Circular material & product flows in buildings

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1. INTRODUCTION

The advantages of materials and products that can function in a circular model are quite well studied, in short: less waste and less exhaustion of resources on the one hand, and a focus on quality – in design, material use en the producer-customer-relation – on the other. But how does this work for a complex accumulation of products, services and materials, as with a building? That is not an easy task. If circularity is a criterion, it should be known what is stored in the building on a very detailed level. In the current build-use-demolish paradigm we get away with a rather rough estimation of the materials in a building, and the corresponding waste management strategies are usually limited to low-grade applications. In order to shift to more *regenerative* models with regard to resource use, radical changes are required.

This accounts specifically for materials. With an ever-increasing number of energy-efficient building concepts, the relative importance of materials grows. There is a continuous search for knowledge concerning materials in existing buildings on the one hand, and designing for high-quality reuse on the other. With all technical, organisational, legal and financial aspects involved, it is a complex interdisciplinary task. The technical side alone – in which lies the focus of this project – shows many challenges. How does one design and build smartly for the future without being distracted by today's issues? And which stakeholders influence which building components over the years? One thing is certain: tracking materials and products – and how they have been applied – is unavoidable. This 'track record', which should constantly be updated, helps to keep the circular intentions – and possibilities – at a high level.

There are multiple initiatives around the concept of enhanced material registration for buildings. *Material passport* is a label utilised in this respect. The underlying thought is that an accurate and detailed registration of products and materials, as well as their application in the building, is crucial for a correct implementation of the circularity concept in buildings. However, there is very little consensus about the exact content, method and value of such an instrument.

This report aims to align the knowledge, skills and initiatives within this theme, in order to co-evolve rather than each initiative running its own race, which is unfortunately still happening in practice. Secondly, we focus on two essential aspects that need further study in order to facilitate the implementation of circularity in the built environment:

A) A set of preconditions for the performance of materials, products, services and buildings in the case circularity is a leading ambition.

B) A stepwise approach to facilitate circularity in building- and renovation projects, which can be applied by multiple stakeholders.

2. POSITIONING & PROCESS

2.1 Positioning of the theme

Within the broad subject of Circular Building, this project focuses specifically on building materials. Other evenly relevant themes, like energy or water, will not be covered. Within the theme of materials, however, there are still many nuances to define. For example, concerning terminology, interpretations and conditions. In this chapter, a further positioning and demarcation of the subject of this research will be explained.

Circular Construction vs. Circular Buildings

In this report we will primarily talk about 'circular construction' or 'circular building' as opposed to 'circular building*s*'. The reason for this is our focus on the fact that a building is not a static physical object but a collection of – hierarchical – functions and processes that are subject to change. Circular building, being a verb and not a noun, can be addressed as the 'dynamic total of associated processes, materials and stakeholders, led by the owner/user'. A building can be a temporary manifestation of that activity. For the sake of materials and products, the stages before and after this physical temporary manifestation are just as important.

Resources, materials and products

The terms resources, materials and products are not synonymous, even though they are often used together. An important distinction has to be made. One could state that products are made up of materials, which consist of raw material resources. With circularity in mind, each level demands for other choices. Homogeneity can for example be an important condition for a material in order to maintain quality in the next cycle, but may not necessarily be a preferred characteristic for a resource and its re-application in a new product.

Our focus is on materials and products for the building industry with the intention to support a correct application of resources on macro level. To explain that, the formula of Figure 1 can be used in which: M= the amount of material (kg per year), P= the amount of products, W= the weight of the products, L = the age of the products, and R = regeneration. The step from linear to circular can be made by adding R to the equation on various levels i.e. maintenance, redistribution, renovation, etc.

$$M = P*W/L \rightarrow M = P*W*(1-R)/L$$

Figure 1: Formula for the transition from linear to circular material use

Existing buildings and new buildings

Acknowledging the fact that the vast majority of the buildings we will be using in the upcoming decades have already been built, we cannot neglect the existing building stock. In the Netherlands, however, this existing building stock imposes many obstacles when judging these buildings from a 'circular' point of view. Although for some construction materials a reuse market exists because of proven quality and ease of demounting, most materials cannot easily be retrieved and reused. For example because the buildings cannot be disassembled or materials have been irreversibly mixed. Securing quality preservation and material recovery of the building (components) needs to be integrated at a very early stage in the design process of a project.

For the purpose of this report it is therefore more relevant to focus on the future building stock, rather than the existing building stock, as we want to define how circular starting points can be integrated into the design process of buildings still to be built in order to facilitate resource preservation. We are well aware, however, that an integrated and realistic approach towards the building stock as a whole – in contrast to a 'tabula rasa' approach – would have an added value. Also renovation and transformation projects contain opportunities beyond traditional reuse and *down cycling*[1] of materials. If we approach the case from an *Open Building* point of view, for example, in which the existing structure is the 'support' or 'base building' and – parts of – the renovation the 'infill' or 'fit out', there are definitely opportunities for circular material use. More on Open Building can be found in chapter 3.

2.2 Process

The research is structured around a series of four workshops in which data, knowledge and experiences have been shared, discussed, tested and redefined. The core group comes from the Delft University of Technology (Faculties of Architecture and Mechanical, Maritime & Materials Engineering), the Rotterdam University of Applied Sciences, Knowledge Centre RDM (Rotterdam Dry-docks Company), the Knowledge Platform of Sustainable Resource Management and the BRIQS Foundation. Next to this core group, there are external experts involved in each workshop. These experts have various backgrounds, and are invited for their specific knowledge regarding subject or projects.

The lessons learned during the workshops resulted in a set of parameters. We aim to integrate these parameters in a clear and 'ready to use' method, without ignoring the complexity of the question.

Furthermore, this method will be tested in a specific project: the *Active Reuse House* (ARH), located in the *Concept House Village* area on Heijplaat, Rotterdam. This area is designated as a test-bed for sustainable and circular development. Ultimately, the ambition is to apply the method on a larger scale. Figure 2 visualises the structure of the process.

[1] Down cycling refers to – a cascade of – new application of the used material in a way that decreases quality.

