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Circular Building Design: An Analysis of Barriers and Drivers for a Circular Building Sector

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Abstract: Circular building design could significantly reduce the environmental impact of buildings and the pressure on natural resources. However, most buildings today are not designed according to the principles of the circular economy. Most literature has focused on either methods for quantifying the lifecycle analysis of buildings and materials, or on innovative circular building materials, but not much is known about the design process of circular buildings and how architects are dealing with translating the principles of the circular economy to the building sector. A series of semi-structured interviews with architects and consultants that have engaged in circular building design has been conducted to identify the barriers and drivers of the transformation towards a circular building sector. Interviews were analysed using qualitative coding analysis. The conservativeness of the building industry, the lack of political priority and the dependency throughout the building industry were found to be the main barriers, while a supportive client with a well-defined assignment and idea was considered to be the main driver. The contribution of this paper to key actors in the building sector is to identify the main barriers and drivers for a circular building sector.

Keywords: circular economy; architecture; building industry; barriers; drivers; architects; clients; material

1. Introduction

The building sector accounts for a significant amount of the total energy use in European countries (42%) [1] and for a significant amount of the waste production (e.g., 30% of the waste produced in Sweden [2] and 40% in the Netherlands [3]). In order to reduce the impact of buildings on the environment, building regulations have become stricter, especially regarding the maximum allowed energy use during the operational phase. The European Union and its member states have set ambitious targets for further reducing the total environmental impact and total energy use of the building sector. As a result, different concepts for low-energy houses have been developed in the last decades such as passive houses, zero-energy buildings and plus-energy buildings. In all these concepts, the focus is on energy use in the operational phase. As a result, it has now become even more important to look at the embodied energy; the energy used to produce a building. This embodied energy could account for 45% of the environmental impact of the building considering its total life span in a low-energy house [4] Choosing the right building materials with a low environmental impact has therefore become an important issue when designing future buildings. Many building materials used today are also still based on fossil fuels and their derivatives, which not only means a high level of embodied energy, but also results in a strong dependence on a limited resource [5,6].

The building industry is a material-intensive sector; in 2019, the world consumed 100.6 B tonnes of materials, of which 38.8 B tonnes was consumed by the housing sector [7]. At the same time, resources are rapidly getting depleted (Table 1) [8].

Table 1. Estimated remaining world supplies of non-renewable resources as of 2020 [7].

Resource	Years Remaining		
Fossil Fuels		**Minerals**	
Coal	34	Aluminium	72
Oil	29	Phosphorus	68
Gas	27	Tantalum	38
		Titanium	36
		Copper	24
		Silver	9
		Indium	4
		Antimony	0

The circular economy (CE) has the aim to gradually decouple economic activity from the consumption of finite resources, and designing waste out of the system [9]. The EU launched an action plan for the circular economy called 'Closing the loop' in 2015 [10], which states that the CE 'will boost the EU's competitiveness by protecting businesses against scarcity of resources and volatile prices, helping to create new business opportunities and innovative, more efficient ways of producing and consuming'. The action plan defines, amongst others, the waste hierarchy (Figure 1); a way of visualising how materials should be kept at their original state in order to preserve the embodied energy. Prevention (of waste) is the highest level in the waste hierarchy, followed by reuse, recycling, recovery and the lowest level is disposal.

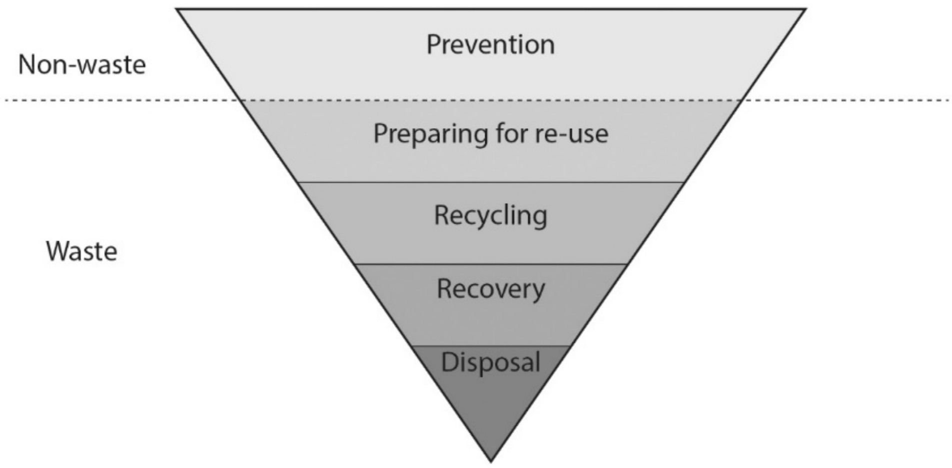

Figure 1. Waste hierarchy [9].

The European member states translated the EU action plan for the CE into national legislation and goals. For example, the Netherlands has the set the goal to be '100 % circular' in 2050 [11]. In order to get there, three goals have been identified: (1) existing production processes should make more efficient use of resources, (2) when new raw materials are needed, sustainable production, renewable (inexhaustible) and generally available raw materials are used as much as possible, and (3) develop new production methods and design new products in a circular way.

There is a growing amount of literature on how circular economy principles can be applied to the construction sector and how it will translate into architecture

Pomponi and Moncaster [12] stated that much of the focus of the research on the circular economy is either on a macro level (the city) or on a micro-level (e.g., building components). Their focus was on the meso-level (the building). For the transformation to a CE to succeed, it is important to understand the economic dimension, the environmental dimension, the technological dimension, the societal dimension, the governmental dimension, and the behavourial dimension.

