THE CORE INTERACTION OF A CIRCULAR CONSTRUCTION PLATFORM

How can a digital market platform address the construction market for secondary materials?

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Content

Acknowledgment

As an entrepreneurial type of student, I have always questioned why the construction industry is stated as conservative, laggard, and non-digital. Besides that, the construction industry is also responsible for 5% of GDP (in the Netherlands). But for 38 per cent of the total waste production, 40% of the CO2 emissions and 50% of all-natural resources are used within the AEC sector (EIB 2015). This negative impact is related to the fact that the built environment is optimized for a linear system and one end of life option; demolition.

Reasons enough to use my master thesis for this opportunity.
After an exploration phase about innovations within the construction industry, I discovered the circular economy's potential and digital applications within the construction industry. The Circular economy is connecting two ideas, the closed-loop economy and 'design to re-design' thinking. Promising 'low consumption of energy,' 'low emission of pollutants' and 'high efficiency.' CE a generic term for an industrial economy, which is, by design or intention, restorative and in which material flows are of two types— those which are biological nutrients, designed to re-enter the biosphere safely, and technical nutrients, designed to **circulate at high quality** without entering the biosphere. The aims are to 'design out' waste, return nutrients, and recycle durables, using renewable energy to power the economy (UNEP 2006). **The use of the word 'restorative' is important, as the Circular Economy is not merely a preventative approach**, reducing pollution, but also aims to repair previous damage by designing better systems within the entity of the industry itself. Drawing on concepts such as 'cradle-to-cradle™,' where the industry operates with no impact upon the environment by being waste-free (McDonough 2002); biomimetics, wherein the structure and function of natural systems inform industrial processes; and industrial ecology, the Circular Economy focuses on optimizing systems rather than components

After reading Material Matters (Rau 2016) and contacting Madaster, a platform giving materials an identity with a Material passport, a thesis concept started. As I linked the concepts mentioned above, circulating "high quality" products and designing better systems within the industry's entity itself. Meaning: researching the building industry's opportunities (current building stock) and providing an answer for a possible marketplace for reused building elements.

Before starting my research, I want to thank the TU Delft by giving me the freedom to do such exciting and relevant research.

After a period of pausing (4 years) my thesis research because of work related opportunities. I am happy to finish this thesis. It is good to see that there is more attention for re-use in the construction industry. And I hope that this research will still provide knowledge and value to the industry. As a last word I want to thank the committee for there patience.

“The Roman building engineer Vitruvius, writing in around 25BC, advises that the strongest walls are those made using old fired-clay roofing tiles since only the best quality tiles would have survived the ravages of rains, winds and frosts. He also mentions that murals painted on brick walls could cut out with their brick backing, packed in a timber frame for transportation and incorporated into another building”. – Building with reclaimed components and Materials (Bill Addis, 2006)

Executive summary

The Netherlands aims to have a fully circular economy by 2050. The construction sector in the Netherlands is only 8% circular (Circularity Gap Report Bouw, 2022). Reuse within construction projects presents various challenges, which will be discussed in this thesis. In the current market, there is more supply than demand (BAMB, 2020). One possibility to stimulate demand is the use of digital marketplaces. This study investigates how a digital marketplace can support the demand side in the design process, leading to the following research question:

How should a secondary 'digital' product marketplace function within the construction industry?

Before addressing this question, a literature review is conducted on various aspects. These include the concepts within digital marketplaces and platforms, as well as those within reuse projects, focusing on specific information about materials and products in the context of reuse. Additionally, the current state of the industry has been examined in terms of challenges, opportunities in general, and those related to digitalization. This is done to get a better understanding of the surroundings in which the marketplace must operate.

The literature research concludes that the core interaction is the most important form of activity on a platform – the value that attracts the most users to the platform in the first place (Parker et al., 2016). It consists of three parts: Participants + Value Unit + Filter. Fundamentally there are two participants on the platform, namely producers and consumers. In this case, producers are building/construction elements and their owners/sellers. Consumers are the ones that are willing to buy them (potentially; architects, engineers, contractors, or suppliers). Where the value unit starts with the exchange of information that has value to the participants. This information delivery to consumers depends on filters. A filter enables the transfer of appropriate value units between users. A well-designed filter ensures that platform users see only information units that are relevant and valuable to them. No filters or a poorly designed filter overwhelms users with units they find valueless and irrelevant, which causes them to abandon the platform. No research has been done to the specific design of the core interaction of a secondary product marketplace within the construction industry.

In addition, few scientific articles investigate software interfaces, ease of use and the user's role and experience within the construction industry. An action- and design-oriented research method is a new approach to this problem/goal. The information system framework is chosen to combine rigor research and the application domain within a design practices.

To structure this research the research question is divided into three steps (based on the core interaction). In step 1, the input for the design is investigated, which includes determining the participants who should use the marketplace (champions), how they should search for products, and what improvements can be made in the design process to promote reuse. In step 2, the filters and interfaces of the marketplace are designed. Within step 2, solutions for situations with limited data or, conversely, when there is sufficient data in the future are also explored. In step 3, the chosen champion validates if they can use the designed solution and whether it provides value.

To define the main users/champions (step 1), potential users-(roles) are interviewed about their needs for such a marketplace, assuming reuse becomes the norm. The literature review covers all aspects of digital (construction) applications and reuse in the construction industry. This is supplemented with expert interviews in IFC (an open data standard), user interface/user experience (UI/UX), current construction marketplaces, and material passports. In addition, various roles from several reuse projects

are interviewed, including designers, project developers, purchasers, demolition specialists, and engineers, in line with the information system framework and action design. This is done to get an complete overview of all the stakeholders involved within the process of selecting/buying reused products.

The information of the literature research and the first interview phase is used in the design process to create ‘search and facet’ filters. Therefor a division based on the Brand/shearing layers (site, structure, services, skin/facade, space, and stuff) is made to improve the design the facet filters. The engineer and the architect is chosen as the primary user but in consultation with the design team. For all the engineers responsible or related to the a Brand layer a recommendation is made for a first set a (search) parameters.