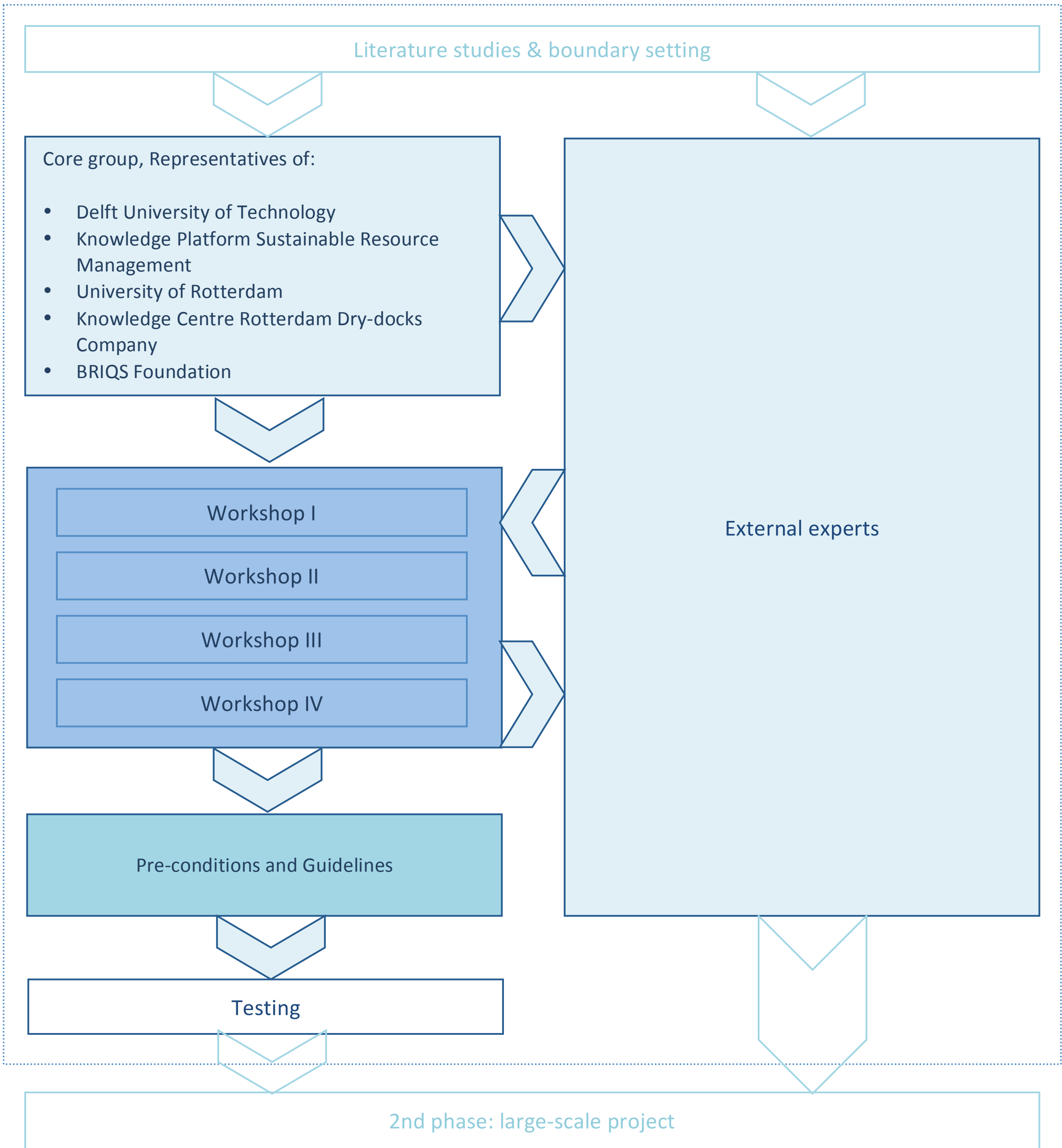


Figure 2: Structure of the process

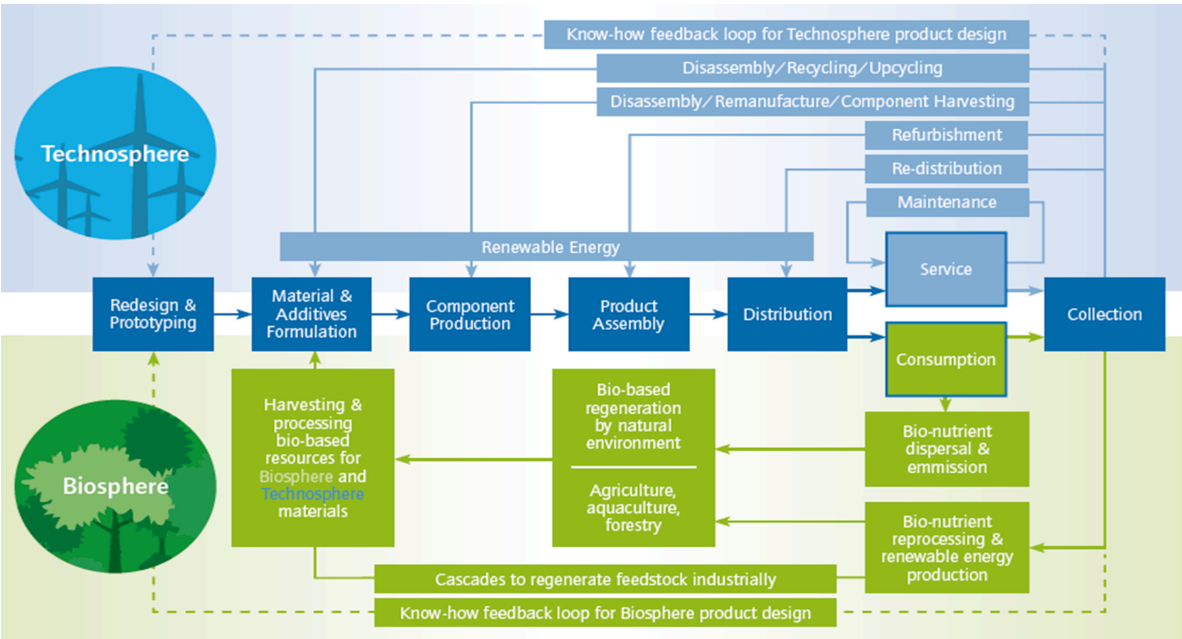
3. BACKGROUND

3.1 Circularity

In the Netherlands, *circularity* is a trending topic and on its way to becoming the new *sustainability*, with its diversity of interpretations. In its most basic form, we explain circularity as being a regenerative approach to resources – and all derived materials and products – based on high quality cycles and ideally without the addition of 'virgin' resources. We say 'ideally' because we focus on the *transition* from our current, predominantly linear system towards an envisioned ideal, circular version. A pragmatic explanation of the concept can be found with regards to the so called *Circular Economy* (CE): "a living economic system, focused on structural changes in the existing economic model, with value creation based on 'use' instead of value destruction based on 'consumption'" [Het Groene Brein, 2014]. CE is based on the assumption that there are short cycles and long cycles of maintenance, reuse and recycling [Ellen MacArthur Foundation, 2012]. This proposition is a legacy of the Cradle-to-Cradle® concept (C2C), in which waste is regarded as 'food' and the distinction is made between biological and technological cycles [Braungart & McDonough, 2002].

