuperscript{12}

A large number of the building parts and components are standard, industrially produced (prefab), so that replacement and reuse of parts and components could be secured in the future, such as the façade panels and second skin system.\textsuperscript{6} This means, according to Frans van Herwijnen, that elements are standards elements, in the sense that they are not produced with a unique, specific building in mind.\textsuperscript{9} By use of standard, prefab elements, work on site could minimized and dimension stability is secured. Besides, the choice for standard elements was also dictated by the need to transport the building elements.\textsuperscript{5} The use of prefab elements in combination with a demountable connection benefits disassembly. The elements can be stacked thanks to their highly precise measurements obtained by prefabrication. In addition, a finishing layers is not required thanks to the smooth service.\textsuperscript{7}

Although the fact that, most often, one type of a certain component is applied for the whole building, this type is often specially designed for this building. For instance, the façade panels are specially designed for this building, although they consist of standard elements. The frame is based on a standard wooden frame size and standard window sizes are used.\textsuperscript{12} Another example is the TT floor slab, with a span of 9 meter – this was very innovative at that time, normally beams would span a 7,20 meter maximum. ABT, in collaboration with Van Oudenallen BV, developed this floor system which fits the grid.\textsuperscript{2}

**Life time**

As can be seen in fig. 13, the functional life time of the building is matched to the, in general long, technical life time. It provides flexibility (loose fit), by over-dimensioning (more materials), by shaping the components in a particular way (prefab wholes and curved shape to offer room for installations), and by using demountable connections. The first means – over-dimensioning – is, unfortunately, not favorable for design for disassembly, since it does not contribute to its aim to minimize waste. Instead it used perhaps more material than necessary.

The ‘short’ economic life time of the building, generally 15 years, is perceived as a given. The design does not aim to optimize or extend this economic life.
Fig. 11 Axonometric view of building parts that are subject to the grid (top), axonometric view of fixed elements that do not comply with the grid (bottom)
Fig. 12. Types of facade elements, extracted from BiermanHenket
time. However, the design aims to overcome this short life time by providing freedom to rebuild (overcome locational obsolescence), reconfigure (overcome functional obsolescence), or reuse (overcome functional obsolescence) in relation to the building and its components. The functional life time is matched to the technical life time, since building parts and components can easily be replaced, maintained, and updated to fit newer innovations. The resulting life times seem more similar to the life times of a flexible building, as determined previously, than to a design for disassembly building.

The long technical life of the building is secured by easy and little maintenance of the building parts. The parts can be accessed easily, because the layers are separated from each other. This means that the different layers and parts could have different rates of change. As can be seen in fig. 13, changes were already made to the skin after the first year that the building was in use. Extra insulation was added (to the ceiling of the first floor) and some parts of the façade needed to be painted. After 5 years the space plan was changed. A lot of interior walls were removed, because of functional obsolescence – the way of working changed. The rate of change for the site is less frequent, it is assumed that this will only be subject to change after 50 years, when the building will be rebuilt.

It can be argued that rates of change, especially high rates of change, lead to waste. Particularly, when the parts that are removed are not designed to be reused or recycled. This is especially the case if a certain layer, or parts of that layer, are removed or replaced, when they are still functional. This applies for stuff layer: ABT will change the office furniture after 15 years, because of fashionable obsolescence, although the furniture can still perform its functional requirements. No provisions have been made to reuse or recycle the furniture components easily.

Process
The original intention behind this project, was to be able to secure functioning of the building parts and components in the long term. In other words, the main objective was not to disassemble the whole building, but to disassemble and replace incapable or damaged parts and components. Thereby, disassembly was a means to secure convenient and feasible maintenance to extend the life time of the building. The building is design for easy maintenance and provides flexibility in use.

This process of easy replacement and maintenance reduces waste. Waste is prevented on site: everything can be removed from the site. However, although waste is minimized on site, the amount of waste is only truly minimized when
Fig. 13. Life times, the functional life time is extended to match the technical life time (top), disassembly intensity, rates of change of the building layers (bottom)
the replaced, old parts or components can easily be reused and recycled. As concluded from the analysis before, this is questionable for some materials and building parts.

**Vision**

On the 15th of May an interview was conducted with senior architect and partner at BiermanHenket architects Yvonne Segers – van Wilderen. A transcript of this interview is provided in Appendix IV. Yvonne explains that obtaining a IFD-building was the focal idea for this building. This was incorporated in the design from the initial phase. This has resulted in certain tradeoffs in favor of demountability, instead of aesthetics. In hindsight, Yvonne would have chosen for larger façade elements, to obtain a more slender façade. Larger façade elements would have resulted in smaller in-between frames.\(^\text{12}\)

Besides, it becomes clear that some elements do not fit the IFD-philosophy. The permanent, plasterwork core does not comply with the flexible and demountable principles of the building design. This core houses an elevator, installations, secondary staircase (in case of fire) and lavatories. Yvonne explains that this element is not designed according to these principles because at that time it was not common to design these building parts in a temporary manner. Besides, this choice was also subject to financial incentives. So, if ABT would like to rebuild their office on another location, they have to buy new toilets. This decision is one of the things she would have done differently, in hindsight. Currently, BiermanHenket designs a student housing in a monumental building (Mariënburg, ‘s-Hertogenbosch). This does include prefab sanitary components. Thus, this demonstrates that it is possible to design this normally permanent building part in a temporary way.\(^\text{12}\)

Interestingly, on the 30th of May during a site visit to The Green House, Gyuszi Florian of ABT elaborates on the philosophy of the ABT office. He explains that the choice for certain materials and systems impeded demountability. This is the case for the office floors, which consist of a sand and cement fixed floor to provide a horizontal floor. The same holds for the foundation, this is a fixed concrete casted foundation. Additionally, as explained, the interior walls were removed after about five years. Unfortunately, although the walls were designed to be reused, a second life time for these walls has not been found. At the moment, ABT questions whether they should stay in this office building. The costs for adapting the building appeared to be higher than expected, which makes it doubtful whether this is even a feasible option.
Fig. 14. Axonometric view of building parts that will become waste at the end of the building life time (at this current location), the fixed core including toilets and an elevator is not demountable.
Notes
“It’s no rocket science”
Jaap Bosch, cepezed, 4th of May 2018
The Green House

Context
Strukton, Ballast Nedam and Albron teamed up in a consortium called R Creators. R Creators got the opportunity to redevelop the former ‘Luitenant Generaal Knoop’-base and to develop the adjacent plot, located in the center of Utrecht. This adjacent plot will obtain its ultimate land use in 15 years from now. The government requested to provide a temporal building for this plot. Architectural firm cepezed is responsible for the design of this building.

This context was the starting point for the design of The Green House. The temporal life time provided an incentive to build a temporal, demountable building. The building should maintain for 15 years at this location. After this, the aim is to rebuild the building on another location. There the building should last for another 15 years.¹

R Creators set the ambition to realize a building based on circular principles. The building houses a restaurant, an urban farm with herbs and vegetables and several meeting rooms. The circular principles are translated into the building design, as well as into the use of the building. For instance, the employees of the restaurant are formerly unemployed people (social return), the management of the public space is taken into account, use is made of biophilic design to provide a healthy environment, furniture is provided by
Fig. 1. Picture of the facade of The Green House, made by the author
Fig. 2. Site plan (top), and ground floor plan (bottom) from cepezed
use of urban mining, and services during the exploitation are based on the ‘pay-per-use’ principle.\textsuperscript{2,3}

\section*{Object}

\subsection*{Level of disassembly}

The building is designed to disassemble and reduce it to its components. When the building is disassembled, a collection of components remains. These are, amongst others: columns, beams, façade panels, lattices, foundation blocks, floor plates, bricks, see fig \textsuperscript{3}. After disassembly, The Green House could be rebuilt – possibly in another configuration – or its components could be reused. Reducing the building to its components is common to the way of working of cepezed, as they usually perceive a building as a kit of parts.\textsuperscript{4}

\subsection*{Separability}

Fig. 4 visualizes the permanent and temporal layers of the building. Additionally, it shows the separability of layers. As can be seen, almost all layers are perceived temporal, not in terms of their life time (almost all are made of high quality, robust materials), but in terms of demountability. The structure, including the foundation, is somewhat more permanent since it requires more time and force to disassembly and remove it. Interesting to mention is the relating with site. The building is designed to be detached from its surroundings, in order to be rebuild and transformed or reuse its parts. This principle is also partly applied to the surroundings. The concrete prefab stair attached to the northern side of the building can be dismantled so that construction traffic can pass to secure the building of phase two of this plot, see fig. 6.

The separate layers are clearly visible. The skin is detached from the structure, and consists of two parts. A glass façade that functions as water barrier and a prefab sandwich panel façade that functions as thermal barrier. The structure, steel beams columns, is positioned behind the skin. The services are not detached, but (partly) integrated in the structure and skin (see fig. 3 bottom, dashed line). The heating and cooling distributions are integrated into the floor and ceiling, but can be adjusted and disassembled, since the floor allows for disassembly; the tiles are not fixed. The services connected to ceiling are easily demountable. The water drainage pipes are integrated into the ceiling (behind a perforated steel plate) and façade (behind wooden sandwich panels). This is not easily accessible, but it can be demounted. Air ventilation ducts and units are screwed to the prefab steel plate ceiling. It
Fig. 3. The building as a kit of parts, after disassembly a collection of components remains, made by the author.
Fig. 4. Layers of change, thick lines show permanent layers, thin lines show temporary layers, dashed lines show layers that are integrated into other layers, extracted from Steward Brand and edited by author (bottom).
must be noted that the building relies on the adjacent ‘Luitenant Generaal Knoop’-base (redeveloped into a government office) for its heating and cooling. The Green House utilizes heating and cooling that is generated from photovoltaic-panels placed on the roof of the ‘Luitenant Generaal Knoop’-base, amongst others. The space plan mainly consists of components that can be demounted or be taken out easily. Each floor (and ceiling) consists of different components and materials, based on the requirements for that particular floor. The floor and ceiling finishing mainly consist of stacked tiles or bricks or screwed plates. As described, the furniture is provided by use of the ‘pay-per-use’ principle. Maasdam projectinrichting is responsible for the furniture and remains responsible after the life time of the building. At the end of life it is taken back by the provider. The provider is responsible for reuse or recycling, therefore this provides an incentive to secure easy reuse or recycling. At the same time, no waste is provided on site. The same applies for the lightning, which is a ‘product as a service’. This means that Trilux provides lightning as a service, instead of light bulbs as a product.

Several sources indicate that the Green House can be completely demounted and rebuild on another location or that its parts can be used in other projects. Even more, when the building is rebuild it is also possible to change its configuration. Whether this is truly the case depends on the type of connections, since this will determine whether the building parts can be disassembled without causing scratches, wrecks, or other harms. Additionally, it is of importance that the building parts are of good quality, to be able to reuse the parts for another 15 years (and another 15 years).

As can be seen in fig. 7 and 8, the façade and foundation and façade and floors are connected by use of screwed and stacked connections. The glass façade panels are connected by use of a lattice construction, which is commonly used in the greenhouse industry. By use of aluminum frame connections and rubbers, use of kit or glue is prevented. The foundation is made of prefab blocks and connected with screws and anchors. The connectors used to connect the prefab façade and floor panels will probably incur some damages and holes when disassembled.

**Homogeneity**

Although the building is designed as temporal on its current location, the building elements consist of high quality, long term materials (i.e. sandwich panels, steel structure, plastic insulation instead of mineral wool). These elements are designed in such a way that recyclability is possible in the technical cycle. Besides, there are some organic materials (biological nutrients) used in the
Fig. 5. Some pictures of the different layers and detailing at The Green House, made by the author.
Fig. 6. Picture of the stair surrounding The Green House, made by the author
Fig. 7. Exploded detail of the facade and floor connection, from cepezed and adapted by author
Fig. 8. Exploded detail of the facade and foundation connection, from cepezed and adapted by author
Fig. 9. Section with reused (or secondhand) building components in blue, extracted from cepezed and adapted by author.