Concerning the information need (step 2) of the structural engineer, the primary focus is on the **elements' functional and physical propertie**s (moment-of-inertia, material type, strength, and dimensions). Thereby the core interaction disregards environmental or economic properties. These are of secondary interest for the core interaction. The three main materials, wood, steel and concrete, require all different ways of working for reuse but share common properties which makes the design of filters less complex. Capacity, dimension, grid size, floor height and more properties could influence the structural design decision, increasing the demand for reusable structural products. However, more traditional engineers prefer to filter within one type of material. Even more in-depth material and product knowledge for reuse could is a next step for the core interaction, thereby evolving into a knowledge marketplace.

The other Brand layers (skin, services and space) information need should also focus on their functional and physical reusability properties, which are covered and designed in this thesis but not validated with real users. The skin and the space layer are more visually oriented; images support the architect's and engineer's decision-making. Aesthetic filters to filter on certain styles, colours, types and tags will support the architect where functional filters relating to dimension are of first need for the façade engineer. Secondly the physical filters benefit the search tremendously, such as; U-value, fire resistance, Rc-value, sound resistance, waterproofness etc. The service/building engineer wants to filter into three categories. Namely the machine, the distribution point (ventilation grille, water tap, heating element) and the transport (cable tray, pipe and wires). The machine (e.g., heating, cooling and air filters) has a more dynamical environment with a high change in regulation, expecting a low reuse pattern. The other two categories, distribution and transport are more suitable for reuse; these filters contain service type (energy, water, air, data and heating), minimum length and the capacity of distribution and transportation.

After step 2 (design) various structural engineers are interviewed using a working digital prototype to examine whether the search filters are effective for their reuse process (step 3). Besides various side notes on the design culture, system changes and the willingness of a client to reuse products. The interviewed users made recommendations which should be taken into account for a next design iteration. The proposed design is usable and could meet its goal/value proposition when reusing products becomes the norm.

This research is a small link in the bigger picture of a ‘circular’ construction industry. Still, many challenges remain that a digital marketplace could not solve. When interpreting the results, the following points should be considered as well. The interviewees in this research are involved or interested in reusing products. When less interested engineers/users must use this marketplace, other items could be of more importance or totally different obstacles could arise.

Further research should examine the other Brand layers and their primary users. Additionally, to succeed as a marketplace, choices need to be made. Which users and product categories will be supported in first place. What is the business plan and initial investment? Building and rolling out a marketplace requires entrepreneurial skills and courage. This research hopes to provide the readers with a holistic view of all the challenges related to a digital market platform that address the construction market for secondary materials. Together with a set of validated user interfaces of such marketplace.

Chapter 1 Introduction

1.1 Pre-research

According to Lansink, reuse is the second most essential accomplishment in the waste hierarchy (Lansink's Ladder) . Reusing has several challenges which are described below. To overcome some of these challenges, research is done on an online (reuse) marketplace. First trends are described below — namely design for disassembly — thereafter- the reuse potential -- thirdly, the shift from a linear to a circular economy— Lastly, the need for a reuse "digital" market. Together this leads to a set of recommendations and will describe the aim of this thesis.

Economical trends

From 1930 to the present, global economic trends have been shaped by the contributions of key thinkers such as Keynes, Hayek, Braungart, McDonough, and Raworth. The 1930s were defined by the Great Depression, prompting John Maynard Keynes to advocate for government intervention and public spending to stimulate economies. His Keynesian policies gained prominence during and after World War II, fostering economic growth and the development of welfare states.

In contrast, Friedrich Hayek argued for minimal government intervention and emphasized the importance of individual freedom and free markets. Hayek's neoliberal ideas gained traction in the 1970s and 1980s, influencing policy shifts towards deregulation and privatization.

In recent decades, sustainability and circular economy concepts have emerged as critical components of economic thinking. Michael Braungart and William McDonough's "Cradle to Cradle" approach emphasizes designing products and systems that eliminate waste and promote the continuous use of resources. This framework has informed a more sustainable approach to economic growth and industrial practices.

Kate Raworth's "Doughnut Economics" further challenges traditional growth-centric models by proposing a safe and just space for humanity, balancing social foundations and ecological ceilings. These contemporary ideas reflect the evolving nature of economic trends, as societies grapple with the interconnected challenges of inequality, environmental degradation, and technological disruption.

Design for Disassembly and Material passports

Reclamation, recycling and reuse are not new ideas (Addis, 2006). The builder John Abrams proposed "the book" in 1968: a book with open-wall photos plus the keyed plans. He knew the value of the book during remodeling, and any time the house is sold. In "Measuring Building Performance"(Duffy, 1990) and "How Buildings Learn: What happens after they are built (Brand, 1994), both writers describe the differences in the technical life cycle vs. functional life cycle of different building layers. In 1999 Crowther continued: Reuse strategy has the advantage that the elements can be reused more flexibly. The reuse structure can have a different structural configuration than the original building. This means the reusable elements or components appeal to a bigger market, increasing their reuse potential". Crowther also started with themes and principles for design for disassembly (DfD) (Crowther, 1999)." Meaning buildings should be designed to make it easier to disassemble them later.

Building material passports like Madaster, Circular Building platform (BAM), Electronic Building Passport Queensland and Building as a Material Bank starts by identifying the building stock. But the link between the passports and the marketplaces is missing. Known is that supply exceeds demand in nowadays second-hand building material market. Therefore attention is needed to stimulate the second-hand market demand, which would be important to the actual realization of material circularity in the building sector. (Peters, Ribeiro, Oseyran, & Wang, 2017)

Reuse potential

Where DfD and new build circular building projects make use of new materials, there are considerable opportunities in the deconstruction of current offices to new houses and buildings. With an office vacancy of 15.7% (Planbureau voor de Leefomgeving, 2017) and a housing shortage of 235.000 houses in 2020 (W. Faessen, K. Gopal, G. van Leeuwen, 2017); Opportunities may arise if reused component costs, in the long run, go down as the infrastructure for deconstruction and reuse establishes, which will unlock funds for higher design fees. In Canada, the cost of a reused steel beam may typically be 60–80% of the cost of an equivalent new beam provided that additional fabrication costs are not high. (Gorgolewski, 2008)

Other benefits of deconstruction that derived from different literature sources (NAHB, 1998), (Kibert, 2003), (Guy, 2000), (Simon, 2007), (Macozoma, 2001) are the following: Deconstruction might cost less than demolition due to the value of the salvaged materials and the eliminated disposal costs. New jobs are created by training unskilled workers for manual deconstructing buildings. The new economic stream is developed (the secondary materials industry of retail businesses for salvaged materials, recycling businesses and recycled content product manufacturers. Example projects have shown the possibilities and realisation of reusing products in new building projects. However additional time is needed, and the need for identifying and buying the reclaimed goods should be done in an early phase (Addis, 2006).