The above mentioned concepts take account of the enormous transition that is required to change our current way of working, but that they believe a symbiotic relation between people and nature is the ultimate goal and that it is the best – if not only – way to keep up with the (growing) welbeing of the world population.

C2C – more clearly than CE – focuses on the ambition for a positive impact in which circularity is only a means and not the goal itself. After all, if we make the wrong products circular, we may make matters even worse. Figure 3 shows the material flows in a circular economy, in which the biological (green) and technical (blue) cycles can be distinguished as well as the different grades of reuse. The diagram also defines Knowledge feedback, as a way of stimulating continuous improvement.



[Source: EPEA & Returnity Partners]

Figure 3: Material flows in a circular economy

The step from linear to circular increases the complexity of systems and subsystems due to the increasing amount of links and/or the intensification of their nature. Table 1 shows interrelated domains and aspects that are all – some more than others – influenced by the transition from a linear to a circular building industry. This report accentuates technical and design aspects.

Table 1: Examples of linked domains and aspects

Domain	Examples of aspects		
Social	User-oriented	Employment	Health & Safety
Technical	Purity	Recycling	Connections
Design	Aesthetics	Division	Diversity
Financial	Total Cost of Ownership	Life Cycle Costing	Profit
Legal	Ownership	Extended Producer Responsibility	Standardisation
Organisation	Communication	Logistics	Governance
Contextual	Environment	Nuisance	Contextual Integration

3.2 Building layers

A building should not be seen as a static object but as a dynamic set of subsystems. This theory is consistent with the ideas of for example Steward Brand, who proposed in the 1990s that buildings should be seen as 'learning objects or processes' [Brand, 1994]. With the slogan '*all buildings are predictions, and all predictions are wrong',* Brand gave insight into the problem of buildings that were not designed for change; components with a long technical or social lifespan were being integrated with components with a much shorter life span. He therefore defined his so-called *shearing layers of change* to introduce a hierarchy for the components of buildings. This is not only relevant within the theme of material use but also in economic, legal and logistic issues. Brand distinguished 6 different layers (see Figure 4): Predicted lifespan of these layers – or of the products and materials used in them – vary from virtually infinite (the site) to 1-10 years (the stuff) and all that is in-between.

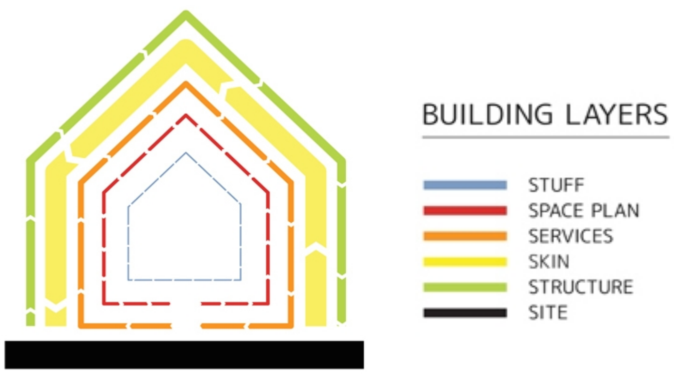


Figure 4: The building layers by Brand

A few decades earlier, John Habraken had proposed a related concept. Habraken's book *Supports, An Alternative to Mass Housing* was a reaction to the social-cultural phenomenon of post-war mass housing [Habraken, 1961]. He proposed a distinction between the generic load bearing structure of a building on the one hand, and specific interior filling of the user units on the other: Open Building.

The load bearing support – or *base building* – will have a longer life span than the interior filling – or *fit out* –, which is strongly influenced by specific, user related dynamics. (See Table 2)

Table 2: Distinction between base building and fit out

	BASE BUILDING	FIT OUT
MAIN CHARACTERISTIC	Long lifespan, Fixed, Architecturally strong	Short lifespan, Variable, Demountable
SCOPE	Main structure, Collective spaces	Partitioning walls Kitchen, bathroom, MEP services (and possibly façade elements)
MAIN INFLUENCE	Owner, Architect, Contractor	Occupant, (Interior) architect, Maintenance services, Fit-out industry
LINK WITH CIRCULARITY	Long lifespan, stable or increasing returns on investment	Adapts to change, Less waste, Facilitates circular reuse

The base building roughly matches the site and structure layers of Brand, whereas the fit out can be compared to Brands services and space-plan layers. Brand's stuff layer is excluded in the Open Building concept, as in Habraken's reading this is by definition the realm of the user. Brand's skin layer, finally, could belong to either the base building or the fit out sphere, depending on the project. In the end, the real distinction lies not in naming the different components, but in the differentiation of predicted life spans on the one hand and decision-making by a stakeholder on the other.

As opposed to buildings in which components are entangled and hard to retrieve, Open Building and Brand's shearing layers theoretically support flows of building parts at diverging moments in time. A connection with our research is therefore inevitable. In the materialisation of the supporting base building (with a long life span), circularity will usually result in very different opportunities and challenges than with regard to, for example, the building services. The underlying principles can be filed under *Adaptable building*, which is further explained in the next section.

3.3 Adaptable building & Flex 2.0

In this study we adhere to the Flex framework of Geraedts [2015], rooted in the notion that the capacity of a building to adapt to social or functional changes defines its future value. In order to understand the 'adaptability capacity' of a building, Geraedts developed a list of indicators organized according to the layers defined by Brand. Not all indicators are directly relevant in respect of materials and products for circular building. Table 3 shows a selection of indicators that have most relevance in this respect. The left column shows the Brand layers to which they refer. If we analyse this selection of indicators, we can roughly distinguish three categories: dimensioning, connections and miscellaneous (for aspects that overlap or fall outside of the first two categories). This is where the relation between circular building and adaptable building becomes most apparent.