- Reused glass roof component from a greenhouse
- Reused brick pavement
- Reused wooden scrap wood boards
- Glass panels from Knoop barracks
- Reused tiles from quay of Tiel
building, such as felt, textiles, and textile air socks as installation ducts.

Appendix V depicts the materials that have been used. The origin of the materials is displayed as new or secondhand. The reused or secondhand materials that have been integrated in the design are also depicted in blue in fig. 9. Interesting to mention is the use of façade panels from the former ‘Luitenant Generaal Knoop’-base. These panels are connected to vertical frames from the greenhouse industry. This connection and suspension system can be disassembled, see also fig. 16 for a similar detail applied in another cepezed building. Besides, use has been made of existing pavement tiles, bricks, interior glass walls (from a former office), reused greenhouse roof, and reused scrap wood.

As can be seen in Appendix V, almost all materials can be reused or (if reuse is not another they can be) recycled. For some materials reuse is not possible, because these components will get damaged when disassembled or their quality is not sufficient (anymore). These components are, for instance, electricity cables, roof foil, and rubbers. For other materials recycling is difficult, because in case of recycling these components cannot maintain their current characteristics in terms of forms and strength. This is the case for the wooden components and bricks. Besides, galvanization of the steel columns and beams impedes recycling – in case of recycling this layer needs to be extracted. However, galvanization does provide better options for reuse, since galvanized steel can be applied indoors as well as outdoors.

As can be seen in fig. 9, the floor composition is different for each floor. The choice for the floor composition is based on the spatial requirements. For the greenhouse, meeting rooms, and restaurant this has resulted in a different floor construction and finishing. The floor finishing – bricks, concrete tiles, or textile tiles – is stacked on the floor construction to provide the possibility to reuse these components. The floor construction, wooden cassettes or densified sand is determined by their enduring characteristics and recycling opportunities.

**Standardization**

The pavilion is subject to a grid based on the size of the glass panels from the former ‘Luitenant Generaal Knoop’-base. The size of one panel is 1,50 by 1,15 meter. These measurements are translated into the size of the steel construction, roof profiles and prefab wooden panels (for the first floor). The steel construction is in line with the width of 1,50 meter of the panels; the steel columns are positioned on a grid with a distance of 6 meter in both directions.
Fig. 10. Picture of interior of *The Green House*, made by the author
Fig 11. Picture of the greenhouse, made by the author
Fig. 12. Recyclability potential, depicting the main materials used in The Green House; based on quality of the material after reprocessing and its embedded energy.
As can be seen in fig. 13, the grid is squared, this contributes to reuse, since beams have the same length in both directions. Two types of beams have been used of which the height differs. Additionally, the columns also have the same length. This also assists reconfiguration of the building in the future.

The use of a grid and its specific measurements should be in line with standard component sizes to secure reuse possibilities in other buildings in the future. This is assisted by use of prefab, modular building components. The building consists of standard components, no use has been made of specially (for this) building designed components. For instance, the components from the greenhouse industry are subject to strict standard measurements. However, the system itself is not modular, in the sense that the grid consists of demountable modules. The sanitary unit is an exception, this is a module that is positioned in the building as a fixed unit.

Working with modular, standard and repetitive components is part of the way of working of cepezed. As also for The Green House, variations of components are kept to a minimum. As already explained for the structure. Subsequently, the windows placed at the ground floor consist of one type of aluminum frame and glazing, which all have the same dimensions and are dryly connected.

Life time

This temporal pavilion should last 15 years at its current location. After 15 years, the building can be relocated and rebuild somewhere else, so the quality of the building components should last for at least 30 years for different locations. In order to fulfil this life time, mainly technical nutrients with high quality and long life time have been applied. The functional and economic life time are extended to match the (longer) technical life time of the building components, see fig. 15 (top). The economic life time is extended by offering possibilities for reuse of the building parts and reconfiguration of the building itself. The investment period in materials and building components could thereby extend the life time of the building at one location (15 years). The possibility to reconfigure the building easily – as provided by the squared grid – extends the functional life time. The building offers the possibility for different uses. And finally, if the buildings life comes to an end, its parts will still be of value and can be reused.

As previously explained, the building is designed to be rebuilt (at least) two times. On every location the building should last approximately 15 years. So, as can be seen in fig 15 (bottom), every 15 years the site layers changes.
Fig. 13. Axonometric view of building parts that are subject to the grid.
Fig 14. Section with standard components in light blue and standard structural components in blue, extracted from cepezed and adapted by author.
Fig. 15. Life times, the functional and economic life time are extended to match the technical life time (top), disassembly intensity, rates of change of the building layers (bottom).
Probably, not all other layers will suffice for (at least) 15 years. The components consist of materials with different life times. For instance, the foil in the façade construction and roofing will probably not survive more than 15 years. The steel construction, on the other hand is able to withstand for 30 years, and even more.

Since the stuff – furniture and lighting – are owned by the suppliers of those products, it is uncertain whether this layer will move with the building to the next location. It could be that the supplier will provide new, more modern furniture. As long as the ‘old’ furniture can be reused or dismantled, this is not contractor to the design for disassembly principles.

Process
An assembly plan was made to provide guidance on how to construct the building. The assembly of the building took place in (only) 6 months. This quick building process was facilitated by use of prefab elements and “remontable” connections – this means that the connections can be demounted and reconnected. Additionally, reuse of close-by components, such as the glass façade panels from the former Knoop barracks, supported this efficient building process.

At the end of its life time on this location (Croesenlaan 16, Utrecht, the Netherlands) the building will be disassembled. After disassembly the building will be rebuilt on another location, for another 15 years. The question remains, however, whether this building and its current configuration will be functional for another 15, and another 15 years. In this sense, disassembly is perceived as reverse building, but room for flexibility is allowed. The building can be rebuild in a different configuration, thereby flexibility is provided in terms of function and obsolescence is prevented or reduced. Unfortunately, no provisions – for instance in the form of a disassembly guide – have been made to facilitate disassembly and rebuilding. Over 15 years it would be helpful to understand how to disassembly the building, how components are connected, and what the quality of the materials will be.

Vision
This way of working and designing, as demonstrated by The Green House, seems to be integrated into the DNA of cepezed. Cepezed is founded by Michiel Cohen, Jan Pesman, and Rob Zee in 1973. This way of working comprises a strong focus on detailing. A lot of attention is paid to the details, cepezed usually designs the details from scratch. The buildings designed by
Cepezed appear transparent, systematic, slender and efficient. Their designs take into account the need for change (of function) in time, this results in flexibility in terms of use and arrangement or configuration of the building. From the start on, Cepezed includes all the different layers of the building, for instance, floor and installation types are considered from the start. Furthermore, working with modular, standard and repetitive components is part of their common way of working. Cepezed applies their philosophy to buildings of wide-ranging scales.

For the design of The Green House, Cepezed has drawn inspiration from previous projects. Fig. 16 shows a picture of the façade of the indoor go-karting circuit in Delft. As can be seen, the façade detailing – the connection of the glass panels on the steel frame – clearly shows similarities with The Green House. These similarities are confirmed during the interview with architect Jaap Bosch (May 4th 2018). He works since 2012 at Cepezed. Additionally, he mentions the use of a perforated metal sheet applied as acoustic ceiling below the roof construction. This component has also been applied in previous projects and in their own office. Furthermore, Cepezed has already dealt with demountability in their design. The design for the temporary court of justice in Amsterdam, also demanded to be demountable. Cepezed has realized this required by use of a demountable steel structure and hollow core floor. Jaap Bosch explains that the design for this building, however, required a higher level of representation than The Green House, in term of architectural representation and aesthetics. In his opinion, disassembly could be easier implemented in the design for The Green House, this programme offered more freedom.

As described, The Green House shows a clear distinction in layers. This is provided by use of a systematic design; the façade is subject to partitioning in certain measurements and runs in front of the construction floors and roof. Besides the façade is separated into two layers based on their different functions.

This approach towards designing and building seems to contribute to design for disassembly. Principles like standardization, prefabrication, dry-assemblage, and high speed construction process fasten the assembly and disassembly process and offer possibilities for reuse. However, the goal of Cepezed might be different. The incentive to implement these principles seems to be provided by their need to design high-quality buildings and connections and details and therefore keep control over the building process.
Fig 17. Picture of facade at The Green House, made by the author
Notes


“A building as a material storehouse”
Marijn Emanuel, RAU & Madaster, 23rd of May 2018
Townhall Brummen

Context

RAU designed an extension for the townhall of Brummen. The municipality demanded a temporal extension with a minimal life time of 20 years, which could be built within 9 months. The building was finished in 2013.¹

The extension surrounds an existing villa. After disassembly, this monumental villa should be unimpaired. The townhall houses working places, meeting rooms, ceremonial spaces, and a reception. The space between the extension and the villa functions as atrium and is considered as outdoor space – therefore this space has a different requirement in terms of comfort. The townhall comprises 3300 m².¹

The design for the extension to the townhall seems to have integrated cradle-to-cradle building principles, as determined by Mulhall & Braungart.² Some principles from the “Cradle to Cradle Criteria for the Built Environment” book are implemented. For instance, the design aims to “actively support biodiversity” by incorporating its surroundings.² ² (p.9) The surroundings comprise a butterfly garden. Besides, some implementations are added to enhance climate quality and provide a healthy working environment.
Fig. 1. Facade of expansion surrounding an existing monumental villa (top), ground floor plan (bottom) extracted from RAU.
Object

Level of disassembly

Regarding the level of disassembly, the building as a whole can be disassembled. Re-assembly, however, on another location is difficult, since the design of the expansion is subject to the shape and position of the monumental villa that it is connected to.

After disassembly the extension can return to its components or raw materials. Given the temporal requirement of the extension, the building was designed to facilitate reuse of the building at component level – i.e. columns, façade frames, windows, and bricks could be reused for instance. Furthermore, the building can return to its raw materials by means of recycling. The option for recycling is made feasible – in terms of energy to recycle and quality of the recycled product – by preserving ownership of the components at the manufacturer of that particular product, see fig. 2 and Appendix VII. If the manufacturer – instead of consumer – owns the components, he is also responsible for the components and its raw materials. Therefore, securing easy reuse and recycling becomes an incentive, for which the manufacturer has the means to incorporate them, whereas for a consumer this is quite difficult.

Separability

Fig. 3 visualizes the permanent and temporal layers of the building. Additionally, it shows the separability of layers. The new part of the building is attached to a monumental villa. This monumental villa can be regarded as part of the (existing) site. Since the expansion is connected to the villa and positioned somewhat around the villa, it can be argued that the expansion is rather dependent on the villa, in this context. Therefore, the site layer is considered permanent to some extent. The current spatial configuration of the expansion interacts with the site. The expansion cannot be rebuilt on another location in the same configuration (probably the office units can be rebuilt), unless that location also includes a similar existing building. When the expansion will be removed from this site, probably, the components will be reconfigured or be separated and reused at different locations.

The skin (exterior façade) is a combination of wooden frames (with glazing and wooden panels), exterior sun shadings, and wooden overhangs. The skin is detached from the structure with a 0,9 meter offset. The skin is also detached from the space plan (roof and floor) and existing monumental villa. At ground level crushed reused bricks enclose the building and provide ventilation.
Fig. 2. Section with materials owned by supplier in blue, extracted from RAU and adapted by author
Fig. 3. Layers of change, thick lines show permanent layers, thin lines show temporary layers, extracted from Steward Brand, edited by author.
The structure, a system of wooden columns and beams, steel connections, and a concrete foundation, is positioned independent from the skin and space plan (interior walls). The columns span the full height of the building. The floor construction consists of wooden laminated beams and wooden cassettes span the ground floor.

The services layer is not visible. Services, including ducts, electricity and lightning cables, are hidden behind the extended ceiling. Besides, some installations are positioned beneath the building. The reason for positioning these installations is unclear, it seems that this position does impede reuse, because accessibility is hampered. The elevator is positioned on the outside of the façade and can be detached.

The space plan – including interior walls, floors, and doors – consists of different types of materials. The roof consists of two types, a green roof above the office spaces, and a glazed roof which closes the atrium. The space plan is detached from the structure, except for the ground floor, this floor is connected to the foundation.