More recently, Rau and Oberhuber published the book 'Materials matter' [13]; a manifesto where the two authors outline how our current linear economy has to be transformed to a circular economy, with the starting point of materials. Key points, related to a circular building sector are the need to change the way the responsibility of materials and products is arranged, as well as how buildings and ownership of buildings can contribute to the shift towards circular buildings.

Habraken defined the open building concept in 1972; an approach to the design of buildings that takes the possible need to change or adapt the building during its lifetime into account [14]. Habraken's concept of open building design has found renewed interest in the light of the circular economy. Other studies concerning adaptable housing or architecture [15–17] defined theories how to design such buildings; e.g., permitting multifunctional use and accessibility without requiring changes or rebuilding, embedding a flexible layout of the building and ensuring that the usable space can be extended and/or reduced through or without rebuilding.

Both Baker-Brown's *Re-Use Atlas* [18] and Gorgolewski's Resource *Salvation: The Architecture of Reuse* [19] focus on the theory and practice of the reuse of building materials. The books show both building projects and examples of circular materials and business models closely related to the building sector. Baker-Bown sees, amongst others, that BIM modelling will provide data to construct material passports; an important tool for the future use of materials, also specified in [13]. Gorgolewski's most important conclusions are that Design for Deconstruction (DfD) has consequences for the design process that requires new skills, greater flexibility in drawings and design, but also more flexibility in terms of deadlines.

Zabek, Hildebrand, Wirth and Brell-Cokcan identified obstacles and opportunities for the reuse and recycling of building materials by, amongst others, surveying regional stakeholders linked to the building sector in western Germany [20]. Amongst others, they found that key players should cooperate with each other by exchanging information about reusing building material and providing prototypes to increase the acceptance of reused/recycled products.

Based on the literature, a conceptual framework was derived. This conceptual framework of the study is presented in Figure 2. The working hypothesis of the study was that circular building design is succesful when the right framework is present: a supportive client with a well-defined need, an architect with in-depth knowledge about materials (as mentioned in [13,14,16,18,19]), available materials with a high circular potential (as mentioned in [13,16,18,19]), and a contractor that could construct the building according to the designed principles. Therefore, two sets of questions were included in the interview guide: one set focusing on more general questions, the other set project-specific questions to analyse barriers and drivers for a specific circular building design. This division was set up with the strategy that the project-specific questions could give an insight what drivers of circular building design can be since the interviewed architects succeeded in designing a circular building. These architects could then, with the experience gained from this project, easier identify barriers for circular building design in general. The traditional cluster of the three key actors in a building process (client, architect, contractor) was assumed to function also in the circular building design process. The dependent variables for the client, in relation to circular building design, were assumed to be the available budget, image of the company, the availabilty of relevant performance-based business models, and the risk of the project. The dependent variables for the architect were assumed to be the assignment from the client, the flexiblity of the client, available supporting tools, image of the company, available materials, and construction methods (design for deconstruction). The dependent variables for the contractor were assumed the assignment from the client, the risk of the project, available materials, and construction method. The presented conceptual framework has many variables; due to the nature of building projects, the ability to control each variable is very limited.

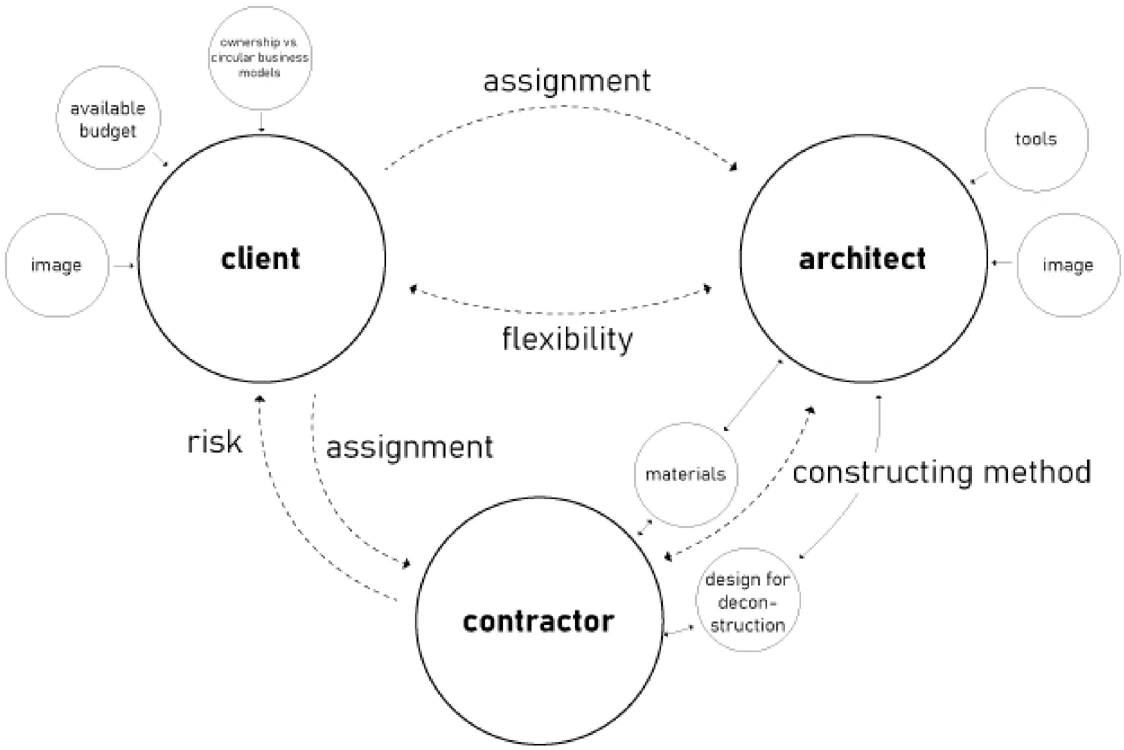

Figure 2. Graphical representation of the theoretical framework.