“Digital” market need

Fujita et al. describe the use of a “digital database” for reuse purposes (Fujita & Iwata, 2008). The reason why DfD is never applied on a large scale is the non-existence of a market for reuse elements is pointed out by Roders in 2004. The market does not exist because the building components cannot be stored and wait until a reuse function is at hand, caused by the loss of investment due to the time value of money and the costs for deconstruction plus storage(Roders & Van Gassel, 2004). Another reason is the lack of digital power to link the virtual modulus to real-world construction projects (Lichtenberg, 2005).

What is needed?

BAMB mentions the need for a change in design culture. Especially in the design phase (new build, renovation, or transformation project) the architects, designers and engineers lack the information on the availability of the potential supply for the projects. Most solutions focus on project managers, realizing the build, but most decisions are made at the design phase (new and renovation) where availability is off-sync, and inventory rules limit product reservations for more extended periods. As the build phase starts weeks or months after the design finished, by which time the materials are no longer available. This challenge calls for integrated and new solutions, supported with innovative business models that assist these professionals with information when they are interacting with a building.

For an overview of the trends see the appendix Pre-research overview.

1.2 Research gap: usability for construction marketplaces

To conclude the needs for further research based on the pre-research. The challenges of stimulating demand in the second-hand market for the building sector to achieve material circularity (Peters, Ribeiro, Oseyran, & Wang, 2017). The issues include the need for early identification and purchase of reclaimed goods (Addis, 2006), the non-existence of a market due to storage and investment concerns (Roders & Van Gassel, 2004), and the lack of digital power to connect virtual modules with real-world projects (Lichtenberg, 2005). Research group building as material bank mentions the need for a change in design culture, and that supply exceeds demand in the current industry (BAMB, 2019). Lastly the low usage of current online marketplaces (Bas Slager & Jansen, 2018). Therefore this research suggests that further investigation into the demand side of the marketplace is necessary, with a focus on addressing these issues through digital technology.

Literature about champions (main users & deciders of a platform), core interaction (see literature) and user interface in the construction industry is rare. However, there is enough literature about e-commerce, e-procurement, and e-marketplaces around 2002. A part of this research around 2002 is specifically related to the construction industry. That literature describes the current data and web server techniques (XML, SQL, etc.) but is not giving attention to such platforms' usage and personas. For example the e-union concept (C. S. Kong et al., 2004). The interface contains many input fields and is not validated with real users. None of the articles describes the user-interface, usability and the role of the various users. There is a considerable research gap in the usability of construction marketplaces and the multiple types of users. Using action and design-driven research method is a new way of approaching this problem.

“The first interface appears in “An e-commerce system for construction material procurement” by C.W Kong & P.E.D. Love (2001). “The searching function of the e-catalogue allows buyers to specify searching criteria such as a price range, categories and keywords so that finding the desired materials and products is efficient. Also, presenting the retrieved results in a way that enables comparisons.”

This master thesis is not only investigating specific marketplaces but combining research done in separate fields that could contribute to the success of an ‘construction’ e-marketplace and her ecosystem's total functioning. Thereby interviewing potential users about their needs of such a marketplace.

Practical

Demand-side asks for different materials and products for one specific construction project it requires searching at different eMarketplaces, which is time-consuming. After a possible match, appointments are made, and peripheral matters must be arranged. To grow as a platform, Madaster has benefits of reliable marketplace partners.

Theoretical

It will accelerate the circular economy within the construction industry. Implementing CE in the construction industry might be considered even more disruptive as in other sectors of our industrial economy (van den Brink, Prins, Straub, & Ploeger, 2017)

1.3 Research question: How should a secondary construction marketplace function?

The above problem definition defines the need for a change in design culture and the need for information about reusable products (with the use of a digital system). This definition leads to the following research question:

How can a digital market platform address the construction market for secondary materials?

Question 1 (answered in chapter 2): What are the fundamental concepts of digital market platforms in the market for secondary construction materials?

- 1.1: What are the concepts for digital market platforms?
- 1.2: What are the concepts for reusing construction materials?

Question 2 (answered in chapter 3): How should this research be designed?

Question 3 (answered in chapter 4): How should a secondary product marketplace function within the construction industry?
After reading the research design, the reader will be informed about three steps to answer this question

Question 4 (answered in chapter 5): How does this research contribute to the literature (discussion)?

Question 5 (answered in chapter 6): What is the conclusion (including limitations and recommendations)?

1.4 Focus area: customers and core-interaction

The canvas in figure 1 is a useful overview of the complexity of a digital platform. Platform literature in chapter two elaborate on this. Essentially, a platform has two sides, producers (supply) and customers (demand). According to the problem statement, the focus is on the demand side. The most critical part of a digital platform is the core interaction. The core interaction has many relations to the other parts as well. As the core interaction always involves both the producer and customers, the literature and research parts will explore both parts; however, not in the validation phase of this research. See figure 1 below, which indicates the focus area of this research. Because supply exceeds demand (BAMB, 2019), the focus is on the customer (demand) side.