The stuff layer can be considered temporal. All stuff – including chairs, desks, printers, and lighting – is detached from other layers (loose objects). The lighting is provided by Philips. Interestingly, the lighting remains under ownership of Philips. This means that Philips is responsible for providing light as a service, instead of providing a product. This brings along the incentive to provide light bulbs that can be maintained and demounted efficiently and effectively.

Fig. 5 depicts a horizontal detail of the connection of the skin to the structure at a corner of the building. As can be seen a lot of prefab components are used, such as the open and closed façade panels and aluminum frame connectors. The connections are mostly dry connections, these are joined by use of screws, nails, and rubbers (depicted in blue). These types of connections do not harm the building components, this is especially the case for the column and beam connection – which has pre-drilled holes. However, for the wooden frames, after disassembly and removing the screws, a holes remains. If reused, this hole should be used, since too much drilling in the frame (adding more holes) would impede the quality. Some façade panels can rotate and thereby provide fresh air. This is provided for by use of a hinge. This connection is demountable. It is favorable that these kind of measures – to regulate the indoor climate – are integrated in such a way that they can be disassembled. It must be noted that in reality the rotating direction is different than as determined in the provided detail drawings, see fig. 4 (bottom).
Fig. 4. Picture of interior, showing different layers, (top), picture of facade with rotating panels (bottom), made by the author.
Fig. 5. Exploded horizontal detail of connection of facade to structure, extracted from RAU and adapted by author (no scale)
Fig. 6. Exploded vertical detail of connection of facade to structure, extracted from RAU and adapted by author (no scale)
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Fig. 8. Picture of the entrance, made by the author
similar measure can be seen in fig. 6. This figure depicts a vertical detail of the connection of the façade, roof, and structure. As can be seen, sun shading has been applied on the exterior side of the façade. The position of the sun shading on the outside is advantageous in case of disassembly, replacement and maintenance. The use of a dry connection also contributes to this.

**Homogeneity**

In order to secure the minimal life time of 20 years, RAU architects opted for materials with a high quality and durability. Therefore, mainly technical nutrients, in contrast to biological nutrients (natural materials that dissipate after a certain time and are not processed) were chosen. To secure optimal reuse and recyclability of the components at the end of the building’s life time, the components and materials remained under ownership of the suppliers. The suppliers were involved in the design phase. The townhall could be perceived as temporary storage for these materials and borrows them for 20 years.4,5

This idea requires that components can be disassembled quickly without incurring damages to the components themselves, other components, or the monumental villa. In order to realize this, RAU collaborated with Turntoo. This organization, also founded by Thomas Rau, aims to help others in realizing circular material use.3 As can be seen in Appendix VII, most materials that are owned by a supplier, also have good reuse and recycling possibilities.

Fig. 9 depicts the main materials that have been used. Appendix VII provides an overview of all materials that have been applied in the extension – including their position in the building in term of layers. The main materials that have been used are: (laminated) wood, glass, steel, aluminum, concrete, ceramics, and mineral wool. The recycling potential of these materials differs, as based on VeGafo et al.6 The ceramics, mainly recycled masonry from the former building on this location, and mineral wool are difficult to recycle. On top of that, mineral wool, generally, is applied in a hybrid form in the building. For instance, in combination with plywood. Fig. 9 also includes the materials ‘vegetation’ and ‘cardboard’ which are highly recyclable. These materials are applied in the interior walls and on the roof (green roof).

The application of hybrid materials is prevented as much as possible.7 However, as can be seen in Appendix VII, the building still includes some hybrids. These are, mainly, applied as wall and flooring composition elements. The extent to which these hybrids can be separated differs. As already described, if separation is hampered – i.e. due to the type of joint – reuse is not an option.
Fig. 9. Recyclability potential, depicting the main materials; based on quality of the material after reprocessing and its embedded energy.
Fig. 10. Picture of connection between the existing building and expansion, made by the author
Fig. 11. Picture of connection between the existing building and expansion, made by the author
Some already recycled materials are applied. The openings in the facade are made of recycled glass (triple HR+++). Besides, materials have been used from the former building that was positioned on this location. This building was (partly) demolished. The bricks from this building were used in the plinth of the new extension.

All materials are somewhat over-dimensioned – to provide standard measurements. This will aid reuse in another configuration or in other buildings. This is especially important to take into account since the main construction material is wood. Wood, in contrast to steel or concrete as construction materials, does not allow for recycling without quality degradation. Commonly, wood needs to be shredded to recycle it, this will change the shape and quality. Therefore, to provide for reuse, the wooden structure components should be of standard sizes.

### Standardization

By use of a grid with certain, repetitive measurements, a degree of modularity could be obtained. This enables reconfiguration of the building and thereby extends the functional life time of the building. In relation to the townhall at Brummen, the use of standard grid measurements facilitates the use of standard components. The grid of the expansion is independent from the grid and structure of the monumental villa. In the direction parallel with the monumental villa, the grid, determined by the wooden columns, follows equal measurements of 5,4 meter. This distance of 5,4 meter consists of six times 0,9 meter. This size is in line with the smallest façade panels, which have a width of 0,9 meter. These panels can be open or closed. A double façade panel has a width of 1,8 meter. The variation of these panels in the façade follow a rhythm of 1,8 m – 0,9 m – 0,9 m with some variations. In the other direction the grid has different dimensions and is symmetrical. The grid follows measurements of: 4,625 m – 6,425 m – 5,4 m – 5,4 m – 6,95 m – 5,4 m – 5,4 m – 6,425 m – 4,625 m, see fig. 12.

These differences in repetition are interesting. The façade panels as well as the structural elements follow a rhythm of certain measurements. If the grid and its component measurements would have excluded variations, such as in the ABT office building, a higher degree of standardization could have been obtained. This would probably also result in more or easier possibilities for reuse, since all components would have had the same measurements. Probably, the choice for a grid with some variations have been made with aesthetic reasons in mind.

Although the grid has different measurements, the beams positioned in the
Fig. 12. Axonometric view of building parts that are subject to the grid
Fig. 13. Facade elements
Fig 14. Picture of the facade, made by the author
north-south direction have the same size (0,4 meter by 0,36 meter and 5,4 meter long). In the other direction, the beams supporting the floor above the entrance have different lengths (as in accordance with the grid).

Life time
The building should withstand a minimal life time of 20 years.\(^1\) Therefore, mainly building components of proper quality and durable are chosen. However, it can be argued that the technical life time is reduced to match the economic life time (of probably 20 years). This is done by preserving ownership of (some of) the building components at the manufacturer. This facilitates replacement and maintenance. For instance, the manufacturer takes care of supplying the building with new innovations that improve the component’s performance. Besides, at the end of life the components return to the manufacturer. The manufacturer takes care of reuse, because the functional life time has probably not (yet) ended, or otherwise he takes care of recycling.

It is assumed that furniture and interior wall finishing will probably not withstand 20 years, see fig. 15 (bottom). Some of these components are made of materials with a lower quality that can decompose (i.e. cardboard).\(^5\) However, this is not the case for most of the furniture, and it seems that this is not owned by the manufacturer. This means that reuse and recycling is presumably not taken into account. If the furniture is replaced this will therefore probably generate waste. Furthermore, the services will probably also need to be maintained and replaced within 20 years. Since (a part of) the services are owned by a manufacturer, it can be assumed that waste is reduced to a certain level.

Process
During construction, soil excavation was reduced as much as possible. The amount of removed soil was reduced by lifting the building slightly above ground level. The different between the ground level and ground floor is overcome by use of reused crushed bricks. Additionally, where possible soil was reused on site. This contributed to minimizing waste, or in this case minimizing leftover earth.\(^7\)

After disassembly, remontage is taken into account.\(^4\) This means that if the building is demounted its components can be assembled again, so no damages should occur to the components. This is made possible by use of reversible joints, mainly screwed connections. Except for the foundation – which consists of concrete piles – this is not the case. Together with the
Fig. 15. Life times, the technical life time is matched to the economic life time (top), disassembly intensity, rates of change of the building layers (bottom)
services (to some extent) this will become waste.

It must be noted that after disassembly, the monumental villa needs to be restored and repaired locally. At the positioned of the connections, which consist of plugs and screws with rubber sealings, the walls need to be restored. Besides, possibly the opening made to connect the atrium with the villa needs to be closed again.\(^8\)

**Vision**

On the 23rd of May an interview was conducted with Marijn Emanuel. Marijn has worked at RAU as an architect and currently works at Madaster. Madaster is an organization, established by Thomas Rau amongst others, that offers a platform to eliminate waste in the built environment. Madaster provides a ‘library’ of all materials that are stored in a building.\(^9\)

Interestingly, Rau and Obenhuber describe in their book that the townhall at Brummen is the first building in the world that has a material passport. All used materials, its composition and raw materials, and the way it is connected, are documented at Madaster.\(^3\) Marijn Emanuel explains, however, that according to him the building has not yet been documented in Madaster. With hindsight, he would have spent more time on documenting the building, including its installations and services, and involved suppliers. Also he would have designed a more standardized building, with standard measurements and products.\(^8\)

In relation to the main question of this study – which is related to what will be left over as waste after disassembly – Marijn answers that the foundation (to some degree) and the services will become waste. This, to some extent, already occurs during the life time of the building. These parts are subject to wear and tear and probably already need to be replaced within 20 years.\(^8\)
Notes


The case study research aims to answer the following sub question: 

“To what extent have preceding projects been able to implement design for disassembly?”

Important to remind is that design for disassembly is perceived as a means to minimize (building) waste. The conclusions that can be drawn from the case study research are, therefore, directed towards this aim. In relation to this question the following can be concluded per case study.

**ABT Office**

For the ABT office, the intention to design a demountable building was given by the need to obtain a building that requires little maintenance and can be reconfigured (in the future). These requirements benefit disassembly. Since maintenance as well as reconfiguration demand the building to be made of connections that can be disassembled and requires accessibility of its ‘layers’. From the case study research it can be concluded that this objective could have been realized more thoroughly. As became clear, some conventional building methods or types of materials have been applied which impede demountability and reuse. This is the case for the floor construction (conventional fixed office floor) and roof configuration (traditional bitumen
Fig. 1. Life times, the technical life time is matched to the economic life time, for ABT office (top), The Green House (middle), and Townhall Brummen (bottom)
Fig. 2. Disassembly intensity, rates of change of the building layers, for ABT office (top), The Green House (middle), and Townhall Brummen (bottom)
and mineral wool insulation), which contain foil and glue. The foundation can be considered permanent and cannot be removed without harm and cannot be reused. Besides the core is also considered permanent and cannot be disassembled and reused.

The building comprises some components that are specially designed for this building, such as the hybrid columns and beams, pre-drilled holes in the beams to provide room for services, and the floor slabs and its connections. These mutations – these components now deviate from standardized components – were made to provide opportunities for easy accessibility and demountability. Yet, these special components hamper reuse and recycling, because this has led to hybrids and less useful components in other building configurations. On the other hand, other building parts, such as the façade system, respect the use of standard measurements and components.

The configuration of the building has not changed since completion. Though, the building is over-dimensioned to provide this opportunity, and thus it houses extra material that has not been utilized yet. This is not favorable from a resource perspective and counteracts conscious dealing with materials. Currently, ABT doubts whether they should alter the building, since the costs seem quite high.

So, it can be concluded that the building can be rebuilt on another location, however its parts cannot be reused very easily. Since, for some components, the usability is restricted to this (special) grid and dimensions. Further, some materials cannot very easily be separated, so these should be reused in their current constellation (i.e. steel and concrete beams and columns). After disassembly and rebuilding, the fixed core, foundation, and office floor remain on site as waste.