Much of the research focus on the circular economy has been on the city level or on building component level and most the most aspects that are researched upon are the definition of circularity, life cycle analysis (LCA) and technical inventions for recycling. The goal of this research is to gain an insight in the design process of building projects that had the goal to be 'circular', to identify barriers and drivers of different key actors in the design process, and to showcase specific solutions for cirular buildings. There is only a limited amount of literature on how building design processes for circular buildings are different from traditional design process, which bariers and drivers are encountered and how it could influence architecture. Therefore, interviews with architects and consultants were conducted to gain a better insight in the design processes.

2. Research Method

The main research method in this research project was the semi-structured interview, since the focus was on the design and construction process of selected buildings. These interviews were combined with a literature review as presented in the introduction and with project data from the architectural projects (drawings, diagrams, etc.). The author had conducted a similar research setup when interviewing architects about the implementation of solar energy in buildings [21]. Semi-structured interviews also provide freedom to explore some of the responses more in detail, which was likely to happen in these interviews.

2.1. Data Gathering and Analysis Procedure

From the beginning, the focus of this research project has been on exploring circular buildings, designed for deconstruction and with a high share of biobased and/or reused materials. Projects that solely relied on (virgin) biobased materials, as for instance many building projects in Scandinavia, were not chosen, because it was expected that they would not have dealt with the same framework as those projects that are designed for deconstruction, incorporated reused building materials, etc. Relevant projects were mainly looked for using internet search engines and architectural databases available at LUBSearch [22] (an EBSCO host search platform). The architects of the selected projects were contacted by email and two architectural offices rejected the invitation. Two interviews with consultants (experts on the reuse of materials and on circular building management) were added to the list of interviewees to get a broader insight of the design and construction process.

An interview guide was prepared and sent to the interviewees prior the architects, providing them time to prepare for the interview (Table 2).

Table 2. Interview guide.

General Questions	*Project-Specific Questions*
What is the circular economy for you? How can architects and architecture play a role in the transformation towards a more circular economy? How do you think that the concept of circular architecture will affect the field of architecture? Do you see that circular architecture requires a new set of skills and competences? According to you, what are the most important barriers for circular architecture? What are the most important drivers?	What was your assignment given by the client? Can you describe the architectural concept of the building? Can you describe one detail of the building that shows specifically how you worked with circularity? How did the client fulfil its role during the design, construction and management process? Were there any special tools (software, etc.) you used during the design process to support you. Did the design require specific consultants to get involved in the design process? Did you assess the environmental impact of reusing materials or using biobased materials? One of the challenges I imagine for circular architecture is a reliable supply of building materials to be reused, both in quality and quantity. Did you encounter this challenge and if yes, how did you solve it? What are the lessons learned from the building?

In the majority of cases, interviews were held at the offices of the interviewees, in some cases at the building that was subject of the interviews. The interviews usually lasted from 30 min to over an hour, depending on the interviewee. Interviews were held in English (in Denmark and the UK) and in Dutch (in the Netherlands and Belgium) and were tape-recorded. The interviews were then transcribed in their original language.

The chosen data analysis method of the interviews was through qualitative coding analysis; which consists of coding (the process of categorising data), constant comparison, saturate categories, and explore relationships between categories. The coding data was done manually, by highlighting different categories as well as adding notes to the transcriptions (an example can be seen in Table 3). Categories were set up with help of the interview guide and notes made during the interviews. Categories were attributed if there was enough depth in the data from the interviews and were saturated with all data from all interviews.

Table 3. Example of open coding analysis.

Category	Initial Statement
Design for de-/reconstruction	It is important that you design for deconstruction, for example, that the materials you use can be neatly disassembled. This applies not only to architects or the built environment, but also at the product level. Every level of material used, actually.
Barriers and drivers	So basically, the conclusion may be that you cannot say that one party should take this on their account. No, it is as they call it in the Netherlands ... throughout the entire chain. All links in that chain will have to do all this. Only then does it make sense.

2.2. Interview Sample

Eleven interviews were conducted from September 2019 to January 2020 with ten architects and two consultants (in one interview, two architects participated). In all cases, the interviewed architects had directly worked with the discussed project, either alone, as part of the design team or as lead architect. The architects worked at a varying size of office, from small to medium size. The two non-architects were consultants, who normally worked closely connected in the triangle developers-architect-contractor (see Table 4).

Table 4. Sample statistics of interviewees.

Gender	Number	Country	
Male	10	Belgium	1
Female	2	Denmark	1
		The Netherlands	9
Profession		United Kingdom	1
Architect	10		
Consultants	2		

2.3. Building Sample

An overview of the sample of buildings or projects that were the focus of the interviews can be seen in Table 5 and Figure 3. It can be noted from Table 5 that the projects are very different in size and function. In two cases, there was a life span set for the building already in the very first phase of the design phase; one building would stand 9 days, another building is planned for 15 years. The proclaimed environmental benefits come from either the website of the architects, from other presentation material or from the interviews.

Table 5. Sample of buildings.