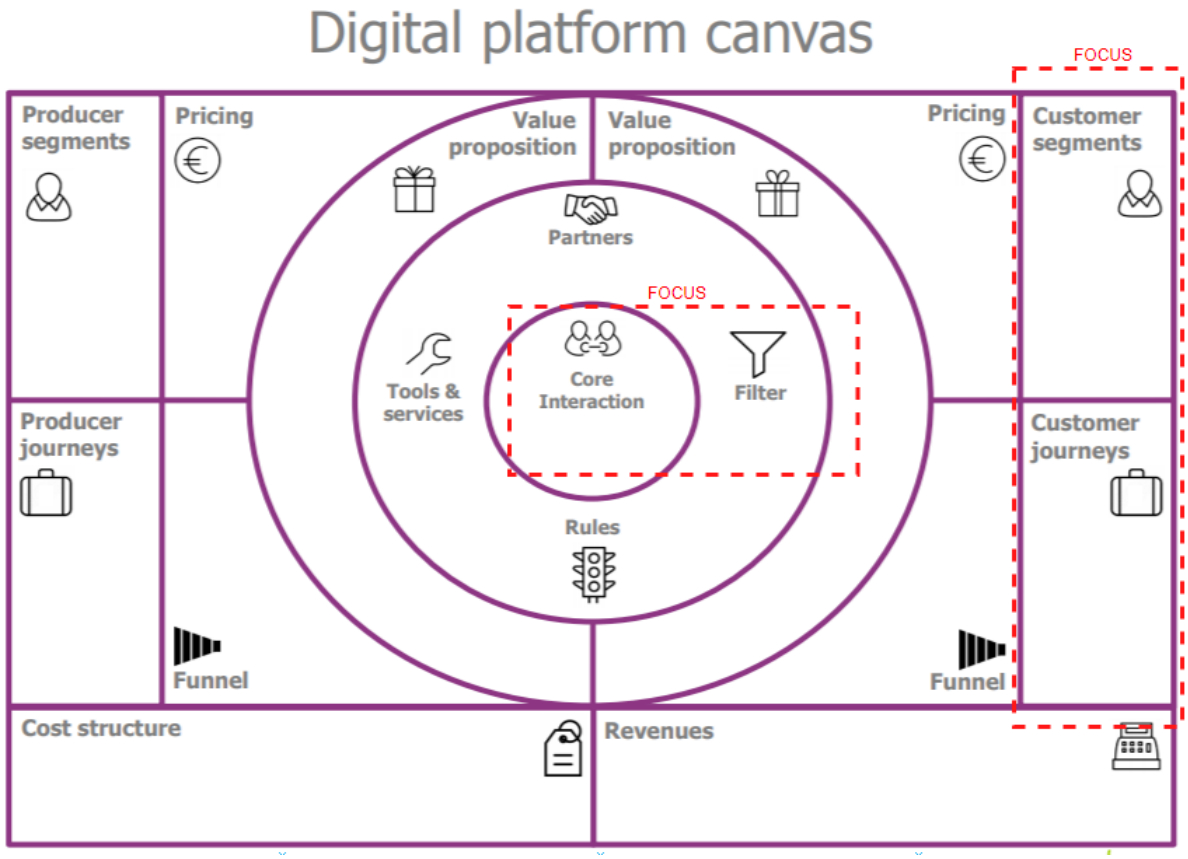

Figure 1: Platform canvas (from thecanvasrevolution.com) with the focus area of this thesis

Chapter 2 core concepts

What are the fundamental concepts of digital market platforms in the market for secondary construction materials?

The following two subjects will be covered during the literate review. Namely what are the core concepts within digital platforms. Secondly, what are the core concepts within the construction industry and the reuse of materials and products?

The core concepts within digital platforms begins by exploring the core interaction of a platform and the differences between well-known e-marketplaces like Amazon, Bol.com, and eBay, compared to e-marketplaces for the construction industry, specifically B2C, B2B, and Construction2Construction. Therafter it examines how user research can be conducted to consider the unique characteristics of a digital marketplace for the construction industry and how it can filter/search all the different product/material properties. Moreover, this part investigates the current status of construction marketplaces, the main challenges, and opportunities within the construction industry, and the challenges and opportunities in the digitization of the construction industry. A comprehensive understanding of the construction industry, its current practices, and the challenges and opportunities presented by digitization is necessary to develop effective solutions.

The second parts delves into the current process of reusing products and materials in the construction industry and the role of design for disassembly in this process. Additionally, investigates what we need to know about material and product usage in the construction industry, including the advantages and disadvantages of the main construction materials, the current status of online marketplaces in relation to the main construction materials, and the most used/most available construction products in the Netherlands compared to the situation in Europe and internationally. Moreover, this part examines the required information to design filters and the relevance of products and materials for the supply side.

Finally, the second part discusses the main challenges of collecting this information in a digital manner. These research questions are essential as a digital tool will function within the current industry/culture and will not solve the challenges related to reusing construction materials on its own.

2.1 Core concepts digital platforms

2.1.1. Platforms and the core interaction

An e-marketplace is a digital platform. Cooperation on a platform resembles any economic or social exchange, whether it occurs in the real world or the virtual world of the Internet in every such exchange, the producer and the consumer exchange three things: *information, goods or services,* and *currency.* The design of a platform should start with the core interaction. (Parker, Van Alstyne, & Choudary, 2016). In this research period, the core interaction aims to realise trading in construction elements from salvages yard or while they are still part of the structure or building (virtual depot).

The core interaction is the most important form of activity on a platform – the value that attracts the most users to the platform in the first place (Parker et al., 2016). It consists of three parts: Participants + Value Unit + Filter. Fundamentally there are two participants on the platform, namely producers and consumers. In this case, producers are building/construction elements and their owners/sellers. Consumers are architects, engineers, contractors, or suppliers. The value unit starts with the exchange of information that has value to the participants. This information delivery to consumers depends on filters. A filter enables the transfer of appropriate value units between users. A well-designed filter ensures that platform users see only information units that are relevant and valuable to them. No filter or a poorly-designed filter overwhelms users with units they find valueless and irrelevant, which causes them to abandon the platform.

To realize this, Parker and Choudary describe three essential functions that platform designers can do to ensure valuable core interactions. Thereby attracting more participants to the platform and enabling a positive network effect. These three essential functions are: *Pull:* attract producers and consumers to the platform, enabling interactions among them (who). *Facilitate:* providing users with rules and tools that make it easy for them to connect and exchange value (filters). *Match:* connect user, producers and consumers, virtually by using information about each to connect them in ways that will find mutually rewarding (value).