The Green House

In regards to The Green House, it can be concluded that the building can be disassembled up to the foundation. The temporal availability of this plot provided an incentive for this. After disassembly, nothing is leftover on site as waste. However, some components are better reusable or recyclable than others. The remaining collection of building components, especially the technical nutrients with a long life time, can be reused in a different configuration or in a different building. This is facilitated by use of a squared grid and by use of the ‘pay-per-use’ principle. The sanitary unit in the form of a module, provides some restrictions for reuse, since this unit has specific measurements and a specific configuration (i.e. position of door).
Possibilities for reuse are taken into account in advance, for instance, the glass panels that have completely been reused in their original form from the ‘Luitenant Generaal Knoop’-base. During the competition for the tender of this plot, cepezed already took into account this reuse possibility. Even more, they decided to base the grid on this panel. It was decided to use the panels in their original form so that as little energy as possible was needed for modification and no materials would be wasted, the panels only needed a clean-up. By taking into account this reuse possibility upfront, proper implementation of this component in the design was assisted. Materials have been chosen mainly in light of their potential for reuse. The possibility to recycle has been taken into account to a lesser extent. Thus, some existing or second hand materials have been used, but mainly new materials are utilized, while keeping in mind possibilities for reuse and recycling.

**Townhall Brummen**

Regarding the townhall in Brummen, it can be concluded that, in general, almost all of the building can be reused as components or can be recycled into raw materials. This is enabled and enhanced by locating ownership of and responsibility for certain materials, components, or products at the manufacturer. Besides, the opportunity for reuse is facilitated by separating the different layers by means of offsets. So, for instance, the façade is positioned in front of the structure with an offset of about 0.9 meter. Additionally, second hand or already used materials have been integrated in the building design. Even more, some materials from the former (at this site) located building have been reused or recycled. This, however, could have been done more thoroughly. Also, some conventional building methods or materials are present, such as the suspended ceiling which hides the service layer.

This building includes an existing monumental villa. This object influences the grid and measurements of the expansion. Probably, this has resulted in a grid with different measurements. In the same way, a grid of different measurements hampers use of standardized components or components with the same measurements, this negatively influences the reuse potential of the components.

Components from the stuff layer (room dividers, floor and wall coverings, lighting, paper, plants, food, chairs, etc.) move through the building at high rates of change, generally higher in comparison to other layers. Thereby this layer could lead to a lot of waste, especially if the products are not obsolete. The ‘product-as-service’ principle, that is applied for this layer, contributes to
less waste – since at the end of life the manufacturer wants to reuse or recycle the product – and provides the opportunity to innovate. The manufacturer could implement ‘state-of-the-art’-products, in terms of improved recycling opportunities, reduced energy use, and easy maintenance.

At the end of life, after disassembly, the foundation and services will be left over as waste. The monumental villa also remains on site, but can still function as an accommodation. Some repairs need to be carried out to the villa locally.
The research question of this report is:

“How can design for disassembly successfully be implemented in the building design in order to minimize waste at the ‘end of life’?”

In relation to this research question, the literature study that provided the theoretical frame, and the case study research, the following can be concluded. These conclusions keep in mind the criteria that followed from the literature study. Although the research question might sound general, in relation to the examined cases and with the criteria (level of disassembly, separability, homogeneity, standardization, life time, and process) in mind, some interesting conclusions can be drawn.

Based on the cases, it appears that disassembly of building components seems to ease disassembly rather than disassembly of building parts. Building parts include a constellation of components. Each component has its own reuse and recycling potential. By separating building parts to the level of a building components, these differences can be accounted for.

Use of screwed connections, as a form of a reversible connection, enable building components to be separated. This contributes to design for disassembly. After disassembly of a screwed connection, the screw leaves a
hole in that particular building component. This hole influences the quality of the component. The use of stacked connections is, therefore, more favorable, since this does not damage the components. This connection type, however, is not always an option, since it does not fixate the components thoroughly or additional measures should be taken.

The separation of layers according to different functions or spatial requirements appears to contribute to design for disassembly. This is demonstrated by use of a second façade, which splits the skin into two (or more) layers. The exterior layer could be design to withstand water, the interior layer could be designed to function as thermal barrier. This separation helps to prevent the use of glue or silicon kit, as demonstrated by The Green House and the ABT office.

Design for disassembly includes being able to reuse or recycle the building. In this case, reuse is preferred over recycling, since reuse requires no energy to reprocess the building component or material, it can be directly reused in the same building or in another configuration. This is, though, enhanced by use of standardized components and by use of materials from the technical cycle. In the case of recycling, use of homogeneous materials is favorable and hybrids should be prevented. Last, use of biological nutrients – which decompose after a certain amount of time – is also favorable, since this does not generate waste. Yet, attention must be paid to secure proper functioning of the components – it must not decay when the building is still in use.

As can be concluded from the case study research, the use of a grid with the same standard dimensions, preferably a squared grid (with the same dimensions in both width and length), enables the use of standardized components and minimizes the use of different types of components. Preferably, this will lead to use of only one type for each component, for instance, the same beams dimensions are used for the whole building.

By matching the different life times of the building – technical, functional, and economic – waste is minimized, since the end of life (technical life) is taken into account. This includes options for reuse and recycling for technical nutrients and recycling or dissipation for biological nutrients – these could be established by perceiving the component as a service. As perceived during the case study research, the functional life time could be extended by offering possibilities for different building configurations. It must be noted that extending the functional life time only minimizes waste if the technical life time of the components is equal or is accounted for in another way. Additionally, different rates of change of the building’s layers should be kept in mind, to secure maintenance, reuse, and recycling and thereby minimize waste.
Discussion

Although these cases show the use of reused or existing materials, these kind of materials could have been utilized more extensively. It seems that, through the years, use of existing materials has become more common. The ABT office does not use existing materials, whereas The Green House and Brummen – both designed and constructed more recently, do apply this principle. The use of already used materials minimizes waste in the building cycle. As explained, use of standard building elements facilitates reuse potential, although use of non-conventional building elements and components is also possible.

In addition, it seems that the scale of a building influences design for disassembly. The Green House is smaller than the ABT office and Townhall in Brummen – these two buildings are of equal scale. It could be that a larger building and thereby larger scale impedes difficulties to implement design for disassembly. The configuration of layers and disassembly process, for instance, could become more complex, in terms of the configuration of layers and the connections between them. Besides, the level of ambition and representation of the building also seem to play a role. It seems, however, that the choice for the ABT office to obtain demountable building parts (instead of components) and use of specially designed parts and components has led to some difficulties for implementation of the concept. On the other hand, the
spatial requirements, climate requirements, and technical requirements are (sort of) the same for each building. Perhaps the experience of the architect in this field influences the extent to which design for disassembly can be implemented (with ease or not).

Interesting to note is the relation with climatic conditions. The Townhall at Brummen integrates climatic measures into the building design in a demountable way. This is visible in the way the sun shading and ventilation measures have been designed. The sun shading is positioned on the exterior by use of screws and the façade panels can be opened to ventilate the building by use of a hinge. For the other two buildings, climatic measures seem not to be integrated in a demountable way very explicitly. Nevertheless, both the ABT office and The Green House have applied the concept of a second skin to function as a climatic barrier – this is also in favor of separating and demounting the different layers of the building.

It must be noted, however, that it seems that the costs for disassembly are an important aspect that hamper implementation. As was experienced for the ABT Office building, it was chosen not to reconfigure or disassembly the building. Disassembly still requires more time and money than demolition.
It seems that design for disassembly contributes to circular building, especially in relation to materials use and waste reduction. Further research could be done to further define and examine the link between design for disassembly and circular building. As became clear from this study, the collaboration between stakeholders in the building process, and especially how their roles should change, is of importance to secure implementation of design for disassembly in the built environment. The research that will be done for the ‘Construction, Management and Engineering’ master will dive into this aspect. Besides, further research needs to be done into relating the results from the literature study and case study results to design input. The follow-up of this research (the design) will include the generation of some design guidance in the form of concrete principles to translate these results to building design.
Fig. 1. Earthrise, the earth as a small element in the universe with only a limited reserve of resources and materials, picture by Frank Borman, 1968
I wish to thank various people for their contribution to this project; Yvonne Segers - van Wilderen, Jaap Bosch, and Marijn Emanuel for their time to conduct the interview and for sharing their knowledge about the concerning case study building; the staff of the Municipality of Brummen, for their help in collecting the data about and their guidance through the Townhall of Brummen; the staff from ABT Delft, and specially Jeroen ter Haar, for the opportunity to visit the ABT office and for providing information about the building; and Bouwen met Staal in collaboration with Booosting for the opportunity to visit The Green House including a tour with the building experts. Additionally, I would like to thank BiermanHenket, cepezed, and RAU for providing me with detailed information about the case studies, including drawings and pictures.

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**Recycling of building materials**

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<thead>
<tr>
<th>Material</th>
<th>Element</th>
<th>Cycle</th>
<th>Possibilities at the end of the life cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Technical</td>
<td>Biological</td>
</tr>
<tr>
<td>Metal</td>
<td>Aluminum profile</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Steel profile</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Copper – electric cable</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Plastic</td>
<td>Copper plates</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Polyethylene tube</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PET fiber</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PVC</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Ceramic</td>
<td>Concrete</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mortar</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brick</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stone</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Wood</td>
<td>Laminated wood</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plywood board</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hardwood without toxic preservative</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hardwood with toxic preservative</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Glass</td>
<td>Tempered glass</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Laminated glass</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>Sheep wool</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cellulose insulation</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

* Material recycled on the biological cycle.

* a: The polyvinyl butyral of laminated glass is not recycled nowadays. It is transported to landfills.
## List of projects