#	Name	Architect	Location	Type	Constructed	Predefined Lifespan/y	Size/m^2	Themes			Proclaimed Environmental Benefit
								Biobased Materials	**Reuse of Materials**	**Designed r/Deconstr.**	
1	Circl	Architekten Cie.	NL	Commercial	Yes	Not defined	3000	•		•	"39% less primary materials"
2	Brighton Waste House	BBM	UK	Public	Yes	Not defined	130		•		"45 tons of material that didn't go to landfill"
3	People pavillion	Bureau SLA/Overtreders W	NL	Public	Yes	9 days	225	•	•	•	"all materials borrowed = 0 footprint"
4	The Green House	Cepezed	NL	Commercial	Yes	15 years	680	•	•	•	"prevent waste"
5	City Hall Venlo	Kraaivanger	NL	Public	Yes	Not defined	27,700	•		•	Cradle to cradle
6	Triodos HQ	RAU	NL	Commercial	Yes	Not defined	12,693	•		•	"100% wood, demountable office
7	Demountable Bicycle Storage	Architectuur maken	NL	Residential	No	Not defined	n/a		•	•	-
8	Hal 7	Vandkunsten	DK	Public	Yes	Not defined	900		•		-
9	Blue City	Superuse Studios	NL	Commercial	Yes	Not defined	1300		•		"90% circular"
10	Multi tower	Conix RDBM	BE	Public, commercial	soon	Not defined	45,000		•		" 2% of new material reused
11	Building cric. index	Alba Concepts	NL								

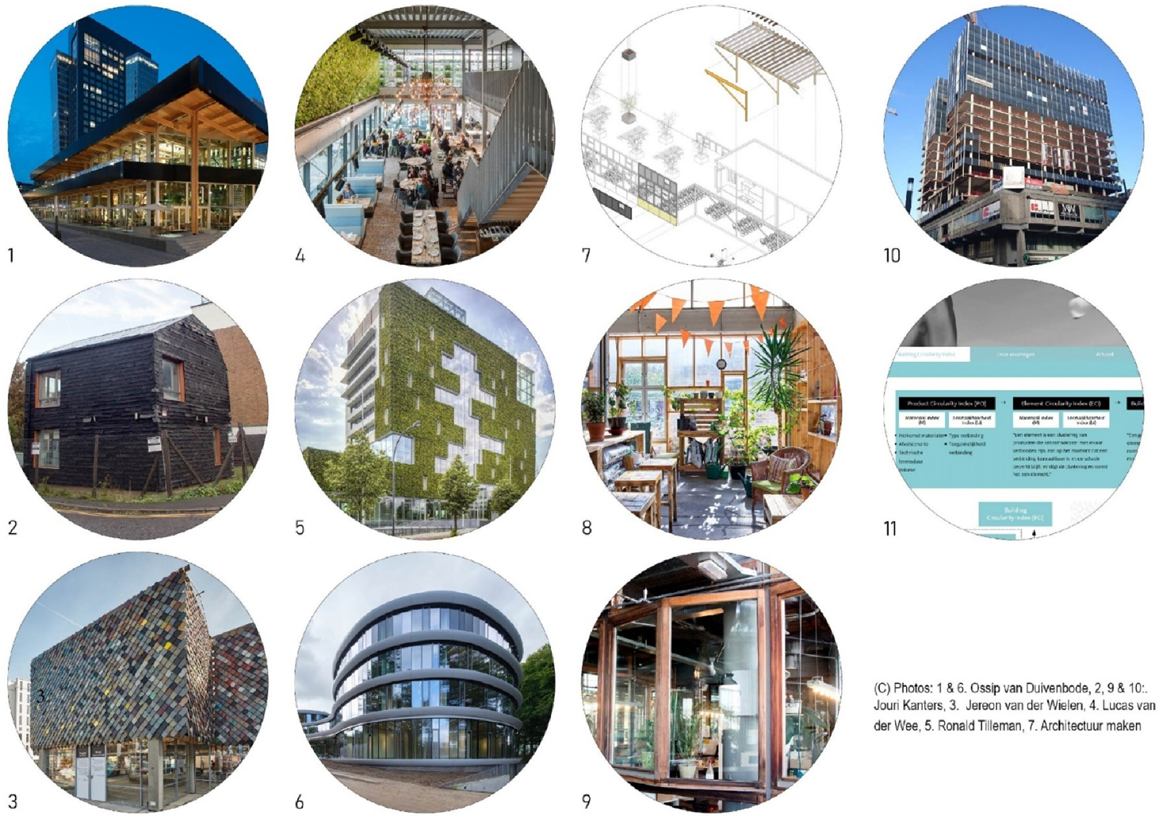

Figure 3. Overview of projects.

3. Results

In this chapter, the results of the interview series are discussed. Table 6 shows the themes/categories as derived from the interview data, as well as its subcategories. The dimension column shows the number of interviewees that in their answers strongly mentioned the subcategory in a positive way ((+), neutral (0) way, or in a negative way (-)). Only those subcategories and their related categories with a dimension of 5 and higher are discussed in this chapter as themes.

Most of the mentioned items from the conceptual framework appeared as themes.

3.1. Theme 1: Defining Circular Building Design

Mentioned goals connected to circular building design were maximising the use of available resources, reducing waste production from buildings, and reducing the environmental impact of buildings. This becomes achievable by *closing loops*, by acknowledging the importance of biobased or reused materials and by taking responsibility for what is produced. Due to the lack of a definition of how the CE can be applied to the building sector, architects tended to rely on the more general CE principles set out, e.g., by the Ellen MacArthur Foundation [9], specifically the butterfly diagram showing the division of two different spheres: the natural components and technical components (Figure 4).

Table 6. The related themes, categories, subcategories and dimensions.