Another research proposes three similar conditions for classifying digital marketplaces. (Täuscher & Laudien, 2017). Namely, connect actors from the demand and supply side (*pull),* actors enter direct interactions to initiate a commercial transaction *(facilitate)*. Third, the marketplace platform provides an institutional and regulatory frame for transactions *(match)*. Research done by Moazed mentions that the core transaction on every platform includes the same basic set of four actions (Moazed & Johnson, n.d.). Namely connect (*pull)*, create and consume (*facilitate)* and compensate (*match).* For now, the words; Pull, Facilitate and Match are used. This research will focus on the facilitate part. See table core interaction in the appendix for an overview of different theories.

The core interaction of a platform is part of the user interaction. A way of measuring user interaction is the usability: the product's potential to accomplish the user's goals. In the field of usability and user-experience, different methods exist. All the user research has in common that it places people at the centre of the design process.

This research focuses on the facilitate (the filter) and the participants' part of the platform. Different strategies exist to attract customers and producers to the platform (pull & push factors) like, piggyback strategy, producer evangelism, single side strategy, and viral growth (Parker et al., 2016). The design of a filter and facilitate tool can influence and support these strategies enormous. It is a logical sequence to start thinking about how a reuse-product marketplace should look like and who should use it and after that start with attracting consumer and participants to the platform, which leads in the end to the actual matching

2.1.2 B2B marketplace vs B2C marketplace

Most of the core interaction literature relates to business-to-consumer (B2C) platforms (see examples attachment). To still apply the literature on the construction industry, where a business-to-business (B2B) situation takes place, understanding the difference between B2C & B2B marketplace is important.

Unique B2B

According to McKinsey B2B journeys involve more individuals as multiple engineers need to certify the product, often adopting a design or process. Where logistics and operations must wait to coordinate deliveries until volumes, prices, and delivery terms are negotiated. This whole process can require decisions by 15 to 20 people. Also, customization is more widespread in B2B than B2C, and the stakes are higher than B2C ones. What does this say about B2B marketplaces?

B2B marketplaces

Specifically, marketplaces have a significant difference between B2B and B2C. The fundamental value proposition of such trading platforms is relatively concentrated; 75% of the platforms increase efficiency or cost savings (Täuscher & Laudien, 2017). Regarding the marketplaces, only eight marketplaces out of hundred match businesses with each other (B2B) (Täuscher & Laudien, 2017). So B2B marketplaces are unique. What is so hard in realizing them?

Usability issue

User testing shows that B2B websites have substantially lower usability than mainstream B2C sites. If they want to increase revenue, B2B sites should follow guidelines and make it easier for candidates to research their offerings, including pricing information (Nielsen Jakob, 2006). In more detail, B2B web users show that 46% of business consumers leave websites because of inadequate contact information, poor design, and inability to see what the company offers (Huff & Edmon, 2015). Low usability B2B systems will increase avoidance and refuse of the system. While empirical research in B2C solutions supports this relation, there is not yet corresponding research in the B2B sector and certainly not in the AEC sector.

B2B websites typically contain more detailed information (e.g., specifications, drawings, and calculations). Although aesthetically features are somehow irrelevant, usability and straightforward menus should help the user find the right information, and details should be quickly accessible. For those reasons, usability is essential in B2B marketplaces. (Konradt, Lückel, & Ellwart, 2012).

2.1.3 The “construction” champion

The previous part highlights the importance and lack of usability in B2B platforms and the difference between B2C and B2B platforms. The next part research the relationship and relevance between usability and users (champions) in the construction industry.

Champion B2C & B2B

When designing B2C services, one person is typically targeted. This is the decider and user at the same time. While B2B services have a higher complexity. Usually, there is a division between the end-user and the decider. Since there are multiple end-users, often, an administrator takes care of the accounts, including onboarding, tracking usage, synthesizing the outcome, and so forth. The following figure shows the champion difference between B2C and B2B.

Still, the discussion arises which “champion” will make use of the e-marketplace for reused products? As the design and product procurement process could be different when reusing products. A similar “team as the champion” is stated by Gorgolweski (2006): “Successful steel reuse projects are generally the result of **a willing client and a tightly integrated team** responsible both for the design and rebuilding.”

Both C. Alexander and S. Brand, two well-known architects, believe that the architect should function as a team with the developers and contractors. This master thesis research how this ‘team’ champion plays a role in a reuse platform's core interaction. This playfield of 4 different users should find the relevant information they need to decide for a specific re-usable building element.

Personas for a construction marketplace for reuse

Personas is a technique used in user research to define potential / different users and from there one pick a champion (main user). This is very useful in combination with semi-structured interviews. The uncertainty of the champion in the process of reusing construction products makes sense to use personas. Using personas is not much done in construction industry research. However, other industries make use of this technique, e.g. medical equipment:

“Although untested, we would expect the persona technique to offer a broad range of advantages to industry: for example, getting recruits to consider important aspects of the customer; disseminating information about users across an organization; making the process of discussing user needs fun; making it easy for employees to represent the user, or switch hats when it comes to discussing user requirements, and giving employees look ahead regarding future customers.”(Vincent & Blandford, 2014) in “the challenges of delivering validated personas for medical equipment design.”

In this research, the following personas are defined: Architect, Engineer, Contractor & Client as these are the most involved in the design process of new buildings. In the appendix detailed profiles of the personas can be found.

Champion research in the construction industry

Till so far know only Dunant involves personas in “reuse” research. It gives insight into the barriers per persona in the steel reuse value chain (Dunant et al., 2017). It involves architects, structural engineers, main contractors, fabricators, stockist, and demolition contractors. Dunant proves that there is a contrast between perceived higher costs and the time required to employ reused steel.

The theory of involving personas and champions is not entirely new to the industry. In “a review of web-based project management & collaboration tools and their adoption by the US AEC industry” Burcin Becerik describes the need for champions as well. “Often, the champion for trying an application in an organization is a project manager who recognizes the potential. The lack of top management support caused many CPE (construction project extranet) experiments to fail, caused by a lack of resources,

unclear expectations, and weak enforcement of new procedures. Once a first pilot failed, other Project Managers were less likely to try. “

Becerik continues during an interview with Amar Hanspal[1]: “Contractors are uncomfortable forcing the use of a technology tool onto the project team members. Vendors have not done a proper job in documenting the value proposition for every member of a team. If only one member is paying for the tool's use by the rest of the team, all members need to understand why it benefits them. Otherwise, adoption inconsistent and success is compromised. This “push back” by companies who are asked to use a CPE tool continues to be a significant retardant to adoption and acceptance. Bercerik shows the complexity of people/companies in the field of circularity and IT related to the construction sector. Therefor the need to investigate and define a persona/champion and get an understanding of their needs to not only develop a tool, but also something that they can adopt is crucial in the succeeding of this thesis.