**Table 2. List of project for case study research selection**

<table>
<thead>
<tr>
<th>Building</th>
<th>Location</th>
<th>Realization</th>
<th>Life time</th>
<th>Function</th>
<th>Architect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portable Colonial Cottage</td>
<td>-</td>
<td>1833</td>
<td>temporary</td>
<td>residential</td>
<td>John Manning</td>
</tr>
<tr>
<td>Do-mino system / house</td>
<td>-</td>
<td>1914</td>
<td>semi-permanent</td>
<td>-</td>
<td>Le Corbusier</td>
</tr>
<tr>
<td>Nissen Hut</td>
<td>-</td>
<td>1920</td>
<td>temporary</td>
<td>military</td>
<td>-</td>
</tr>
<tr>
<td>Schröder House</td>
<td>Utrecht, the Netherlands</td>
<td>1924</td>
<td>permanent</td>
<td>residential</td>
<td>G. T. Rietveld</td>
</tr>
<tr>
<td>Dymaxion house</td>
<td>-</td>
<td>1930</td>
<td>temporary</td>
<td>residential</td>
<td>R. Buckminster Fuller</td>
</tr>
<tr>
<td>Erasmushaan</td>
<td>Rotterdam, the Netherlands</td>
<td>1931</td>
<td>permanent</td>
<td>residential</td>
<td>G. T. Rietveld</td>
</tr>
<tr>
<td>De Eendracht</td>
<td>Rotterdam, the Netherlands</td>
<td>1935</td>
<td>permanent</td>
<td>residential</td>
<td>J. H. van den Broek</td>
</tr>
<tr>
<td>Montage Maison Demountable</td>
<td>Le Bourget, France</td>
<td>1944</td>
<td>temporary</td>
<td>residential</td>
<td>Jean Prouvé</td>
</tr>
<tr>
<td>Eames house</td>
<td>Los Angeles, USA</td>
<td>1948</td>
<td>permanent</td>
<td>residential</td>
<td>Charles and Ray Eames</td>
</tr>
<tr>
<td>Aircraft hangar</td>
<td>USA</td>
<td>1953</td>
<td>permanent</td>
<td>military</td>
<td>Konrad Wachsmann</td>
</tr>
<tr>
<td>Walkable city</td>
<td>-</td>
<td>1964</td>
<td>permanent, location independent</td>
<td>residential</td>
<td>Ron Herron, Archigram</td>
</tr>
<tr>
<td>Fun Palace</td>
<td>Montreal, Canada</td>
<td>1964</td>
<td>temporary</td>
<td>leisure center</td>
<td>Cedric Price</td>
</tr>
<tr>
<td>Potteries Thinkbelt Project</td>
<td>-</td>
<td>1966</td>
<td>temporary</td>
<td>recreation</td>
<td>Cedric Price</td>
</tr>
<tr>
<td>Les Immeubles</td>
<td>-</td>
<td>1970</td>
<td>temporary</td>
<td>residential</td>
<td>Marcel Lods</td>
</tr>
<tr>
<td>Diagoon houses</td>
<td>Delft, the Netherlands</td>
<td>1971</td>
<td>permanent</td>
<td>residential</td>
<td>Herman Hertzberger</td>
</tr>
<tr>
<td>t Hool</td>
<td>Eindhoven, the Netherlands</td>
<td>1972</td>
<td>permanent</td>
<td>residential</td>
<td>J. H. van den Broek, J. B. Bakema</td>
</tr>
<tr>
<td>Molenvliet</td>
<td>Papendrecht, the Netherlands</td>
<td>1974</td>
<td>permanent</td>
<td>residential</td>
<td>Frans van der Werf</td>
</tr>
<tr>
<td>Heiwo house (prototype)</td>
<td>-</td>
<td>1982</td>
<td>temporary</td>
<td>residential</td>
<td>cepezed</td>
</tr>
<tr>
<td>IBM Travelling Pavilion</td>
<td>Rome, Italy</td>
<td>1986</td>
<td>temporary</td>
<td>pavilion</td>
<td>Renzo Piano</td>
</tr>
<tr>
<td>Maison Latapie</td>
<td>Floirac, France</td>
<td>1993</td>
<td>temporary</td>
<td>residential</td>
<td>lacaton &amp; vassal</td>
</tr>
<tr>
<td>Next21</td>
<td>Osaka, Japan</td>
<td>1994</td>
<td>permanent</td>
<td>residential</td>
<td>Yositaka UTIDA, Shu-Koh-Sha Architectural and Urban Design Studio</td>
</tr>
<tr>
<td>XX Office</td>
<td>Delft, the Netherlands</td>
<td>1998</td>
<td>20 years</td>
<td>office</td>
<td>XX Architecten</td>
</tr>
<tr>
<td>Building</td>
<td>Location</td>
<td>Year</td>
<td>Duration</td>
<td>Type</td>
<td>Function</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------------------------</td>
<td>------</td>
<td>----------</td>
<td>------------</td>
<td>------------------</td>
</tr>
<tr>
<td>IGUS Factory</td>
<td>Cologne, Germany</td>
<td>2000</td>
<td>permanent</td>
<td>factory</td>
<td>Nicholas Grimshaw</td>
</tr>
<tr>
<td>R128</td>
<td>Stuttgart, Germany</td>
<td>2000</td>
<td>permanent</td>
<td>residential</td>
<td>Werner Sobek</td>
</tr>
<tr>
<td>Abt</td>
<td>Delft, the Netherlands</td>
<td>2001</td>
<td>50 years</td>
<td>office</td>
<td>BiermanHenket</td>
</tr>
<tr>
<td>Spacebox</td>
<td>Utrecht, the Netherlands</td>
<td>2001</td>
<td>temporary</td>
<td>residential</td>
<td>Mart de Jong</td>
</tr>
<tr>
<td>Emotional House</td>
<td>-</td>
<td>2002</td>
<td>temporary</td>
<td>residential</td>
<td>Kas Oosterhuis</td>
</tr>
<tr>
<td>LUMC Research Center</td>
<td>Leiden, the Netherlands</td>
<td>2002</td>
<td>permanent</td>
<td>IFD research, hospital</td>
<td>EGM Architects</td>
</tr>
<tr>
<td>Cancer Center</td>
<td>Amsterdam, the Netherlands</td>
<td>2005</td>
<td>temporary</td>
<td>research</td>
<td>MVRDV</td>
</tr>
<tr>
<td>Casa Muro</td>
<td>Lampa, Santiago de Chile</td>
<td>2007</td>
<td>semi-permanent</td>
<td>residential</td>
<td>FAR Frohn Rojas</td>
</tr>
<tr>
<td>Loblolly House</td>
<td>Taylor Island, Maryland, USA</td>
<td>2007</td>
<td>semi-permanent</td>
<td>holiday home</td>
<td>KieranTimberlake</td>
</tr>
<tr>
<td>No Flat Future</td>
<td>Rotterdam, the Netherlands</td>
<td>2007</td>
<td>permanent</td>
<td>residential</td>
<td>Superuse studios</td>
</tr>
<tr>
<td>Cellophane House</td>
<td>New York, USA</td>
<td>2008</td>
<td>semi-permanent</td>
<td>residential</td>
<td>KieranTimberlake</td>
</tr>
<tr>
<td>Holebox</td>
<td>Passau, Austria</td>
<td>2008</td>
<td>temporary</td>
<td>recreation</td>
<td>Holebox</td>
</tr>
<tr>
<td>Villa Welpeloo</td>
<td>Enschede, the Netherlands</td>
<td>2009</td>
<td>permanent</td>
<td>residential</td>
<td>Superuse studios</td>
</tr>
<tr>
<td>WORM</td>
<td>Rotterdam, the Netherlands</td>
<td>2011</td>
<td>temporary</td>
<td>recreation</td>
<td>Superuse studios</td>
</tr>
<tr>
<td>Townhall Brummen</td>
<td>Brummen, the Netherlands</td>
<td>2013</td>
<td>20 years</td>
<td>governmental</td>
<td>Thomas Rau</td>
</tr>
<tr>
<td>Liander</td>
<td>Duiven, the Netherlands</td>
<td>2015</td>
<td>permanent</td>
<td>office</td>
<td>Thomas Rau</td>
</tr>
<tr>
<td>Temporary court of justice</td>
<td>Amsterdam, the Netherlands</td>
<td>2016</td>
<td>3 years</td>
<td>governmental</td>
<td>cepezed</td>
</tr>
<tr>
<td>ICEhouse™</td>
<td>Davos, Switzerland</td>
<td>2016</td>
<td>temporary</td>
<td>recreation</td>
<td>Mcdonough</td>
</tr>
<tr>
<td>Ciel</td>
<td>Amsterdam, the Netherlands</td>
<td>2017</td>
<td>30 years</td>
<td>pavilion</td>
<td>ArchitektenCie: Pi de Bruijn, Hans Hammink</td>
</tr>
<tr>
<td>People's Pavilion</td>
<td>Eindhoven, the Netherlands</td>
<td>2017</td>
<td>1 month</td>
<td>pavilion</td>
<td>Bureau SLA, Overtreders W</td>
</tr>
<tr>
<td>The Green House</td>
<td>Utrecht, the Netherlands</td>
<td>2018</td>
<td>15 years</td>
<td>pavilion</td>
<td>cepezed</td>
</tr>
<tr>
<td>Classroom</td>
<td>-</td>
<td>?</td>
<td>temporary</td>
<td>educational</td>
<td>Onix</td>
</tr>
<tr>
<td>Triodos kantoor</td>
<td>Driebergen-Zeist, the Netherlands</td>
<td>under construction</td>
<td>permanent</td>
<td>office</td>
<td>Thomas Rau</td>
</tr>
</tbody>
</table>
## List of materials for ABT office

*Table 3. Materials used for the ABT office, based on Vefago et al.*

*without quality degradation.*

<table>
<thead>
<tr>
<th>Material</th>
<th>Part of</th>
<th>New or secondhand</th>
<th>Connection</th>
<th>Cycle</th>
<th>Reuse?</th>
<th>Recycle?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum ducts</td>
<td>Services</td>
<td>New</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Aluminum frames second skin</td>
<td>Skin</td>
<td>New</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Aluminum T-profile (connector outside)</td>
<td>Skin</td>
<td>New</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bitumen roofing</td>
<td>Skin</td>
<td>New</td>
<td>Stapled</td>
<td>Technical</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Concrete tiles roof</td>
<td>Skin</td>
<td>New</td>
<td>Stacked</td>
<td>Technical</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Fiber plate at parking floor</td>
<td>Skin</td>
<td>Recycled</td>
<td>Stacked</td>
<td>Technical</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fiber-concrete hybrid plate</td>
<td>Skin</td>
<td>Recycled</td>
<td>Stacked</td>
<td>Technical</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Foil at roof and facade</td>
<td>Skin</td>
<td>New</td>
<td>Stapled</td>
<td>Technical</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Glass door</td>
<td>Skin</td>
<td>New</td>
<td>Fixed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Glass windows</td>
<td>Skin</td>
<td>New</td>
<td>Fixed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Gravel ballast roof</td>
<td>Skin</td>
<td>‘New’</td>
<td>Stacked</td>
<td>Biological</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Hard foam insulation</td>
<td>Skin</td>
<td>New</td>
<td>Stacked</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Mineral wool insulation</td>
<td>Skin</td>
<td>New</td>
<td>Stapled</td>
<td>Technical</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Multiplex cladding indoor</td>
<td>Skin</td>
<td>New</td>
<td>Nailed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Multiplex-mineral wool prefab roof element (shed roof)</td>
<td>Skin</td>
<td>New</td>
<td></td>
<td>Technical, hybrid</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Pinewood window frames</td>
<td>Skin</td>
<td>New</td>
<td>Screwed</td>
<td>Biological</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Plastic exterior shading</td>
<td>Skin</td>
<td>New</td>
<td>Stacked</td>
<td>Technical</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Polycarbonate cladding outdoor</td>
<td>Skin</td>
<td>New</td>
<td>Stacked</td>
<td>Technical</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Item</td>
<td>Skin</td>
<td>New</td>
<td>Stacked</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>---------------------------------------------------------------------</td>
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<td>-------</td>
<td>---------</td>
<td>-----------</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Rubber setting roof</td>
<td>Skin</td>
<td>New</td>
<td>Stacked</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Sand-lime plate</td>
<td>Skin</td>
<td>New</td>
<td>Stacked</td>
<td>Biological</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Steel console for steel floor grid</td>
<td>Skin</td>
<td>New</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Steel floor grid second skin</td>
<td>Skin</td>
<td>New</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Steel profile</td>
<td>Skin</td>
<td>New</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Triplex setting</td>
<td>Skin</td>
<td>New</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Wisa birch wood (connector interior)</td>
<td>Skin</td>
<td>New</td>
<td>Screwed</td>
<td>Biological</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Anhydrite floor</td>
<td>Space plan</td>
<td>New</td>
<td>Staked</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Concrete floor at parking floor</td>
<td>Space plan</td>
<td>New</td>
<td>Fixed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Plasterboard interior wall</td>
<td>Space plan</td>
<td>New</td>
<td>Nailed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Rubber tiles interior floor</td>
<td>Space plan</td>
<td>New</td>
<td>Stacked</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Steel flooring tiles</td>
<td>Space plan</td>
<td>New</td>
<td>Stacked</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Wooden doors and frames</td>
<td>Space plan</td>
<td>New</td>
<td>Screwed</td>
<td>Biological</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Concrete column/beam</td>
<td>Structure</td>
<td>New</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Concrete hollow-core slab ground floor</td>
<td>Structure</td>
<td>New</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Concrete prefab TT-slab</td>
<td>Structure</td>
<td>New</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Concrete-steel hybrid beam and column</td>
<td>Structure</td>
<td>New</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Mineral wool ground floor insulation and first floor</td>
<td>Structure</td>
<td>New</td>
<td>Nailed</td>
<td>Technical</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Reinforced concrete foundation</td>
<td>Structure</td>
<td>New</td>
<td>Fixed</td>
<td>Technical</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Steel column/beam</td>
<td>Structure</td>
<td>New</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Wisa birch wood cladding beam</td>
<td>Structure</td>
<td>New</td>
<td>Nailed</td>
<td>Biological</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Steel part staircase</td>
<td>Stuff</td>
<td>New</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Wooden part staircase</td>
<td>Stuff</td>
<td>New</td>
<td>Screwed</td>
<td>Biological</td>
<td>Yes</td>
<td>-</td>
</tr>
</tbody>
</table>
Wat wel interessant is, dit gebouw is al 15 jaar oud. Toen was de kreet “IFD bouwen” in zwang, oftewel “long life loose fit, low energy”. Dit IDF uitgangspunt was de kapstok voor dit project. Dit kantoor werd ontworpen voor ABT. ABT wilde vooruitstrevend zijn en wilde laten zien wat er mogelijk was. De constructie moet naast demontabel ook nog wat langer mee kunnen gaan en mogelijkheden bieden om uit te breiden. Deze ideeën zaten er dus al vanaf het begin in.