Furthermore, Geraedts defines a way to evaluate each indicator on a scale from 1 to 4 (in which 4 is 'good'). Table 4 displays one indicator per category as well as an explanation of a desired scenario for a 'good' score of 4. This scoring system and the underlying theory, however, still need further research and debate in order to render them fair and measurable.

Table 3: Selection of Flex 2.0 indicators with direct relevance for material and product use

STRUCTURE	Dimensioning system: modular coordination
	Dimensioning system: facade-grid
	Extension/Reuse of stairs and elevators
	Load bearing capacity of floors
	Load bearing floor systems
	Self bearing facade
	Geometry of Columns
	Use of fontanel constructions
	Fire resistance of load bearing structure
	Interruptions in structure
	Connection detailing of foundation en ground bound installations
	Building technology of load bearing structure
	Thermal and acoustic quality of floor insulation
SKIN	Demountable facades
	Reuse windows
	Daylight entry
	Thermal and acoustic quality of façade insulation
	Connection detailing of facade components
SERVICES	Over dimensioning shafts
	Over dimensioning the capacity of installations
	Over dimensioning the capacity of facilities
	The way installation components can be disassembled
SPACE PLAN	Inter-changeability of fit out components
	Movable separation walls
	Connection detailing of partition walls
	Individual fit out / finishing

Table 4: Indicator categories with examples and explanations

CATEGORIE	EXAMPLE INDICATOR	EXPLANATION AND VALUE 4 =GOOD
Dimensioning	Over-dimensioning of shafts	The more pipes and shafts of installations have been over-dimensioned, the easier it is to expand the building. Good (4) = 90<% of the shafts
Connections	Connection detailing of partition walls	The easier it is to detach partition walls, the more flexibility there is in redefining spaces, in coping with changing demand in facilities and services as well as the overall building quality, and the easier it will be to split up the building. This also makes it easier to replace and (re) divide units and their place in the building, giving more possibilities for relocation of the units within or outside the building and making it possible to split up units even further. Good (4) = standardised (not project-bound) adjustable coupling pieces
Miscellaneous	Presence of fontanel constructions	The more fontanel construction have been applied in load bearing walls and/or floors, the easier it is to subdivide and re-allot spaces in the building and subsequently the better the changing demands of the user can be met. Good (4) = no load bearing walls present

3.4 Aspects of Adaptable

The term 'adaptable' itself has been subject to study, since a building can be 'adaptable' in many different ways. Figure 5 shows diverging aspects of adaptability, as proposed by Schmidt et al. [2009] and gives insight into the complexity of its meaning. The program *Adaptable Futures* at Loughborough University (UK) has done interesting work on this matter. Table 5, based on their work, shows how an adaptable design can have varying aspects and how these relate to the building layers of Brand [Schmidt et al, 2009]. Even more interestingly, it gives insight into which stakeholders influence these aspects, primarily being the user or the investor. In the table, the colour green is used to show to which extent the three variables – adaptable aspect, building layer and stakeholder – overlap. Once again, this shows that ownership issues play a big role in the feasibility of circular models. A correct distinction between legal and economical ownership is evenly important. In the Netherlands, for example, a change in economical ownership is not always legally supported, making adaptability less efficient implementable.

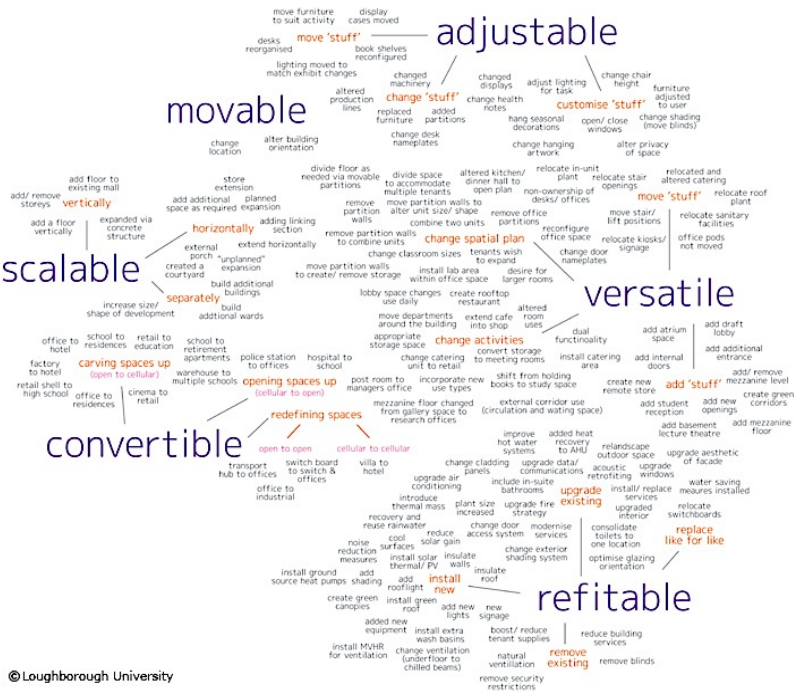


Figure 5: Positioning of adaptable aspects

Table 5: Adaptable aspects, building layers en decision-making

ADAPTIVE	BUILDING LAYERS: STUFF	SPACE	SERVICES	SKIN	STRUCTURE	SITE	DECISION-MAKING
ADJUSTABLE *(Change in task)*							USER
VERSATILE *(Change in space)*							USER
REFITABLE *(Change in performance)*							USER/INVESTOR
CONVERTIBLE *(Change in use)*							INVESTOR
SCALABLE *(Change in size)*							INVESTOR
MOVABLE *(Change in location)*							INVESTOR

4. WORKSHOPS

Four workshop sessions were held at Delft University of Technology's Faculty of Architecture. Each of the workshops had a specific theme and consisted of a specific group of invited experts to elaborate each topic fully. The workshop-themes were:

1. Introduction on the theme of Circular Building
2. Flex 2.0 and the Adaptability of Buildings
3. Building Materials and their Properties
4. Economic Models and Circular Building concepts

The aim of the first workshop was to get a grip on the concept of Circular Building. What is the role of resources, materials and products in it? Who are the current stakeholders and how may this change in the future? How does circularity relate to adaptable and open building concepts? What are the main obstacles? And which key themes can we define? Three angles were explored: freedom of choice, preservation of quality, and management of resources.