	Themes/Categories	Subcategories	Dimension Positive	Neutral	Negative
I	Defining circular building design	Own interpretation of CE to the building industry	11	0	0
		There is a lack of definition/misuse of the term CE	5	0	0
		CE vs. sustainability	3	1	1
II	Circular materiality	Design for de-/reconstruction	8	1	0
		Choice of materials	8	0	0
		Use of reuse/recycled materials	9	0	2
		New materials: biobased vs hybrid solutions	5	0	0
		Calculation of environmental impact	3	2	4
III	The new role of the architect	Architect as driver in the process / flexibility in the process	8	1	0
		Architects as innovator/entrepreneur/spin-off	5	0	0
		Architect with deep material knowledge	9	0	0
IV	The building as piggy bank	Buildings = temporary storage of materials	7	0	0
V	Barriers and drivers	Willingness of the building sector to change	9	0	0
		Dependency on other sectors	4	0	1
		Need for access to circular materials/business models	7	0	0
		Need for flexibility in building codes, regulations (or more forcing approach)	7	0	0
		There is a mismatch in supply and demand of reused materials	3	1	0
		Labour is expensive	5	0	0

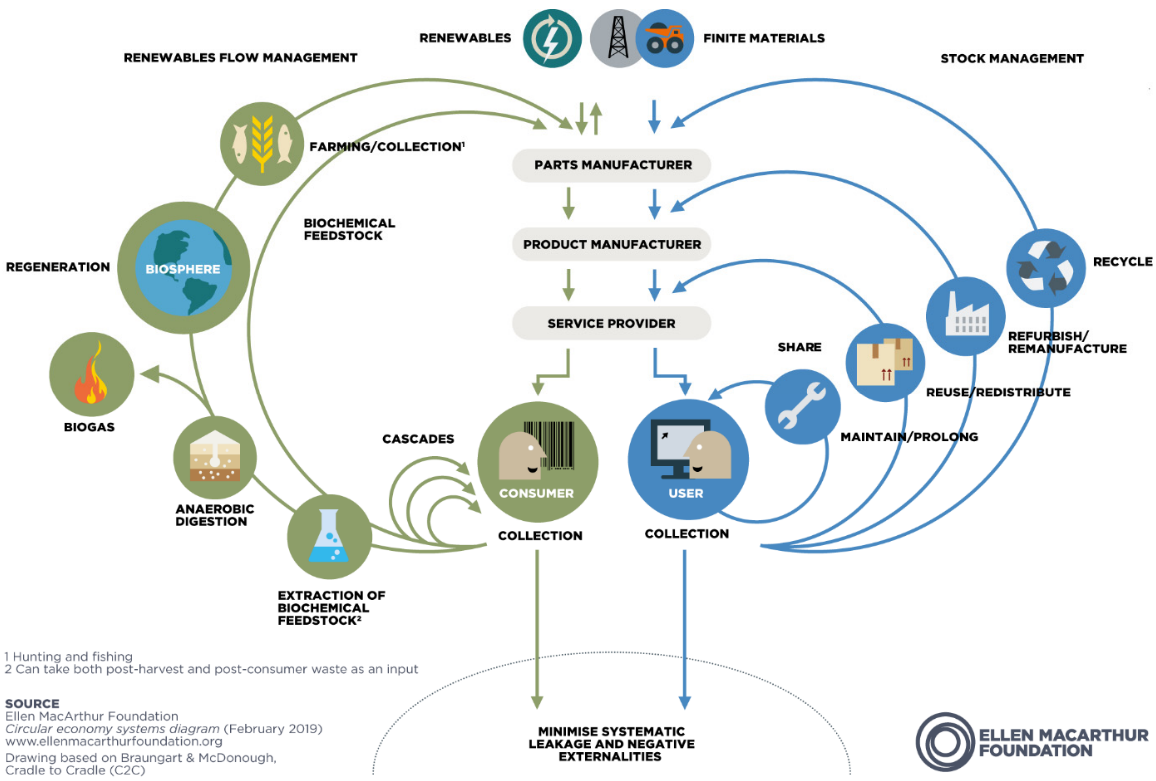

Figure 4. Butterfly diagram of the principles of the circular economy [9].

Another supporting theoretical framework for circular building design was the 'shearing layer' concept by Brand [23]; a theory that defines different layers in a building and their approximate expected time scale. In this case, the time scale should not be considered as a technical life span (Figure 5).

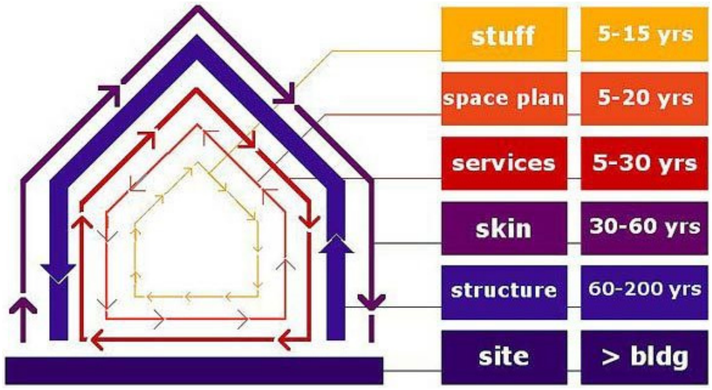

Figure 5. Different layers of the building and their expected time scale [23].

The concept of the circular economy was found to be related to the concept of sustainability, but architects mentioned that although the concept of sustainability is still very present in the building sector, it has become rather nonspecific; sustainability has become much of 'do less bad' rather than good, and that fully embracing the principles of the CE will provide the needed change to 'do good'..