Het Delftechpark was in die tijd nog leeg. ABT werkte samen met Damen. Ze wilden een gebouw maken wat uit elkaar gehaald kon worden; geen schuim en kit gebruiken, maar juist met schroeven uit elkaar te halen. Je kunt het totaal-product dus hergebruiken, zoals het in die vorm nu is. Dus niet ‘shredderen’. Dus niet dat de betonvloer wordt vermalen en met een lagere kwaliteit wordt hergebruikt.

Dit zat vanaf begin af aan in het ontwerp. Twee lagen kantoren en een parkeerlaag eronder. In de toekomst moest er een laag bovenop kunnen komen en het parkeergevelde kan kantoor worden. De mogelijkheid om te parkeren bepaalde de afmetingen van het gebouw. Deze maat was gebaseerd op een maat zodat twee auto’s naast elkaar kunnen parkeren. Bovendien moest dit een logische stramienmaat zijn voor een kantoorindeling, anders heb je verloren meters. Het uitzetten van de stramien maat (1,80 en 9 meter) bepaalde het systeem.

Er is gekozen voor staal en beton als constructiemateriaal, het is zo ook brandwerend zonder dat de kolom ingepakt hoeft te worden. Door staal konden demontabele verbindingen tot stand komen.

Als IFD vanaf de start niet was meegenomen had het gebouw er waarschijnlijk anders uitgezien. Er is gebruik gemaakt van veel dezelfde elementen: één type kozijn gebruikt. Die kan op verschillende manieren ingevuld worden:
open of gesloten. Deze gevelelementen zijn allemaal geprefabriceerd. Dit gevelpakket moest zo dun mogelijk, want je wil deze om kunnen wisselen (licht), maar het moest wel voldoende isolerend zijn. De plastic-plaat is gevuld met lucht, dit werkt deels isolerend. Er kon zo aan de standaard houtmaat voor de kozijnen voldaan worden, zo werd afval verminderd.

*Het gebouw heeft twee gevels, waarom is deze keuze gemaakt?*

Deze jas is de wind- en waterdichting. De houten verbindingen erachter hoeven dan de winddruk niet op te kunnen vangen en hoeven niet waterdicht te zijn. Dit maakte demontabelheid makkelijker. De tweede gevel maakte zonwerking makkelijk mogelijk. Deze tweede gevel komt letterlijk uit de kassenbouw. Deze gevel is helemaal uit elkaar te halen. Het zijn standaard aluminium profielen met rubbers. De tweede gevel is ook een klimaatgevel, dit was ook gunstig voor de warmte- en koude energie.

De kolommen werden neergezet, balken eraan gedraaid en vloerplaten werden er los ingelegd. In de toekomst kan er in de vloerplaten een carbonfiber rib geschroefd worden om zo meer stijfheid te verkrijgen zodat er dan een verdieping extra op het gebouw kan. De vloerplaat is losse uit de vorm. Kunststofblokjes zijn er in geschroefd, want je mag niet in de plaat boren. Hier kan een akoestisch plafond aan bevestigd worden.

Er zijn open en dichte panelen in de gevel. Een zeker percentage mag open zijn. Op basis hiervan en de gevelpaneel varianten is een indeling gemaakt. Deze kan gemakkelijk veranderd worden door panelen te verwisselen. De panelen kunnen er gemakkelijk ingehangen worden. Deze elementen zijn speciaal voor dit gebouw ontwerpen, maar er is wel gebruik gemaakt van standaard (aluminium) profielen.

We hebben toen niet goed gekeken naar, het ‘cradle to cradle’ verhaal van nu, waar komen de bouwstoffen vandaan? En wat kunnen we er na de levensduur mee doen? Dit gebouw is vooral ontworpen op bouwproductniveau. Er is dus geen gebruik gemaakt van reeds gebruikte of gerecyclede materialen.

Op de vloeren zijn los plaatjes neergelegd. De elektra is dus ook niet ingestort, maar neergelegd op kunststof blokjes met gezette staalplaten. Dit maakt hergebruik en een andere functie in het gebouw mogelijk.

Op bepaalde punten is voor het systeem gekozen en niet voor de esthetiek. Bijvoorbeeld, de grootte van de gevel elementen bepaalt de dikte van de detailering. Als het element groter was gekozen, zouden de tussenstijlen (die er dus nu niet zijn, elk element heeft twee stijlen) slanker gemaakt kunnen worden.
De wanden staan haaks op de vloerplaten, dus dit sloot niet goed aan op de ribben. Met behulp van rubbers is geprobeerd dit akoestisch toch dicht te maken, dit was heel lastig (en is dus ook niet helemaal gelukt uiteindelijk). Uiteindelijk is het element uit een andere industrie gehaald.

Die ingestorte kunststoffblokjes in de vloer zorgden voor een vast stramien voor elk type installatie. Elke installateur moest zijn installaties hier op aanpassen. Wat ieder heeft zijn eigen ritme en bevestigingsmiddelen (elektra, leidingen, lucht, etc.), ook in de balken zat een standaard grid met gaten.

De vloerligger was een nieuw type beton, deze kon niet helemaal los liggen op de liggers. Dus er is een conus-vormige opening ontworpen die gevuld is met een betongoedje die er uitgehaald kan worden, om een bevestigingspunt te creëren, de conus is dus wel lossend.

De details zijn in samenwerking met ABT ontwikkeld. ABT heeft zelf een tekenafdeling. De ambitie kwam ook echt vanuit ABT om een IFD-gebouw neer te zetten.

Welke elementen voldoen niet aan dit systeem? (bijvoorbeeld de fundering)

Ik denk dat het op zand is gefundeerd.

Het is allemaal koud op elkaar gemonteerd. Het gebouw is dus volledig her te bouwen of je kunt de onderdelen doorverkopen. Je kunt delen van het gebouw demonteren of uitbreiden.

De kern met toiletten en lift is niet demontabel. De sanitaire wanden zijn betegeld. De wand is Metal stuc. Dit zal gesloopt moeten worden.

Waarom is deze keuze afgemaakt?

Ik kan me niet meer herinneren waarom de toiletten niet geprefab zijn. Het was waarschijnlijk financieel niet haalbaar, ook omdat het maar om 6 wc’s ging. Als ABT het kantoor verplaatst, hebben ze dus wel weer nieuwe wc’s nodig. Deze blijven achter als afval.

De daklichten zijn ook op de stramienmaat gemaakt, deze zijn demontabel.

We doen nu ook een project in Den Bosch met studentenwoningen. Hier is wel gebruik gemaakt van prefab sanitaire voorzieningen, deze zijn er in gehesen.

Hanteren jullie dit soort demontabele principes ook bij andere gebouwen en ontwerpen?

Is helemaal afhankelijk van de opgave. Wij hebben veel transformatie en renovatie projecten. In monumentale gebouwen zit weinig maatvastheid. Dan is het heel complex om prefab onderdelen te gebruiken, want je moet
het daarna toch nog dichten. Bij studentenhuisvesting kon het wel, omdat het heel veel bouwtijd scheelde. De tegelzetter, stukadoor, en kitter hoefden niet allemaal individueel langs te komen voor 75 badkamers. Dat is dus een belangrijke afweging.

We zijn in Deventer een bibliotheek aan het bouwen met een duurzame gevel. Deze bestaat uit keramische gevelelementen. Dit industriële product hangt er los in en kun je er gemakkelijk af halen. We proberen wel steeds meer circulair te bouwen.

_Wat hebben jullie geleerd van het ABT gebouw en wat hebben jullie meegenomen in het ontwerp voor andere gebouwen?_

Vooral het gedachtegoed, maar niet de details bijvoorbeeld, dus vooral IDF bouwen. Dit is niet zo extreem bij andere projecten van ons toegepast.

Het kantoorpand van Jouke Post was gelijktijdig klaar. Hij had hetzelfde idee, maar hij focusde juist op een korte levensduur. Hier is juist gericht op hergebruik en hoogwaardige producten. De schaal van dit gebouw is ook anders.

Het bleek heel belangrijk te zijn je uitgangspunten vanaf het begin duidelijk te hebben. Het doel om een IDF gebouw te maken was iets om vanaf het begin mee te nemen. Dit is bij het ABT kantoor ook vanaf het begin meegenomen.

_Zijn jullie nog tegen zaken aan gelopen die het moeilijk maakten om de uitgangspunten door te voeren?_

Dit was vooral voor de gevel het geval. We wilden dit zo dun mogelijk maken, maar we moesten wel aan een Rc-waarde voldoen. En we wilden aan de standaard hout maat voldoen.

Daarnaast was de overspanning van de betonplaat erg ambitieus. 7,20 meter was toen de langste betonplaat. ABT wilde perse een overspanning van 9 meter om ambitieus en innovatief te zijn, dit was toen op het randje van wat mogelijk was.

Het gebouw is heel erg onderhevig aan het stramien. Wij hebben geprobeerd wat variatie in het gebouw aan te brengen, bijvoorbeeld door de richting van de daklichten te wijzigen.
**Appendix V**

**List of materials for The Green House**

*Table 4. Materials used for the The Green House, based on Vejgo et al.*

*without quality degradation.*

<table>
<thead>
<tr>
<th>Material</th>
<th>Part of</th>
<th>New or secondhand</th>
<th>From</th>
<th>Connection</th>
<th>Cycle</th>
<th>Reuse?</th>
<th>Recycle?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum ducts</td>
<td>Services</td>
<td>New</td>
<td>-</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Plastic electricity cables</td>
<td>Services</td>
<td>New</td>
<td>-</td>
<td></td>
<td>Technical</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Textile ducts (air socks)</td>
<td>Services</td>
<td>New</td>
<td>-</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Aluminum frame ground</td>
<td>Skin</td>
<td>New</td>
<td>-</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>EPDM rubber roofing</td>
<td>Skin</td>
<td>New</td>
<td>-</td>
<td>Screwed</td>
<td>Technical</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Galvanized steel girder façade and greenhouse roof</td>
<td>Skin</td>
<td>New (based on greenhouse industry)</td>
<td>-</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>-(due to galvanization)</td>
</tr>
<tr>
<td>Glass inner façade first floor</td>
<td>Skin</td>
<td>Secondhand</td>
<td>Former office</td>
<td>Clamped</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Glass outer façade ground floor</td>
<td>Skin</td>
<td>New</td>
<td>-</td>
<td>Clamped</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Plastic tape to make (roof) construction air and watertight</td>
<td>Skin</td>
<td>New</td>
<td>-</td>
<td>Glued</td>
<td>Technical</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Plastic water and airtight foil</td>
<td>Skin</td>
<td>New</td>
<td>-</td>
<td>Fixed</td>
<td>Technical</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Reused wooden scrap boards for ceiling</td>
<td>Skin</td>
<td>Secondhand</td>
<td>?</td>
<td>Nailed</td>
<td>Biological</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Silicon, glass, aluminum PV panels</td>
<td>Skin</td>
<td>New</td>
<td>-</td>
<td>Screwed</td>
<td>Technical, hybrid</td>
<td>Yes</td>
<td>Yes, if layers can be separated</td>
</tr>
<tr>
<td>Steel perforated roof cover</td>
<td>Skin</td>
<td>New</td>
<td>-</td>
<td>Screwed</td>
<td>Technical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Material Description</td>
<td>Status</td>
<td>Type</td>
<td>Method</td>
<td>Technical</td>
<td>Upcycling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------------------</td>
<td>--------</td>
<td>------</td>
<td>--------</td>
<td>-----------</td>
<td>-----------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood + polystyrene (hybrid) prefab panels</td>
<td>New</td>
<td>-</td>
<td>Screwed Technical, hybrid</td>
<td>Yes</td>
<td>Yes, (H)CFK-free</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminium hand-rail/ balustrade</td>
<td>Space plan New</td>
<td>-</td>
<td>Screwed Technical</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ceramics brick pavement of ground floor</td>
<td>Space plan Secondhand</td>
<td>Quarry of Tiel</td>
<td>Stacked Technical</td>
<td>Yes</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete tiles green house floor</td>
<td>Space plan Secondhand</td>
<td>Pavement tiles</td>
<td>Stacked Technical</td>
<td>Yes</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fabric carpet meeting rooms</td>
<td>Space plan Secondhand</td>
<td>From old fishing nets</td>
<td>Stacked Technical</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural stone prefab outdoor staircase</td>
<td>Space plan New</td>
<td>-</td>
<td>Glued Technical</td>
<td>Yes</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perforated prefab steel ceiling plate</td>
<td>Space plan New</td>
<td>-</td>
<td>Screwed Technical</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand ground floor</td>
<td>Space plan</td>
<td></td>
<td>Stacked Biological</td>
<td>Yes</td>
<td>Yes (even upcycle: make glass out of it)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vinyl tiles in kitchen</td>
<td>Space plan New</td>
<td>-</td>
<td>Stacked Technical</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete prefab blocks foundation (stelcon plates)</td>
<td>Structure New</td>
<td>-</td>
<td>Stacked Technical</td>
<td>Yes</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galvanized steel columns and beams</td>
<td>Structure New</td>
<td>-</td>
<td>Screwed Technical</td>
<td>Yes</td>
<td>-(due to galvanization)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prefab sanitary facility</td>
<td>Stuff New</td>
<td>-</td>
<td>Screwed Technical</td>
<td>Yes</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RVS steel stair case and hand-rail</td>
<td>Stuff New</td>
<td>-</td>
<td>Screwed Technical</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wooden stairs</td>
<td>Stuff New</td>
<td>-</td>
<td>Screwed Biological</td>
<td>Yes</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Interview - The Green House