The second workshop was dedicated to the Flex 2.0 framework, as developed – and presented – by Rob Geraedts. Flex 2.0 is based on the notion that adaptable capacity defines the future value of a building, alongside sustainability and financial performance. The aim of the workshop was to explore the relation between adaptable building and circular building and whether they may resolve similar issues. To a certain extent, circular building demands for flexible and adaptable buildings in order to facilitate change without loss of material quality. Defining different building layers is essential to both. However, for circular building the focus lays on the materials used and their quality, recyclability and health. Adaptable building – from the viewpoint of Open Building – primarily defines the quality relating to decision power between base building and fit out domains, but not the actual material component quality itself.

The third workshop concerned resources, materials and products. What kind of materials and products are traditionally being used in the building industry and how will this change when moving towards a circular building industry? The aim of the discussion was to define properties and conditions that stimulate circularity. What is the reuse-potential of a certain material or product? How can it maintain its quality after the lifespan of a building? The focus automatically shifted from materials to connections. Two guest speakers were invited to elaborate on their vision of the subject:

- Jouke Post (XX Architecten), who designed an office building in which all elements have a predicted lifespan of 20 years, and in which all connections can be dismantled. He believes that circularity does not necessarily mean standardisation of dimensions and elements, but that prefabrication and adaptability can also lead to customized buildings and components, whilst not limiting architectural freedom.

- Bas Slager (Repurpose), on matching stakeholders from the demolition industry to architects/builders in order to generate flows of reusable materials. His view on circularity is more from a present-day point of view: how do we maximise reuse of existing material?

During the fourth and last workshop the focus lay on exploring the economical possibilities and obstacles in a transition from a linear to a circular economy. The most important subjects discussed were: business, procurement, laws and regulations, digitalisation and private/public added value. To support this theme, two guest speakers were invited:

- Ruben Vrijhoef (TU Delft) on the role of BIM (Building Information Model) and computerization as a way to stimulate and regulate material reuse. He pinpointed areas of tension between solutions for our current linear economy and future propositions for a circular economy.

- René de Klerk (Rendemint) on his experience with managing the (design) process for the interior of an office building in such a way that it is fully circular. The essence, according to him, lays in the contracts with suppliers, a shift in responsibilities, and in respecting the full meaning of circularity i.e. all the way and including social factors.

Table 6 displays key discussion points and findings that emerged from the workshop sessions and that informed the determination of pre-conditions for circular building.

Table 6: Selected findings from workshop sessions

Session I	All components and materials of the demountable fit out can be reused or recycled without any loss of quality	Only if resource scarcity has large economic consequences, it will be relevant to design buildings in such a way that materials maintain their quality. In other words, the circular economy comprises few incentives if we manage to substitute all resources.	A separation between building layers: each with their own lifespan, demands specific attention to the intersection of these layers and a clear definition of which components belong to which layer. Having to deal with different suppliers, for example: who will provide the connection from the ducts to the installations?	Ownership plays an important role in defining the feasibility of circular models. A distinction should be made between legal and economical ownership to pinpoint diverging decision-making domains.
Session II	From the research on adaptability, two main themes can be defined which have a strong relation to circular building: measurements/dimensioning and interface/connections.	A building should be adaptable to keep up with the demands of the users as well as the investors. This flexibility should not be an aim in itself, but a method to generate quality and save money.	The indicators as defined by Rob Geraedts in Flex 2.0 are linked to an assessment form in which each indicator can be valued with a score from 1 to 4 in order to make them measurable. These scores are arbitrary and an important topic of discussion.	Communication is a keyword. Buildings can be adaptable, demountable or extendable but if the user is not aware of this, it is a loss of energy and time.
Sesseion III	By standardising materials, you define conditions for recycling. By standardising products you define conditions for connections.	Digital production techniques can regulate demand for custom made elements in a material-efficient way, making standardisation not the best option.	If the connections between elements have been standardised, the (measurements of the) elements do not necessarily need to be.	Defining the lifespan of a building should be part of the design process in order for material- and product choices to be adjusted to it.
Session IV	Collecting data on all the materials used in a building has advantages in every stage.	The transition from a linear to a circular economy can take place in two ways: bottom-up and top-down	The transition to circular economical models will have to be facilitated / regulated by law, at least for the following aspects: Quality and properties of materials (e.g. toxicity, purity, etc.), and Tenders, contract methods, procurement.	Recycling techniques need serious improving if we strive for 100% recycling (that is, without the addition of any raw material).

5. PRECONDITIONS & STEPWISE APPROACH

This chapter combines the lessons learned from existing literature and the workshop sessions into practical guidelines for a circular building industry. A set of preconditions will be derived from the gathered knowledge. Subsequently, these preconditions are applied to a series of practical steps.

5.1 Introduction

Materials and products need to fulfil some criteria in order facilitate circularity. We can distinguish intrinsic properties and relational properties.

Intrinsic properties

A material or product should be:

1. Of high quality (functional performance),
2. Of sustainable origin, and able to 'reincarnate' sustainably (after every iteration),
3. Non-harmful (only healthy material use),
4. Consistent with a) biological cycle and cascades, or b) one or more technical cycles.

Of all the sustainable and non-harmful materials or products applied in a building, the composition and quality performance should therefore be defined, as well as the use- and reuse paths. Complex products with multiple short maintenance or redistribution cycles are not necessarily better or worse than homogeneous recyclable products with a high purity and concentration. Furthermore, one should be aware of the fact that the administration required to register all these properties is a learning process rather than a one-off; interventions to the material or product in time will all need to be registered.

Relational Properties

Besides their intrinsic qualities, a material or product should relate to the design and use of the building. These relational properties are about anticipating multiple future user scenarios. Technically, this can be defined by:

a. Dimensions (taking account of modular coordination and changing capacity-demands)
b. Connections (should be 'dry' and 'logical')
c. Performance time (defining the lifespan)

Like in the case of intrinsic properties, also these relational aspects have to be seen as part of a learning process in which all relevant interventions – e.g. changing partition walls – should be registered.

Defining Circular Value

From a circular point of view, the real 'value' of a product is at the intersection of intrinsic and relational properties. This value, defined by multiple parameters, is not absolute. A few examples of different values:

- Use or user value: how does the user value the building component of which the product is part?

- Reuse potential: how easily can the product be removed and restored?
- Circular Economy value: to which extend can the product function within designated cycles?
- Financial value: depending on a) market value, b) material- & resource value and c) cultural value.