“Where precisely the need most significant challenges ahead do not lie in further technological innovation but instead in people's role, both as individuals and as a society (Pomponi & Moncaster, 2017).

[1] http://usa.autodesk.com/adsk/servlet/index?siteID=123112&id=2407898

2.1.4 Filters

After investigating participants, filters needs to be designed (remember core interaction = participants + filters + value). Therefor this part investigates the possibilities and development of filters in the last years.

Facets an introduction

An important aspect of filters is facets. In the early 2000 retailers explored the use of faceted search, which was initially based on a classification for libraries developed by S.R. Ranganathan in 1933. According to a 2014 US benchmark[2], only 40% of e-commerce sites implemented a faceted search.

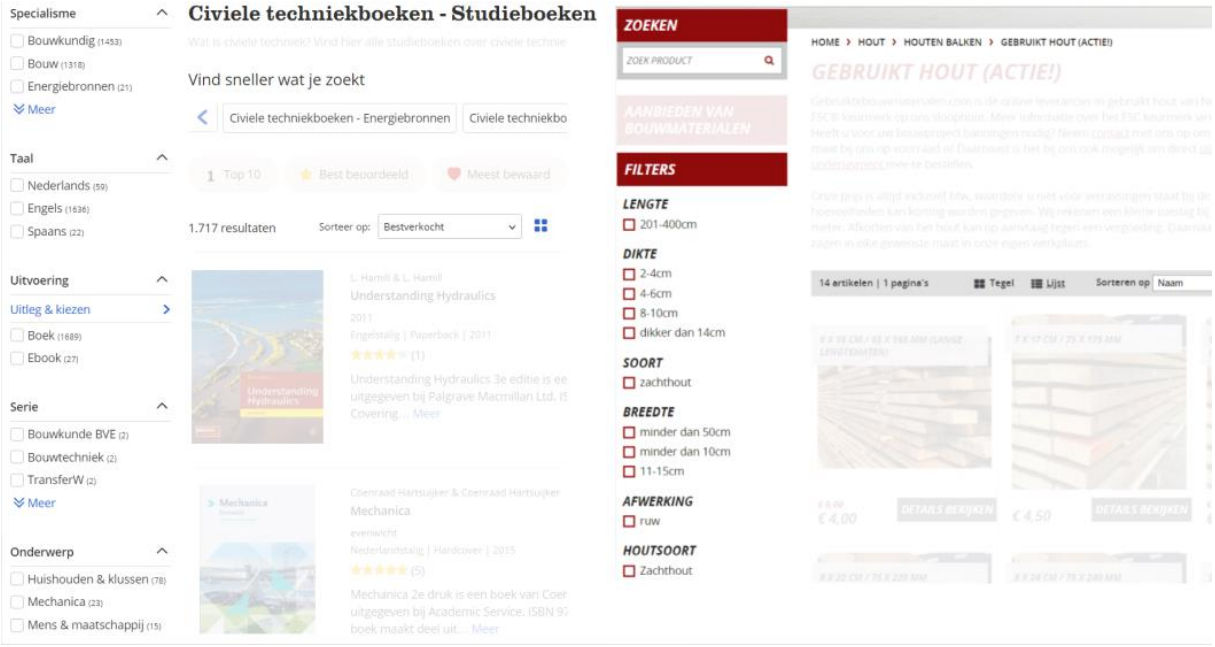

Figure 2 – faceted search on B2C e-commerce site and B2C/B reused material site (own collection from known sites)

While faceted classification has five major advantages:
Faceted search allows filtering rapidly with a combination of facets. (Broughton, 2001). Secondly faceted classification allows the assignment of multiple groupings and enables search in numerous ways, rather than in a single order. (Foskett, 1959). Jargon or knowledge about categories is not needed; the facet navigation presents a controlled vocabulary with the number of search hits matching each vocabulary term. Facets could be created at any time without disturbing the hierarchy or reorganising other facets. Lastly faceted system focuses on the essential or persistent characteristics of content objects, useful for categorising fine-grained rapidly changing repositories. For example filters could be combined with images to specify search results as can be seen in figure 3.

Figure 3: facet with images (from an online retailer)

Facets and current marketplaces

The existing reused material marketplaces in the Netherlands do not make use of facet navigation. One exception is gebruiktebouwmaterialen.com. Even existing construction e-commerce websites for new products do not make use of facet filters. See for example, the Dutch e-commerce site www.limtrade.nl.

[2] https://www.smashingmagazine.com/2014/08/the-current-state-of-e-commerce-search/

An example of proper home navigation and facet search[3] is www.build.com. The difference between home page navigation and facet search is that home page navigation is always there, where facet search depends on the specific category and aims to specify the search and filters on particular needs that the user has (e.g. type, price and/or dimensions).

Classification systems in the AEC industry

There have been various classification systems developed by several countries and institutions over fifty years such as BSAB in Sweden, Uniclass in the UK, DBK in Denmark and OmniClass in North America (Ekholm A., 1996; Jorgensen, 2011). The most used systems in the Netherlands are Stabu and NL-SfB.

Moreover, there is a need to have a structured guideline for combining classification systems in international scale. In fact, mapping information between major product classification systems would benefit the industry. There have been some studies in Sweden to map BSAB with IFC (Ekholm, 1999). Future research needs to clarify how IFC's classification structure (Industry Foundation Classes) as a neutral international open standard can be coordinated with established industry standards and classification systems. This paper aims not to create a new classification system but tries to identify which facets are essential for reuse. More information on IFC is in the appendix.