Jaap Bosch, cepezed, 4th of May 2018

“Hoe kan ‘design for disassembly’ op een succesvolle manier geïmplementeerd worden in het ontwerp van een gebouw om (bouw)afval te minimaliseren aan het eind van de levensduur?”

Om op je hoofdvraag terug te komen: het is een vrij algemene vraag en een algemeen antwoord zou kunnen zijn, dat je een gebouw niet meer ziet als een klassiek gebouw. Maar meer als een bouwpakket, dat al gemaakt is, letterlijk. Je kijkt dan veel meer naar gebouw componenten dan naar het gebouw aan zich. Wij, als bureau, deden dit eindelijk altijd al. In dit ontwerp is dat nog eens maximaal doorgevoerd. Van fundering tot dak is alles beschouwd als los element. Dit is dan aan te leveren op de bouwplaats en kan zonder grof hakken breekwerk ook weer verwijderd worden.

Het gebouw bestaat dus uit componenten. Hoe wordt het onderscheid tussen componenten gemaakt? Wordt de gevel dan gezien als iets anders dan de constructie of is het een kleinere schaal?

Het is een kleine schaal. Als hoofdopzet heb je de fundering, draagstructuur en in dit geval invulling dichte en open delen, en buiten spouwblad (+ spiegelglas panelen) en vloer elementen (in het skelet gehangen). Maar in de fundering kun je een kleiner fragment onderscheiden: prefab betonblokken in dit geval. Op elk schaalniveau is demontabelheid en denken in componenten terug te vinden. En dat maakt dat het letterlijk uit elkaar te halen is.

Is daarbij ook rekening gehouden met een grid/stramien?

Het grid is een bijzonder verhaal hier, in die zin. Misschien moet ik eerst wat meer achtergrond van het gebouw vertellen.

Als bureau benaderen wij gebouwen al jaren als bouwpakketten. De brug in Utrecht is zo ook benaderd, dit is in segmenten in elkaar gezet (inclusief bomen en boombakken).

The Green House was onderdeel van de renovatie van de Knoopkazerne. Het
hele gebied wordt in opdracht van Rijksvastgoedbedrijf nu en de komende jaren ontwikkeld. In fase 3 van dit plan, komt er een hoogbouwontwikkeling op de huidige locatie van The Green House. De overheid vroeg daarom om een tijdelijk gebouw voor de komende 15 jaar, zodat het niet leegstaat. Samen met het consortium werd besloten hier horeca in te plaatsen, de plint ligt op een strategische hoek (binnenstad + Croeselaan). Een horeca gelegenheid zal, omdat dit een kantoreengebied is, ook in de avonduren levendigheid met zich meebringen. Daarnaast is er een vergadercentrum, voor iedereen te huren. Later is het idee voor een kas er bij gekomen, zodat het restaurant zijn eigen groente, fruit en kruiden kan verbouwen.

De glaspanelen komen van de Knoopkazerne, tijdens de prijsvraag hadden we dit al bedacht. Toen is al rekening gehouden met het demonteren, opslaan en hergebruiken van deze panelen.

Was de kwaliteit van de panelen nog voldoende?
Ja, de kwaliteit was nog voldoende. De paneelmaat is 1500 mm bij 1150 mm. De panelen moesten letterlijk in deze vorm terugkomen, er werd niet gesneden. Dus het hele gebouw is uitgezet op deze maat van 1,5 meter. Dit is dus de kleinste maat, keer vier geeft dit 6 meter, daar is de draagstructuur op gebaseerd. Dit is een goede overspanningsmaat voor de houten prefab elementen voor de eerste verdieping en voor de lichtere staalplaat die is toegepast als dak.

In het gebouw zijn drie verschillende vloertypes gehanteerd. De begane grond bestaat uit een klinkervloer. De fundering is prefab betonnen blokken, het gebouw is heel licht dus dit is voldoende (geen palen slaan). De begane grond bestaat uit een laag isolatie, daarbovenop een verdicht zandbed met vloerverwarming en -koeling. En daarbovenop een laag hergebruikte klinkers, dit is de vloerafwerking.

Op de eerste verdieping is gekozen voor houten cassettes met isolatie. Dit zijn prefab houten elementen, alleen bij de begane grond van de kas zit er isolatie in, daar is een thermische overgang van binnenruimte naar de kas die geïsoleerd wordt als buiten. Op het dak is dit dikke pakket niet nodig (lagere vloerlast), hier is gekozen voor een dunne staalplaat. Het staalskelet is door dat vierkante stramien van 6 meter super generiek, je kunt alles uit elkaar halen en weer anders terugplaatsen, zolang het maar een veelvoud van 6 meter is. Die flexibiliteit wordt geboden door dit system.

Is het ook het idee dat het gebouw er na 15 jaar anders uit kan zien?
Ja, het is de vraag hoe circulair een gebouw is dat je uit elkaar kunt halen,
maar vervolgens maar op een manier weer in elkaar kunt zetten. Misschien vraagt een andere locatie om een andere configuratie. Dat is het voordeel van zo’n generiek system.

Het gebouw kan gezien worden als een *kit of parts* van losse elementen die samen het gebouw vormen. Op de bouwplaats zelf hoeven weinig handelingen verricht te worden, dat is fijn in de stad, door gebruik van *demontabele verbindingen* (schroeven). Het gebouw is zo simpel en no-nonsense mogelijk (geen rocketscience), heel elementair.

*De elementen zijn een combinatie van tweedehands en nieuwe prefab materialen?*

Het grootste deel is nieuw, vooral omdat veel tweedehands materialen nog niet (goed) voorhanden zijn. Circulair bouwen doet nu pas zijn intrede. Er werd hier voorheen geen rekening meer gehouden, materialen zijn dus lastig te vinden. Al het nieuwe moet wel goed her te gebruiken zijn, goed los kunnen en niet van vorm veranderen. De spiegelglas panelen en klinkers zijn wel tweedehands, dak van de kas is ook hergebruikt.

Staal skelet heeft allemaal dezelfde kolom- en ligger afmetingen, zelfs de toiletgroep is prefab. En niet vast/gefixeerd in het gebouw, normaal wel daar gaan dan leidingen naar beneden. Dit kan nu overal geplaatst worden.

De gevel staat los van de draagconstructie. Op de eerste verdieping zijn delen dichtgemaakt, met houten cassettes. Daaronder een eenvoudig vliesgevel systeem. Zo kan pur voorkomen worden, nu gedaan met rubbers, ingeklemd.

De gaten openingen worden vaak gekit, nu afdekplaat met rubbers. Er is dus rekening gehouden met het gemakkelijk uit elkaar halen van elementen achteraf.

De tweede huid is bevestigd aan traliespanten, een standaard element uit de kasbouw. De glaspanelen zijn ingeklemd.

*De gevel is niet luchtdicht?*

Het heeft een open spouw, ventilatiespouw met warme lucht die boven wordt afgevoerd. Er zit een rooster aan de onderkant, zodat er geen vogels in kunnen vliegen. We hebben een glaspaneel bij de sloop meegenomen en opgemeten, want het gebouw is er op uitgezet. Ook om te kijken hoe het licht hierdoorheen zou vallen.

Het dak is dus ook losse onderdelen. Op het dak staan pv panelen en een compact installatiedoosje (pijpen vanuit keuken eindigen hier). Dak is netjes georganiseerd want omliggende kantoren kijken hierop. De nokken van het dak zijn hierop uitgelijnd.
Zijn de gekozen elementen standaard elementen?

Geen nieuw ontwerpen dingen, maar standaard of al bestaande elementen: stelton platen met beton blokken, klinkers, oude stoeptegels in kas. Er zijn dus geen unieke elementen.

In hoeverre is er rekening gehouden met de levensduur bij het ontwerp (ongeveer drie keer 15 jaar)?

Het ene component zal langer meegaan dan het andere. Dingen als dakbedekking en folies zijn eerder versleten. Aan de andere kant als het makkelijk uit elkaar te halen is, een staalskelet gaat prima nog twee keer 15 jaar mee, geldt ook voor glaspanelen. De levensduur wordt vooral beperkt door de plek waar de materialen zitten en hoe ze verbonden zijn. Bij de kazerne kon veel materiaal niet worden hergebruik omdat het vastgebakken zat.

Er is dus rekening gehouden met de levensduur voor de materiaalkeuzes?

Voor folies en dakbedekking zijn er geen alternatieven die 15 jaar meegaan. De glazen gevel en houtencassettes wel, en deze zijn gemakkelijk te recyclen. De fundering en traliespannen kunnen heel lang mee.

Over het recyclen van materialen, sandwichpanelen zijn combinatie van materialen, is dit gekozen om hergebruik te vergemakkelijken of is dit ook recyclebaar?

Hout is gemakkelijk te recyclen, maar beschadigd snellen dan beton of staal. De sandwich panelen zijn gevuld met piepschuim, dit is te recyclen maar hier is energie voor nodig. Binnenwanden zijn van glas, komen uit een ander kantoorgebouw. Dit is vooral gericht op hergebruik in plaats van recyclen, dan zou het downcycle worden. Dan is het ook het beste om het in de huidige vorm te kunnen gebruiken. De kwaliteit moet dan voldoende zijn.

Wat zijn de consequenties van deze levensduur?

Een hoop elementen in het gebouwen worden geleased voor 15 jaar, bijvoorbeeld verlichting (dit wordt per maand betaald). Daarna kan de verlichting in een ander gebouw terecht komen. De contractduur van het consortium duurt 15 jaar en zij zijn en blijven eigenaar van het gebouw. Dat maakt het voor het consortium aantrekkelijk om de levensduur te verlengen, omdat zij eigenaar zijn en er weer geld mee kunnen verdienen. Daarom moet de waarden van de materialen behouden worden (dus gemakkelijk uit elkaar) omdat anders nog steeds te sloopkogel er tegenaan gaat.

Aan het eind van de 15 jaar worden de geleasde dingen eruit gehaald, de leverancier bepaalt waar dit naartoe gaat. Met de overige delen kan gekeken
worden of dit herbouwd wordt of ook naar andere gebouwen gaat. Dit hangt af van de vraag op dat moment. Dit soort flexibiliteit moet zo’n gebouw bieden.