"Sustainability is optimising the system. If you optimise something it becomes more and more expensive and the steps you take become smaller and I think the system will not change. I think that there are some aspects in the system that we shouldn't optimise, but we must change." (Interviewee #6)

3.2. Theme 2. Circular Materiality

3.2.1. Design for De-/Reconstruction

Design for deconstruction (DfD) was considered to be a key aspect for circular building design, providing the possibility to re-use building materials and components to their highest degree. One architect suggested to use the term 'design for reconstruction' instead; the rewording adding the condition that materials and components will be re-used. In this article, this concept is now further called Design for de-/reconstruction or DfD/R. DfD/R is the core for circular building design, but it does not necessarily show in the architecture of a building. Here, clients and architects cared about their image and looked for means to express DfD/R by looking for a new architectural language (two examples of circular building details can be seen in Figure 6).

3.2.2. Choice of Materials

Materials were identified as a cornerstone in circular building design. Therefore, making the right choice of materials is an important aspect in the design process. The choice of materials for circular buildings could be summarized as following:

(1) New biobased materials that are from non-fossil sources,
(2) New technical materials that can be from fossil sources, but designed for de/reconstruction in such a way that these materials can be reused in the highest possible grade,
(3) Reused materials (biobased or technical),
(4) Hybrid system solutions where parts are biobased, technical and/or reused.

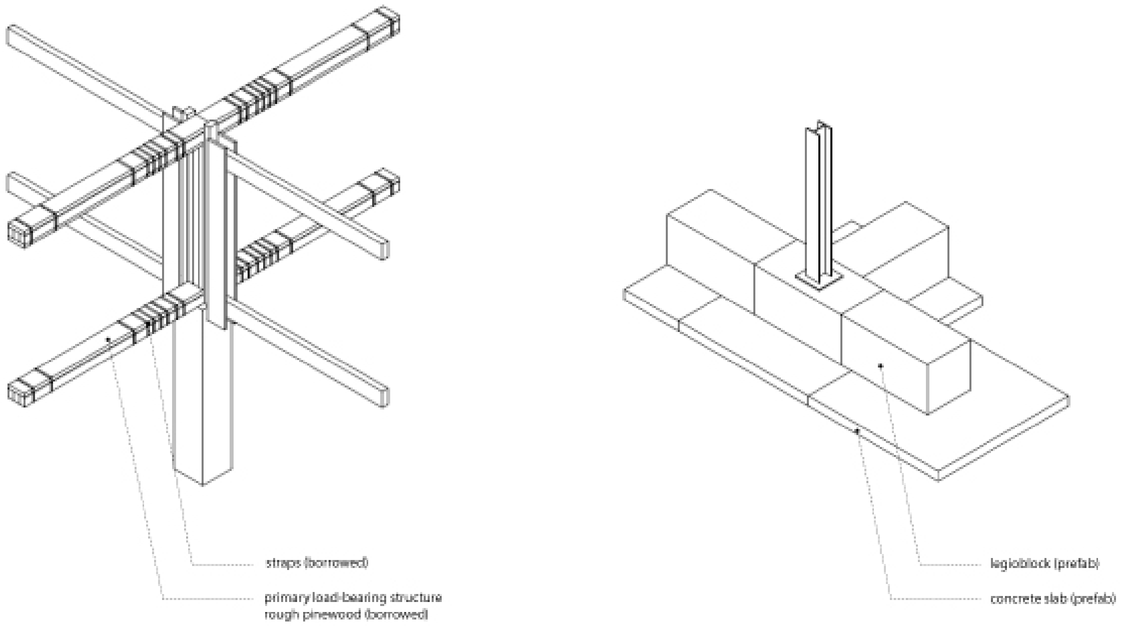

Figure 6. Different building details that were designed for de-/reconstruction.

Calculating the environmental footprint (mainly expressed in CO_2-equivalent) or performing a Life Cycle Assessment (LCA) for circular buildings did not always provide good answers in the building design process since there is a lack of standard methods how to take multiple life cycles into the equation and there were many uncertainties. Quantifying DfD/R in the building process is still very uncertain since there are not many established methods. One consultant had developed their own method by analysing (a) the input of material, its output and the average lifetime, (b) the disassembly potential, and (c) how materials were assembled into elements. Other architects discussed material passports or resource passports; a document describing all materials that are included in a building. Materials passport are not only expected to provide a good foundation for future material reuse and for calculations of the remaining financial value of the materials at End of Life (Eol), but they can also provide feedback to architects regarding material choices during the design process.

The reuse of materials and the use of recycled materials divided the interviewed architects: on the one hand, there were architects that said that the reuse of materials (extending its life span from the first to the second cycle) is not a valid strategy for circular buildings. Other architects argued that the reuse of building materials and components is a part of the circular economy (as is defined for example in Figure 4), acknowledging it being on a lower scale in the waste hierarchy. One of the arguments of the architects to reuse building materials and components was the fact that these materials otherwise would go down on the waste hierarchy, resulting in a higher environmental impact. As one consultant mentioned, it is important to already now start reusing materials to create a mature market for such materials, otherwise new materials now embedded in buildings that are DfD/R will not be reused. Quantity and quality of reused building materials and components has been an issue, as well as the fluctuation between supply and demand. In those projects where it was unknown which materials would be available at the time of construction of the building, architects had to build in a certain flexibility into the design process and the technical documents. So-called donor buildings, where large quantities of building materials and components can be extracted were seen as beneficial for the reuse of materials, and to a lower extent relying on external/commercial websites where companies and/or people offer reused building material and components.