[3] https://baymard.com/ux-benchmark

Examples bol.com

Bol.com facet filter over the years (2009 till 2020 – left to right)

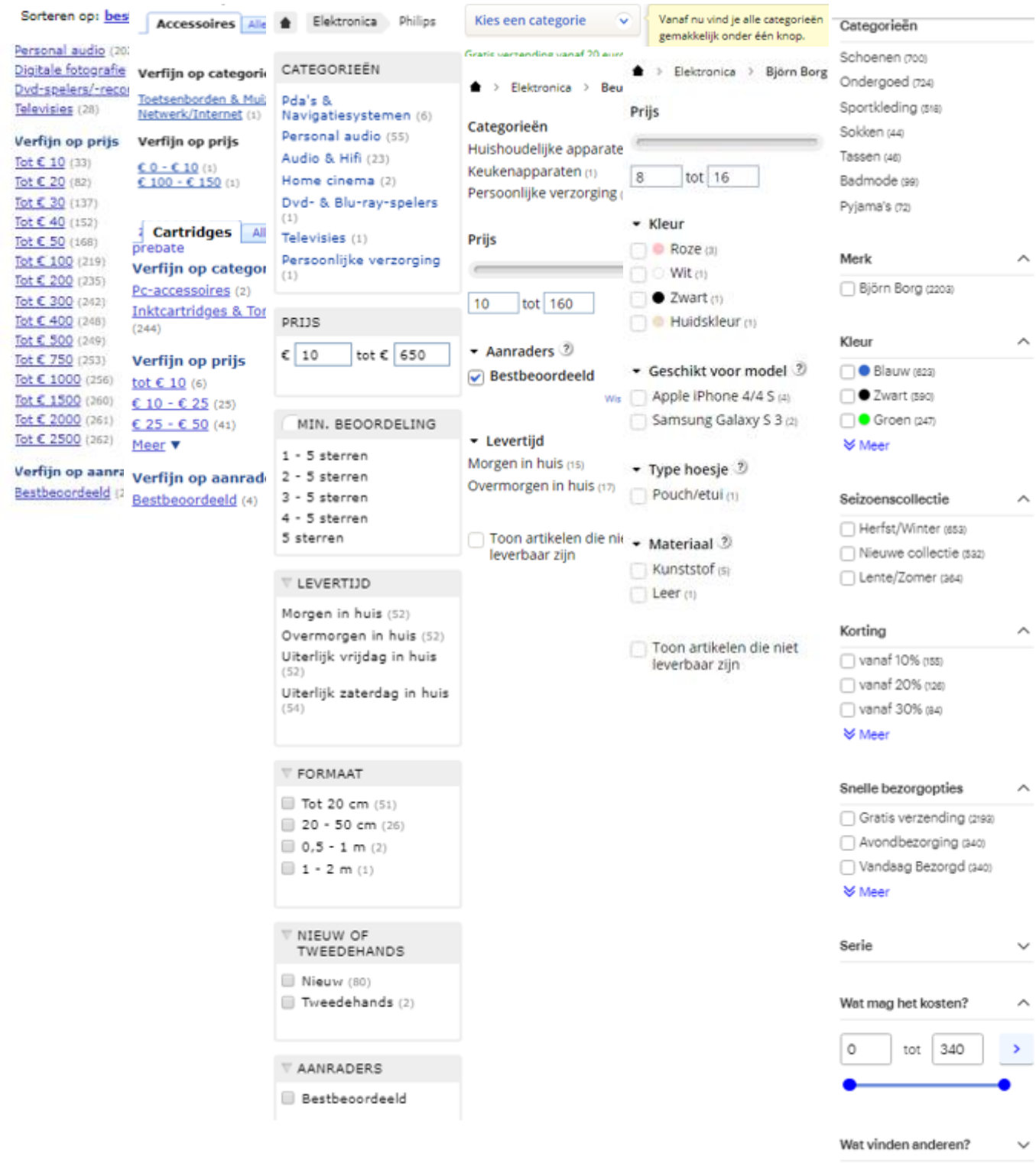

Figure 4: bol.com overview facet filters over time (own collection by using wayback machine/web archive)

2.1.5 Construction marketplaces and filters

BAMB mentions the lack or working platforms. What could be learned from these existing marketplaces?

Marketplaces

Existing marketplaces for building materials reuse face several challenges that limit their effectiveness. One significant barrier is the limited supply of materials, which can make it time-consuming and challenging to find suitable items. Another challenge is that a single construction project may require multiple different materials and products, which are often available from different suppliers, adding complexity to the procurement process. Specifications and data for these materials are often limited, which can make it difficult to compare products and make informed decisions. Additionally, the supply of materials may be insufficient for project needs, requiring the use of alternative sourcing options. While digital searching is attractive, oral tuning is often necessary to ensure that the materials meet the project's requirements. Furthermore, many things must be arranged before a transaction can occur, further complicating the process. Finally, timing products can be difficult, requiring the reservation of products selected during the design phase but not needed until years later. Addressing these barriers is crucial to ensure efficient and effective procurement of building materials for reuse. (Slager & Jansen, 2018)

Filters

What do current filters of these platforms do? Attention is given to connections, materials, quality, and product type. All the marketplaces make no to little use of facet navigation (see appendix).

Table 2: marketplaces and search options for different categories

Connections	
Marketplace 1	Assembly: glued, welded, nails, wire nails, screwed, loose, expected to be dismountable
Marketpace 2	Connection type (free, adjustment needed, simple & standard), accessibility (easy, hard & limited,), Remove product(no damage, some damage, damage), Remove material (Easy to separate)
Product type	
Marketplace 1	Six Brand layers / shearing layers
Marketpace 2	Interior finish, Interior construction, outer shell, outdoor design, outer shell, construction
Material	
Marketplace 1	Wood, Metal, Stone
Marketpace 2	The material is related to strength class
Marketplace 3	Wood, Plastic, Textile, Metal, Glass, Electronic, Stony, Chemical, Organic, Paper & Cardboard
Condition	
Marketplace 1	1 to 5, inspection date
Marketpace 2	Esthetical and Technical (good, moderate)
Availability	
Marketplace 1	Available, Reserved
Marketpace 2	Delivery options (on appointment, delivery)
Filters	
All	Search bar but no facet navigation/search
Marketplace 1	Brand layers
Marketpace 2	Location, availability
Marketplace 3	Different categories within a certain material, little use of facet navigation

See the appendix for some visual representations of existing marketplaces.