In hoeverre is er rondom het gebouw rekening gehouden met deze principes? Bijvoorbeeld de trap

Dat is een grappig verhaal. Tussen fase 1 en 3 zit fase 2, die gaat binnenkort al van start. Dit houdt de bouw van twee torens aan het spoor in. Met de Rabobank is afgesproken om bouwverkeeroverlast te beperken, dit is ook gunstig voor het terras van The Green House. De trap is demontabel om zo een verbinding van de Croeslaan naar het plein erachter te maken om het zo voor bouwverkeer bereikbaar te maken. De trap bestaat uit losse elementen die er met een kraan uit te hijsen zijn, dit zijn los opgelegde kanaalplaten.

De inrichting van het parkeerterrein bij de Knoop is tijdelijk, in afwachting van parkeergarage op termijn. De bomen hier zijn afkomstig van het voormalige parkeerterrein, bomen zijn dus weer herplant.

In hoeverre heeft demontabelheid negatieve consequenties gehad voor het ontwerp?

Zaken moesten vooral anders beschouwd worden, bijvoorbeeld de hergebruikte binnenwanden uit een ander kantoor, er bleek een horizontale stalen regel midden in dit glas te zitten. Dit was eigenlijk niet wenselijk, esthetisch gezien. Hier moet je als ontwerper wel flexibel mee om kunnen gaan.

Verder zijn installatietechnisch wat zaken niet helemaal lekker gegaan (hemelwaterafvoer is niet goed weggewerkt) waarschijnlijk door bouwsnelheid. Cepezed had weinig invloed op de bouw, er vond weinig afstemming met installateurs plaats. De installatiekanalen zijn gemaakt van luchtzakken (in plaats van blik), dus beter her te gebruiken. Er is flexibel omgaan met esthetische kwaliteiten, zonder dat de algehele sfeer eronder leidt. Het blijft natuurlijk een heel charmant dingetje. Voor dit ontwerp vonden wij het ook niet belangrijk hier heel strikt mee om te gaan, wellicht doe je dat bij een andere opgave wel, bijvoorbeeld bij de Knoop kazerne. Daar pas je misschien wel een verlaagd plafond toe, dat vonden we hier niet nodig en juist bij de functie passen om het niet te doen.

De tijdelijke rechtbank in Amsterdam, ontworpen door cepezed, is ook een bouwpakket. Maar dit gebouw had strengere esthetische eisen, representatief gebouw, meer aandacht voor dit soort zaken. Dit is vanwege de gemoeide kosten en wij konden er dichter op zitten. The Green House is een bij-project geweest (van de Knoop) en heeft een minder representatieve functie.
*Past deze manier van werken bij het bureau?*

Denken in flexibele bouwpakketten heeft er altijd ingezeten. Een voorbeeld hiervan is de opgave voor een oude kerk in Helmond, daar werd gevraagd een theater te maken, de tribune bestaat uit losse componenten en is in de kerk gemonteerd. En staat los van de oude structuur. Dit is ook toegepast in woonhuizen, zit dus altijd wel in hun werk. Deze filosofie brengt efficiëntie en bouwsnelheid met zich mee, zonder te korten op de kwaliteit. Dit was gunstig in tijden van crisis. Dit staat haaks op de *SuperDutch* beweging.

*Hoe staat het met het ‘bouwteam’ van cepezed?*

Dit is weer in het leven geroepen. Het is een soort bouwconsortium of aannemerstak, een aantal mensen van ons hebben dit opgepakt. We merkten bij aanbesteding dat de aannemer een andere richting inslaat, lastig om ontwerp goed door te voeren. Wij kiezen dus zelf het bouwteam en onze onderaannemers. Zo kan beter worden toegezien op uitwerkingsfasen en kan er beter kwaliteitscontrole worden gewaarborgd. En stukje kostenefficiëntie, veel aannemers hebben veel overheadkosten. Dit is niet ingezet bij The Green House, was een DBFMO en is door het consortium uitgevoerd. Cepezed was onderaannemer van dit consortium.

*Zijn jullie tegen andere zaken aangelopen, regelgeving, brandveiligheid?*

Nee, het was een heel gangbaar gebouw. De vergunning werd gemakkelijk aangevraagd, er was geen sprinklerinstallaties nodig, en één branduitgang was voldoende. Het gebouw viel bij welstand heel erg in de smaak. Geen bijzonder vergunningstraject.

*Wat zou je anders hebben gedaan?*

Installaties zouden beter verwerkt moeten worden, kwam door tijd en vraag om alleen een casco te ontwerpen. Hier zouden zij liever meer invloed op gehad willen hebben. Daarnaast hebben zij de ambitie om nog meer bestaande materialen ingezet te hebben. Al met al, geslaagd dingetje.

*Wat heb je ervan geleerd?*

Veel was al bekend vanuit eigen werkwijze. Eventueel zouden we nog meer kunnen kijken naar welk element op welke plek het beste geplaatst zou kunnen worden; bijvoorbeeld keuze voor verschillende typen vloeren in het gebouw. Verder redelijk *no-nonsense*. Geen grote nieuwe openbaringen voor ons. Meer een voortgang/weer een toepassing van wat wij al deden. Ook in de details, sommige zijn letterlijk toegepast uit bestaand werk: bijvoorbeeld de detailering van het cart-gebouw, dit is toegepast voor de gevel en het geperforeerde stalen plafond (ook in eigen kantoor toegepast).
## List of materials for Townhall at Brummen

Table 5. Materials used for the Townhall at Brummen, based on Vefago et al.
*without quality degradation.

<table>
<thead>
<tr>
<th>Material</th>
<th>Part of</th>
<th>New or secondhand</th>
<th>From</th>
<th>Connection</th>
<th>Cycle</th>
<th>Reuse?</th>
<th>Recycle?*</th>
<th>Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic exhaust grill</td>
<td>Services</td>
<td>New</td>
<td>-</td>
<td>Screwed</td>
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<td>-</td>
<td>-</td>
<td>BAM techniek</td>
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<td>Plastic supply grill</td>
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<td>New</td>
<td>-</td>
<td>Screwed</td>
<td>Technical</td>
<td>-</td>
<td>-</td>
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</tr>
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<td>-</td>
<td>Screwed</td>
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<td>Yes</td>
<td>BAM Techniek</td>
</tr>
<tr>
<td>Glass elevator</td>
<td>Services</td>
<td>Secondhand reuse</td>
<td>Former demolished building</td>
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<td>-</td>
</tr>
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<td>-</td>
<td>Screwed</td>
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<td>-</td>
</tr>
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<td>Wooden railing staircase</td>
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<td>-</td>
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<td>-</td>
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<tr>
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<td>-</td>
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<td>-</td>
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<td>Yes</td>
<td>-</td>
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<tr>
<td>Glass roof openings</td>
<td>Skin</td>
<td>Secondhand, recycled</td>
<td>-</td>
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<td>Yes</td>
<td>Brakel Atmos</td>
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<td>Yes</td>
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<td>Lime stone threshold beneath door</td>
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<td>-</td>
<td>Fixed</td>
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<tr>
<td>Sediment/ green roof</td>
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<td>-</td>
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<td>Mostert de Winter</td>
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<td>-</td>
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<td>-</td>
<td>Screwed</td>
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<td>-</td>
<td>Screwed</td>
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<td>-</td>
<td>Oskamera</td>
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<td>Yes</td>
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<td>Prefab insulated wooden-mineral wool floor/roof</td>
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<td>Fixed</td>
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<td>Cardboard reception desk</td>
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<td>Yes</td>
<td>Yes</td>
<td>Neenah Coldenhove</td>
<td>-</td>
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</table>
Interview - Townhall Brummen
Marijn Emanuel, RAU & Madaster, 23rd of May 2018

Ik wil het interview graag starten met stellen van mijn hoofdonderzoeksvraag. Ik zou graag u reactie willen weten op deze vraag aangaande het gemeentehuis in Brummen:

“Hoe kan ‘design for disassembly’ op een succesvolle manier geïmplementeerd worden in het ontwerp van een gebouw om (bouw)afval te minimaliseren aan het eind van de levensduur?”

Dit is wel een hele algemene vraag, waar al een hoop studie naar verricht is (zie o.a. Durmisevich “Design for disassembly”). Op jouw “hoe” vraag, gaat het wat mij betreft vooral om de rol van de aannemer. Die moet overstappen van een traditionele bouwmethode naar een “industrieel, logistiek” proces. Randvoorwaarden voor disassembly zijn o.a. standaardisatie, prefab. Een aannemer moet het bouwproces nog meer gaan aansturen als een logistiek proces.

Het gebouw is ontworpen om montage en demontage eenvoudig te maken. In hoeverre kunnen de componenten, na demontage, in gezet worden in andere configuraties of andere gebouwen?

Het gebouw is voor 90% demontabel, wat blijft als ‘afval’ over na demontage?

Traditioneel denken. Koud watervrees om zaken te proberen die nog niet eerder gedaan waren - met name procesmatig. Technisch weinig zaken - het kan gewoon heel goed ontworpen en gebouwd worden.

Dat zit met name in de funderingsconstructie en de technische installaties, daar

Appendix VIII
waar het om slijtage gaat. Er is natuurlijk ook weinig zicht op voortschrijdende techniek en kwaliteit.

*Onderdelen van het oude gebouw zijn hergebruikt. Op basis waarvan zijn herbruikbare delen uitgekozen? Wat is de kwaliteit van deze onderdelen?*

Het gaat hier met name om alle steenachtige materialen (beton, baksteen). Die zijn vermalen en gebruikt als gevelmateriaal in schanskorven.

*Het gebouw heeft een tijdelijke levensduur van 20 jaar. Daarnaast wilde de gemeente dat het gebouw in 9 maanden gebouwd zou kunnen worden, is dit behaald en hoe?*

Ja - omdat er heel goed nagedacht is over de opzet en bouwmethodiek (omdat het ook een omgekeerd “bouw/demontage” proces kende), was de bouwtijd zo snel: een voorbeeld van een bouw als goed opgezet logistiek proces.

*Wat wordt hiermee bedoeld? Dat er gedacht is vanuit de mogelijkheden tot demontage?*

Ja – omdat je hebt ontworpen vanuit demontage – is het bouwen (namelijk: monteren) ook sneller te doen.

*Blijft de villa na demontage ongeschaad?*

Er is een nieuwe opening gecreëerd voor de loopbrug. Daarnaast zullen de aansluitingen van de gevel villa en nieuwbouw hersteld/geheeld moeten worden.

*Wat voor aansluiting zit hier?*

Weet ik niet zeker. Ik vermoed dat er “pluggen” in de muren zijn aangebracht en moeren die de pui vastzetten tegen de muur van de villa. En afdichting met rubbers.

*Van wat voor type verbindingen is gebruik gemaakt? In hoeverre is hierdoor hergebruik van de onderdelen bevorderd?*

Veel geschroefde / bout&moer verbindingen. Dus veel droge verbindingen waarbij het losmaken geen schade toebrengt aan de onderdelen.

*Het gebouw is opgenomen in Madaster, kunt u hier iets over vertellen?*

Dat zou kunnen, maar ik weet niet of het daadwerkelijk al in Madaster staat. RAU is wel van plan al haar gerealiseerde projecten - daar waar mogelijk op basis van de beschikbare IFC (Industry Foundation Classes) modellen - in Madaster te registreren. Maar daar komen ook de constructieve en installatietechnische modellen bij - en idealiter de CAD modellen van de diverse leveranciers (gevel, glaskap, constructie, binnenwanden, technische installaties).

*Zou u het, achteraf bekeken, zo weer doen op deze manier? Wat heeft u van dit project*
geleerd?

Achteraf bekeken wil ook zeggen met de lessen die we geleerd hebben en de stand van de techniek nu. Dus niet helemaal op dezelfde manier maar qua grote lijn/concept blijft het wel staan. In ieder geval zou ik veel meer aandacht besteden aan het informatie vastleggen: de IFC bestanden van alle partijen, met name de leveranciers. Waarschijnlijk nog verder gaan met standaardisatie in maatvoering en producten.