3.3. Theme 3. The New Role of the Architect

Architects considered themselves as being one of the main key actors for driving circular building design, connecting all other key players—their client, the contractor, and other consultants and engineers. A circular building sector will require a new role for the architect on top of their traditional role of ensuring a high-quality architectural building design; they can raise the ambition level for circular buildings, can be a link between the producers of innovative products and clients, can be opinion makers, and they can be entrepreneurs finding business solutions which they classify as necessary for the transition to a CE. The consultant for reuse however questioned the central role that architects could play because the role of the architect is based on consensus between the client's needs and the plans of the architect.

"The architect must realize that their job is a service. A service with the result of a temporary aggregate [of building materials] and then the architect would realize that we have to design in a totally different way, that we are no longer going to build but that we are organizing a logistic process" (Interviewee #6)

"Can we [design] a building that makes people feel better? Can we purify water on-site? Can we generate electricity on-site? What if we make a building that makes air that comes out cleaner than the air that goes in?" (Interviewee #5)

Architects demonstrated a strong entrepreneurial approach to their role in the circular economy, which was demonstrated by the start-up of different spin-off companies, e.g., providing a material passport service, developing plastic tiles for facades, and providing for the exchange and consultancy of reused materials.

To be able to play a new role in a circular building sector, architects have to acquire additional competences in two competence areas: technical knowledge and process skills. The technical skills that were mentioned by the interviewees consisted of three areas, (1) a more in-depth material knowledge, (2) more construction knowledge, and (3) the ability to work with flexibility in the design process. The design and building process of a circular building might look rather different to the traditional process where architects are hired by their clients, design the building relying on a secure supply of building materials and components, and finally, the building is constructed. Circular building design process sometimes had contractors and suppliers of new or reused materials already being on the board of the design team early in the process.

3.4. Theme 4: The Ideal Business Case: Buildings as Piggy Banks

The client played, as in traditional building design process, a prominent role in circular building processes. Clients sometimes had high ambitions regarding circularity but were not always aware of how to define their needs into a workable assignment to the architect. Some clients designed innovative solutions to the design process, for instance by asking for an approach rather than a finished design early in the design phase, allowing flexibility in the design process regarding deadlines, were open to new solutions for buildings proposed by the architects, scouted for suitable reused materials, or cleverly put out tenders or specifications for scope statements to contractors.

"Setting up a scope statement is actually writing down what [kind of materials] you will be purchasing. At that moment you stop innovating. You document things, then you start building, then everything is outdated three years later. It is a bit contradictory. (Interviewee #5).

The interviewed architects expressed that both within traditional building projects and circular building design projects, clients are very aware of their corporate image. Especially since sustainability has become an important element in many building projects, clients are aware of the fact that their buildings could contribute to their 'sustainable corporate image'. In the light of the circular economy, it has become more and more important for clients to show that they are embracing the circular economy and therefore the discussed project and its architecture should reflect this attitude. Besides the architectural solutions, a handful of claims for the circularity of the projects were made that were only sometimes quantifiable and verifiable. While some of these ambitious goals were experienced as a driven force in the building process, architects also recognised that it is hard to reach for instance a fully circular building because of the current lack of available materials, components and services.

The ultimate business case for a circular building is the concept of the 'building as material bank'; meaning that buildings are considered to temporarily store materials, and at EoL materials are reused. This will only be achieved when there is a financial incentive to fully design building for de-/reconstruction because circular buildings are currently, in the best case, as expensive as traditional buildings, but in most cases more expensive to build (some interviewed architects and consultants estimated a 10–20% additional cost). Only in two projects, clients got the financial incentive for considering their 'building as materials banks' by obtaining a reduced mortgage from their investors. In both projects, a remaining building value of around 5–15% at the end of life was considered, resulting in reduced mortgage and thus reduced costs for the mortgage interest.

3.5. Theme 5: Barriers and Drivers

Throughout the interviews, the interviewed architects and consultants identified several barriers of the transformation towards a circular building sector;

1. The building industry was considered to be very conservative. Interviewees stated that there is a lack of flexibility to do things differently because it might be considered a higher financial risk,
2. The tight connection of the building sector with other sectors, mainly the financial sector, makes the transformation to a CE more difficult because it would mean other sectors have to make the same transformation simultaneously. As an example, the financing of buildings is still mainly traditional, and is for instance not considering the End-of-Life value of materials. In the same reasoning, architects discussed if the traditional role of the real estate developer, that does not have the intention to own the building for a long time, should still exist in the circular economy because they might value decisions for circularity in building differently,
3. New circular building materials, components and services are needed to keep up with the demand,
4. Interviewees identified that there is a lack of flexibility in the building codes and regulations. These codes and regulations have become very focused on the energy use in the operational phase and do not include the embodied energy. Especially the reuse of material was considered to be hard to fit into existing regulations because mainly of energy performance requirements.
5. Interviewees identified a mismatch between supply and demand of reused materials. Storage could become a key aspect to reduce the mismatch but is expensive. Interviewees also identified that there were not enough people with specific knowledge about 'reused materials' or the actual harvesting of materials.
6. Many architects commented about the fact that labour in Europe is so much more expensive than materials. That means that sometimes decisions are taken in the design and building process that are not beneficial for the circularity of a building, for instance allowing more time to find the right materials or to harvest more materials from elsewhere. Interviewees discussed how a tax shift (making labour cheaper, materials more expensive) could speed up the transition to a more CE.

Interviewees also identified the consequences of a fully circular building sector: (a) conventional building materials, components and services will fail because they are not designed for the CE, (b) some professions will not be needed in the CE anymore, (c) architects that do not follow the transition to the CE will be forced to due to adapt if stricter regulations come into place.