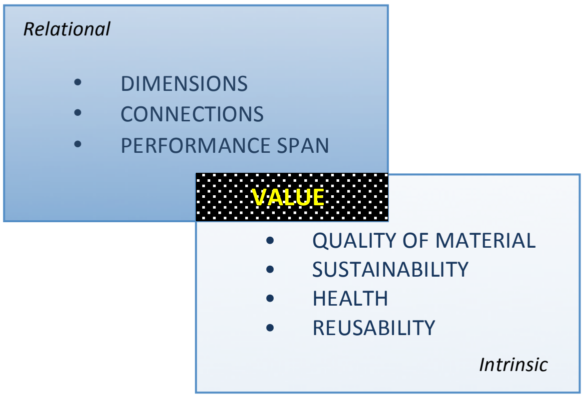


Figure 6: Circular value at the intersection of intrinsic and relational aspects

In separation, neither intrinsic nor relational properties have great significance with regard to circularity: it is on the intersection where preconditions for circular building manifest themselves (see Figure 6). This concerns data with regard to:

- *Exact composition of the material or product*
- *Performance quality of the material or product*
- *Intended (re) use path of the material or product*
- *Performance time of the material, product, component or service*
- *Connections applied between materials, products or components*
- *Dimensioning of materials, products or components*
- *Quality of the registration system and process*

A next step would be to qualify the materials, products and components of a building according to their future perspective in biological or technical cycles based on Circular Economy and Cradle-to-Cradle (see Figure 3). Table 7 shows the six layers of Brand in relation to these CE/C2C cylces. Using such a scheme is a complex task, demanding coordinated efforts regarding expertise and alignment of specific stakeholders.

Table 7: Building layers vs. anticipated cycles of Circular Economy and Cradle-to-Cradle

	Bio-cascades	Bio-feedstock	Maintenance	Redistribution	Refurbishment	Remanufac turing	Recycling
STUFF							
SPACEPLAN							
SERVICES							
SKIN							
STRUCTURE							
SITE							

5.2 Practical steps Approach

Because of its straightforward nature on the one hand, and its significance with regard to sustainable design and development concepts developed at the Delft University of Technology on the other, the New Stepped Strategy [Dobbelsteen, 2008] has been taken as a starting point for applying the pre-conditions defined in the former section. The New Stepped Strategy (NSS) is based on three steps towards sustainable design and development, *reduce, reuse, and produce*, with an accent on the second step in order to fully integrate circularity.

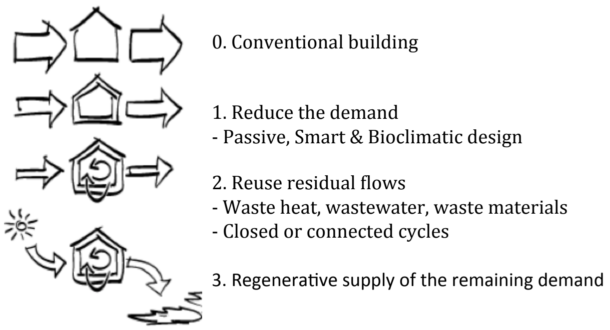


Figure 7: New Stepped Strategy (at the building level)

Preconditions for circularity can be integrated into the NSS, albeit with important adjustments. To begin with, differentiation between planning and building design on the one hand, and materials and products on the other is required. Next, there is an area of tension with regard to the step 'Reduce the demand': from a circular point of view it is more about intelligent dimensioning, linked to an intended lifespan. Furthermore, there are multiple routes imaginable, which makes the hierarchical order more complex. The stepwise approach for circular building projects is further explained below.

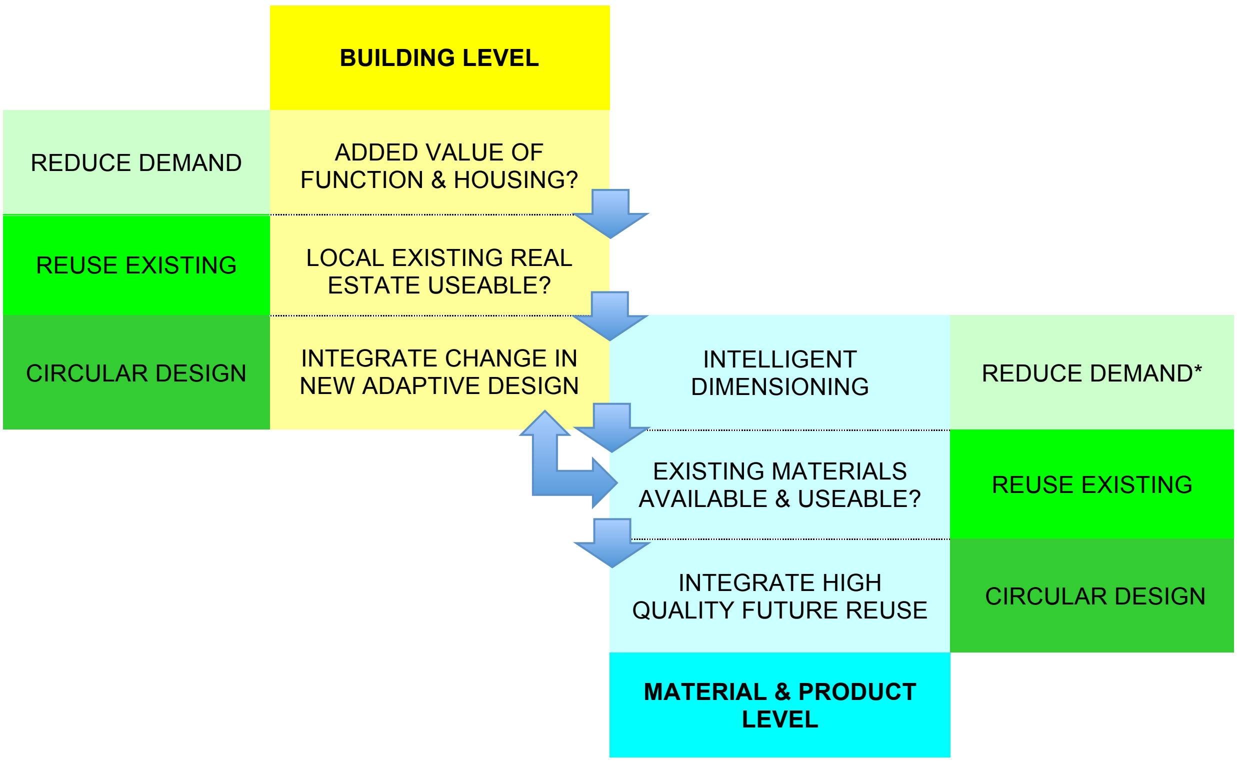


Figure 8: Stepwise approach Circular Building

__Step 1: Evaluate the added value__ of the intended functions and their materialization e.g. is a new office building necessary or can extra workspace be generated by new ways of working, whilst reorganising the space?

__Step 2: Explore current and future vacant buildings__ with regard to availability and usability. If possible, make use of local or regional data inventories regarding vacant real estate.

__Step 3: Integrate 'change' in a new adaptable design__ - Distinguish generic elements with a long lifespan and high architectural/functional value from the specific changeable elements with a varying or short lifespan. Elaborate on this in close dialogue with the relevant stakeholders. Dimensions and connections are the leading principles in the design and construction of the building, e.g. integrating cut outs in load bearing walls (so-called fontanel constructions) for future connections.*

**NB: If local availability is driving and dictating the design, step 3 may be preceded by step 5.*

__Step 4: Use intelligent dimensioning –__ In the field of materials and product design, measures and capacities should be suited for the planned function, performance and lifespan. In order to facilitate future changes in function or use, over-dimensioning can be an option, whilst implying a surplus material use in contrast to lean design. The notion to 'reduce the demand' should therefore be linked to an intended lifespan: increased material demand upfront can actually mean a reduction of material demand for adaptation in the total lifespan of the building.

__Step 5: Explore the availability and usability of existing materials –__ Which materials in proximity to the building site can be recuperated? Define a radius for the maximum distance for which collection of materials is still relevant. A 'harvest map', showing planned construction activities, is a useful tool in this respect.*

**NB: this step can also be leading in the design. In this case, it should move forward in the sequence.*

__Step 6: Integrate high quality future reuse –__ Include Change as a design principle, whilst anticipating biological and technical regeneration routes. Design for disassembly and flexibility. Use material and products that keep or increase their value.

Table 8 links the domains of the practical steps approach with the preconditions defined in section 5.1, as well as the most relevant associated stakeholders. The last domain – knowledge & skills development – emphasises the importance of keeping up to date with developments (changing demands, new technologies etc.): it is all about 'Learning products in learning buildings'.

Table 8: Domains, characteristics and stakeholders involved

Domain	Characteristic	Main stakeholders
Material/Product	Composition	Product designers, manufacturers
Material/Product	Quality	Product designers, manufacturers
Material/Product	Use path	Product designers, manufacturers, architects
Building design	Performance span	Architects, contractors, investors, users
Building design	Connections	Architects, contractors, manufacturers, suppliers
Building design	Dimensions	Architects, contractors, manufacturers, suppliers
Knowledge & Skills development	Data quality	All stakeholders: facility managers, investors, users, suppliers, manufacturers, designers, contractors etc.

6. CONCLUSIONS & IMPLEMENTATION

6.1 Conclusions

Intrinsic and relational properties

Potential scarcity of resources – and the related supply risk – is an important driving force in the urge for a shift from a linear to a circular economy. If this scarcity cannot be resolved by, for example, the massive introduction of alternative materials, it will have big social and economic consequences. In order to limit virgin resource input, embedding future reuse of resources/materials in our economic models is therefore essential. The building industry has great relevance in this respect, being responsible for approximately 40% of the resource use [Ecorys, 2014]. This, in turn, incentivises design of buildings and components that assure the preservation or increase of material quality. In order to facilitate this, we defined intrinsic properties and relational properties, on the intersection of which lies the *circularity value*.

Intrinsically, all materials or products a building (or building layer) comprises, should be:

1. Of high quality (functional performance),
2. Of sustainable origin, and able to 'reincarnate' sustainably (after every iteration),
3. Non-harmful (only healthy material use),
4. Consistent with a) biological cycle and cascade, or b) one or more technical cycles.

Relationally, the following properties can ensure cycles of quality, whilst anticipating future change:

a. Dimensions (taking account of modular coordination and changing capacity)
b. Connections (dry and logical)
c. Performance (according to diverging lifespan of components)

Circularity and adaptability should not be seen as goals themselves, but as a means to generate value and quality based on the capacity of a building to keep up with the demands of its users and investors. This is found to be essential for the future value of the building and its subsystems, whilst accommodating circular material flows.

Down cycling and up cycling

The Cradle-to-Cradle concept defines the difference between 'less bad' and 'good'. Down-cycling – the extension of a (technical[2]) material's lifetime in increasingly lower grades – is 'less bad' because it merely delays the material's low-value fate. Upfront anticipation of sustained value, on the other hand, is 'good' from a regenerative point of view. Creating awareness regarding this crucial difference is necessary to make the change in emphasis. In the transition, however, down-cycling tactics may be the best available solution. Another consideration lies in the viability of proposed solutions with regard to the energy intensity of recycling processes and transportation miles.

[2] In the case of biological material, so called *cascades* apply, in which increasingly 'lower grades' occur up to the point of complete biodegradation

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Standardisation

A certain level of standardisation is inevitable in a circular building industry – it ensures that materials and products can be reused in multiple buildings or systems without significant adjustments. Standardisation of connections is found to be key in this respect, particularly (dry) connections in the fit out domain. The design freedom of the architect and the need for diversity in our built environment are aspects that should be respected and considered when talking about standardisation on a big scale. The role of the architect will shift to designing the base building, whilst avoiding obstructions for the fit out plan to change over time. Moreover, occupants may well commission architects to guide the fit out design process too.

Ownership

This research emphasizes the fact that basically two clients can be distinguished, with each their own perspective: the investor and the user. It is the task of a cooperation to defend the demands of both clients. Clear demarcations will have to be agreed upon, and the key questions are which decisions are to be made by which stakeholder and how does this translate to a physical building? The demarcations – following the principles of base building and fit out, as concluded in this report – have to be determined and communicated unambiguously: a basic rule to facilitate the different, and partly unknown, user iterations. Implementing this rule will vary according to typology: a hospital will need a different approach than an office or apartment building.

Bottom-up initiatives can mean a lot in the transition from linear to circular economical models. However, a large change in emphasis has to come from top-down regulations, since a legal change is required to facilitate and organise circular economic models. Regulations for procurement and contract methods need revision in this respect, as well as the regulatory and monitoring frameworks for quality and transparency surrounding building products. Last but not least, a legal and economic distinction is required regarding ownership of the base building on the one hand, and the fit out on the other. See the example of Japan in Box 1.