In general, the interviewed architects and consultants were positive about their experiences in the design processes of the discussed projects, but more negative when it comes to the transition towards the CE in general. The main driver in the projects had been the conviction of the client to aim for a circular building which resulted either in the right request/assignment for the building from the beginning of the design process, or allowed the architect and others in the design team to explore new ways of working, new products and materials or new business models.

4. Discussion

The transformation towards a circular building sector seems to be a slow process but unavoidable. The circular economy is a very popular buzzword, with many actors in the building sector (and others) using it to re-brand their existing products in a new way without changing the underlying business model. In contrast to sustainability which aims to gradually optimise things, the circular economy can offer a new economic model, where products (building material and components) are not just sold to customers, but instead new business models are created that offer a service. That does not only imply a long responsibility for the provider of such a service, but it also means that the customer will not end up owning things it doesn't want to own. Providers of such services need to ensure that products with which they provide a service are well-designed and have a long maintenance, leading to less waste and less products. On a small-scale level (product level), there have been many examples of how the principles of the CE can be implemented. On a building level, this has been more problematic.

On the building scale, layers of complexity are added compared to the product level, especially in form of ownership, and the number of actors involved in the case of buildings: client, architect(s), consultant(s), contractor(s) and subcontractor(s), municipality, etc., all with their own requirements/view and business models. A visualisation of this dependency throughout the construction chain can be seen in Figure 7.

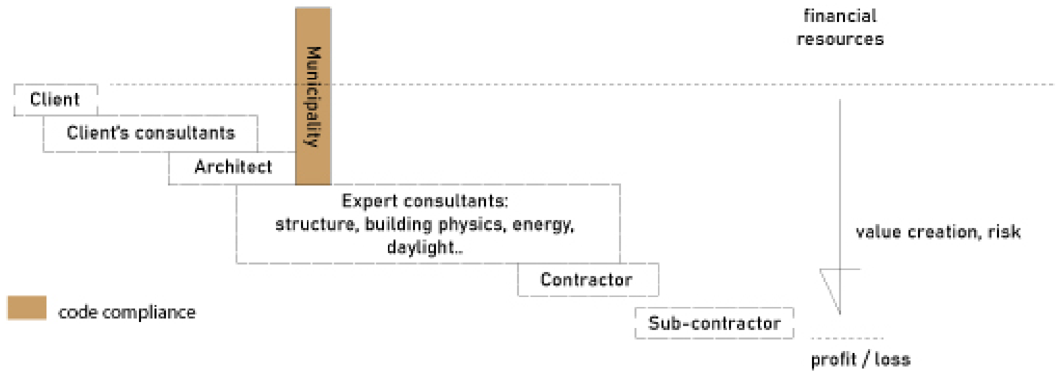

Figure 7. Involved stakeholders and value creation.

As Figure 7 shows, the client is the main actor in circular building design projects. The working hypothesis of this study was that circular building design is succesful when there is a supportive and ambitious client, an architect with the right skills set, available circular materials and a skilled contractor.

Findings of the current study support the idea of the importance of the client. With the right assignment or attitude from the client, the other key actors (architects and contractors) will have the opportunity to explore how to best formulate circular building design solutions for this client. The client on their turn should have the financial assets to fulfil the whole journey. If banks or other institutions that provide money to clients are not willing to 'think outside the box', it gets hard for the client to fulfil the high ambitions. For instance, banks not willing to think provide a lower loan that considers the remaining product value after the End-of-Life. The discussed building projects in this article show that 'where there is a will there is a way. With a very pro-active client and/or architect, a circular building design is possible, although a 100% circularity was currently hard to achieve. The dependency throughout the construction chain shows that a transformation to a more circular building sector could take long time, if actors are not forced.

This study also supports the fact that architects are pivotal in the transition to a circular building sector. Architects could play a central role in the design process, by linking different actors with each other, next to providing innovative solutions for an architecture that fully translates the principles of the circular economy to a new architecture. To be able to fulfil this position, architects will need to acquire additional skills like leadership and a more in-dept material knowledge.

The third factor of the hypotheses, the availability of materials with high circular potential, has been identified to be an issue at the moment. Not that many materials and/or services were found available for the discussed building projects or were found not to fit these projects. While the discussed projects showed that circular building design can be successful, the majority of the building sector is not mature yet, including materials producers.

It is very likely that the pressure on our natural resources could force the transformation towards the circular economy, if the raw materials needed to produce building materials or components become scarce and thus expensive. At the same time, focus will be on phasing out of waste which will also accelerate a more circular thinking. The conservative building sector, as it was experienced by the interviewees in this study, will therefore have to increase its speed towards a more circular economy.

5. Conclusions

A series of semi-structured interviews with architects and consultants was conducted to gain an insight in the design process of successful circular building designs and to identify barriers and drivers for the transformation to a more circular building sector.

In general, five themes were identified out of the interviews: (1) Defining circular building design, (2) Circular materiality, (3) The new role of the architect, (4) The building as piggy bank, and (5) Barriers and drivers. Interviewees expressed the absence of a definition of circular building design, which has led to multiple approaches in the discussed projects. Choosing the right materials was considered to be crucial, but there is currently a lack of standard methods and tools to help architects to take the right decision. Architects can play a renewed role in circular building design processes where they, besides providing innovative circular architectural solutions, also link key actors to each other. In order to accelerate the transformation to a circular building industry, a building that is designed for deconstruction and with the right materials, should be seen as piggy bank, where materials with a certain financial value are temporarily stored.

This research has highlighted drivers and barriers in circular building design projects. However, many architects indicated that it was hard to take the right design decisions during the design process when it comes to the environmental impact of a building. Future research therefore should be on analyzing and/or developing (open-source) methods that can provide early feedback on design decisions in the early project phase.

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