Box 1. Example Japan: 200 year Housing Law

In Japan, adaptability principles were recently embedded in the national law. The 'Long Life Housing Law', implemented in 2009, demands for buildings to be adaptable in all technical and social aspects. The goal is to provide the country with dwellings that have a life span of 200 years – instead of the current 30 years on average – and are capable of adapting to every new user without the large waste flow of materials and energy that usually come with it. The argument is that most materials, products and components used in buildings have a longer life expectancy than 30 years but become waste as soon as a building can no longer adapt to change. The new law consists of a list of technical requirements that a building must meet in order to apply for tax deductions and subsidies. This list has many similarities with the theory of Open Building, based on the general notion that a building is a composition of sub-systems and material components each with its own expected life span. The law states, for example, that the replacement of a sub-system or component should be possible with minimum disturbance to other sub-systems [Habraken, 2013].

Communication

Lastly, managing the desire to and implementation of change is only possible when clear communication between stakeholders – over time – is respected. Experience shows this is not self-evident. A building can be adaptable, changeable or extendable, but if the user is not aware of it, this potential is wasted and the effort largely counter-productive.

6.2 Testing and implementing in practice

This study underlines once more that the implementation of circular principles for product - and material use in buildings demands a radically different approach in all stages; before, during and after the performance span. We have aimed to list the most important preconditions and guidelines to stimulate technical adjustments of the current building practice, but it is also about organisational adaptations that will eventually lead to critical changes in relations and collaborations. A major innovation on multiple fronts is therefore required. The good news is that 1) the awareness grows that this line of thinking is the way forward, and 2) pilot projects have been initiated and realised here and there. However, this is not enough to change the building industry.

Lessons learned from demonstration projects have validated, disproved or adjusted certain guidelines, but the typological differentiations, and shifts in ownership that come with those, will have to be further developed on a larger scale.

From small to larger scale levels

The relatively safe environment of a small demonstration project, with only a few parties with vested interests, is the perfect condition for testing innovations. But many innovations in the field of circular and adaptable building have already passed this stage of experiment. The time has come for testing on a larger scale. This will bring along different obstacles, hindering certain innovations, but it also creates many opportunities. One of the advantages of a bigger scale is that certain interventions and processes will be cheaper, possibly making circular models economically feasible. Also, we can start thinking about a synergy between large-scale renovation projects and energy optimisation in which circular material use and product-service combinations can create added value.

Small projects are therefore crucial to gather information and expertise. In turn, large-scale projects may generate experience with, for example, combined technical interventions and shared values, which can be applied in new demonstration projects. In this way, innovative ideas need to keep developing by means of a forward-thinking process. The way this knowledge and innovation is monitored is of course crucial in this respect. Only if we continually collect the correct, high quality data on these projects, it is possible to draw conclusions on the effect of circular building on stakeholders and contracting processes.

Active ReUse House

The 'Active ReUse House' is an example of energy-neutral and circular building with a focus on reuse i.e. building with secondary resources and designing for disassembly and future reuse. Structure, facade, space plan and services are disconnected in order to realise a future-proof building. The project is in search of a balance between making a building maximally adaptable (vertically, horizontally and in combining houses), taking account of extra costs and materials this may imply.

Five 'Active ReUse Houses' (ARUH) are envisioned within the *Concept House Village* at Heijplaat in Rotterdam, the Netherlands. The ARUH consortium is currently working on the final design. This design will be used to test the market and search for potential buyers. Depending on the feasibility, the plan will be developed further, and by the end of 2015 construction should start.

The goal is to realise the five houses at once. Different fit out, extensions and installation concepts can be tested in these cases. The owners/residents select their own floor plan and finishing. Due to the adaptable structure, the floors can be placed on different heights. Also the positioning of partitioning walls and stairs remain adaptable. Next to monitoring the energy - and comfort levels in relation to user behaviour during two years, a multi-year monitoring of adaptability (use and function) relating material use is envisioned. The following questions will be addressed:

- To which extent has the adaptability been used?
- Does the construction principle contribute to a circular material use?
- What is the role of a material passport (and possible connection to BIM) in the project?

The conclusions and findings of this report have been taken along in the development of the ARUH where possible and will be applied to all further progress. So far, this has already led to new discussions and insights within the ARUH team. The other way around, those discussions provide new food for debate and a refinement of the conditions and guidelines.

Final word

The Active ReUse House team regards the pilot described above as a prototype for further development. All partners involved have expressed their interest in realising the concept on a larger scale. Due to the adaptable structure and facade it is possible to build context specific, which offers many opportunities. Design and development based on value-preservation or value creation – key aspects in a circular economy – can connect parties with different interests and backgrounds. That is one of the lessons coming out of this small-scale project. How this will work on a larger scale needs to be seen in practice. There are already several parties that are ready to contribute; parties who realise that circular systems are the future, and who are willing to invest in that. Who else dares?

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SOURCES

Brand S., How Buildings Learn – What happens after they are built, Viking Press, New York, 1994

Braungart M & McDonough W., Cradle-to-Cradle - Remaking the Way We Make Things, North Point Press, New York, 2002

Dobbelsteen A. van den, Towards closed cycles – New strategy steps inspired by the Cradle-to-Cradle approach, in: Proceedings PLEA 2008, 25th Conference on Passive and Low Energy Architecture, UCD, Dublin, 2008

Ecorys, Resource efficiency in the building sector, DG Environment, 2014

Ellen MacArthur Foundation, Towards the Circular Economy – Economic and business rationale for an accelerated transition, EMF, 2012

Geraedts R., Flex 2.0, Indicators for Adaptable Capacity, version 09032015

Het Groene Brein, Circular Economy Science Lab, Onderzoeks- en kennisagenda thema Circulaire Economie in Nederland – Bouwstenen voor onderzoek naar essenties, principes en toepassingsgebieden, 2015

Habraken, N.J., The support and the people, Scheltema en Holkema, Amsterdam, 1961

Habraken, N.J., The Long Life Housing Law in Japan, 2013

Hansen, K. en Brey, M., Circular Economy, Powered by Cradle-to-Cradle®, 2014, EPEA en Kienbaum Management

Schmidt R., Deamer J., Austin S., Understanding adaptability through layer dependencies, ICED 11, 2011