2.1.6 Digital construction industry status

Research into e-commerce within the construction industry is not combining usability research and user research. Therefore the literature in this specific field is quite rare "Except of" One scholar researching customer experience in the construction industry of a software company (Enhancing customer experience in the construction industry, Huang, 2010). By the lack of these "recent" usability papers, research of the dot.com area (ca. 2002) is used to get a better understanding of the (digital) challenges the industry is facing. As many challenges (realizing software and platforms) could be applied to this research question.

The chapters' challenges and opportunities are split-out in general and e-commerce challenges/opportunities. Reusing construction elements is not only related to digital / e-commerce solutions. This overview is input for the thematic analysis after the interviews of step 1. This summary is important to make sure the 'to-be' designed digital artefact will fit within the industry.

Challenges AEC industry in general:

The industry is fragmented (Sanders, Temkin, Brown, & Martin, 2001) & (Luening 2000) and has a mindset in producing cost savings ((Issa, Flood, & Caglasin, n.d.). Recently newspapers publish (https://www.cobouw.nl/310223/bouw-krijgt-nog-respijt-maar-co2-uitstoot-materiaal-gaat-echt-meetellen) about the introduction of a CO2 tax. Every project is unique ((Pries ∗ & Janszen, 1995). This could make automation and adoption of digital practices hard.

Establishing new product channels (with reused products) can be hard as there is a long and customized relationship with the client (Issa et al., n.d.) And most innovation diffuses rather slowly in the building industry (BIS, 2013; Fernie et al., 2006),

The focus has been on energy use and energy efficiency (Lucon et al., 2014) instead of reusing materials. Indeed, according to the IPCC (Lucon et al., 2014), buildings accounted for 32% of total global final energy use in 2010. Moreover, the building industry consumes 40% of the materials entering the global economy (Khasreen et al., 2009), while only an estimated 20-30% of these materials are recycled or reused at the end of life of a building (EMF, 2014)

Challenges within Products & reuse

There could be a demand on the consumer side, but suppliers do not see the need to compare their products with reused products. Worried it would drive down prices and there is no need if they already have well-established channels to sell to. Most products have fixed positions (Ballard, 1998) and a long life span ((Pries ∗ & Janszen, 1995) which means low trialability (Rogers, 2010). Therefore the industry sticks to proven methods.

Challenges e-commerce / e-marketplace in construction

Several problems have occurred within ecommerce platforms/marketplces in the construction industry. Many e-trading marketplaces have been developed, owned and/or hosted by different companies. Each forming a closed system with their own customers and clients and therefore not open for automated search (C. S. Kong et al., 2004). The variety and heterogeneity of different E-commerce websites create problems for buyers. Finding materials in these sites requires buyers to acquire and maintain a list of web addresses, interpret and understand the semantics and navigation methods in different sites, and integrate product information in these sites for evaluation manually. (C. S. Kong et al., 2004).

The lack of standardization of procurement processes and problems with interoperability of product data presents a complex challenge for collaborative and transactional processes across BIM models and e-

Marketplace systems. Hence, presently the Cloud-based BIM models fall short of their potential to be effectively utilized for e-trading purposes. (Pala, Edum-Fotwe, Ruikar, Peters, & Doughty, 2016)
More work is needed to convince the AEC industry to adopt B2B practices. Without seeing the technology's quantifiable benefits, the industry will likely hold back for some more time until convincing evidence of such benefits is produced. (Pala et al., 2016)

Many (online) hubs have failed, and those that have survived have struggled to achieve critical mass. The success of hubs depended on the number of buyers and sellers participating. No single hub has reached a level of participation to realize these effects fully. Instead, hubs connect buyers and sellers to only a portion of the market. Hubs seldom connect to other hubs and competition for subscribers has resulted in market fragmentation (also outside the construction industry). (Albrecht, Dean, & Hansen, 2005)

IFC, XML or STEP standards since their application aimed primarily for the design, construction and export processes in a project's life cycle, the use of the IFC and STEP file types for the transactional exchange is currently limited to cost information sharing (Ren et al., 2012).

General opportunities in the AEC industry

Construction industry (worldwide) purchases exceed $3 trillion annually. The traditional organisation of the building process is a core item in most studies (Bakens, 1992 ; Hawk, 1992; Louwe and van Eck, 1992). Large, fragmented sources of supply could also be potential. Because small industries often don't have enough scale to justify building out a network. This depends per Brand (building/shearing) layer, where for example the façade industry has some tremendous players. The concept of many-to-many marketplaces is powerful, but the scope of such a deep transformation will require ages of interim steps and incremental changes in business processes to realise the vision entirely. (Becerik, 2004)

Opportunities e-commerce / e-marketplace in construction

Create a solution for procurement of materials using non-traditional methods, avoiding delays, high prices, lack of specified products (Harmelink, 2001). Buyers can efficiently purchase cheaper products with a variety of choices, i.a. cut-the-middle-men. (Bakos, 1991)

The physical limitations of storage do not limit online construction trading places. They carry a much larger variety of products and different styles and sizes. Therefor virtual storage(Glias, 2013), using donor buildings by having the information online before demolition could potentially save a lot of logistics. Therefor data interoperability: Ren et al. (2012) explain that the information stored inData from and IFC can be exported into CIS/2 exchange standards (BuildingSmart, 2015). These online tools' will use information from corporations knowledge management systems so that even those who do not work on a project can benefit from the knowledge gained. (Becerik, 2004)

A reason for slow ICT adoption could be the internet bubble around the dot com area. The urgency to be the first-to-market with a solution led to many cases where there was no technology. This fact was hidden behind shiny marketing campaigns intended to buy time and attract capital. The time that the most popular technology development platform for these new AEC Internet offering was not Windows or Java, but was PowerPoint. (Becerik, 2004) Unfortunately, once AEC industry professionals sign up, they were often disappointed with the real value. Since bad news spread ten times faster than good news, this damaged the group of offerings' credibility and thereby slowed adoption.

Data format and IFC

The rigour interviews related to challenges in the digital construction field do mention the need for one (digital) language. The need for clarity in trading is crucial. There are already several initiatives that try to tackle this problem. Namely; IFC, IFCowl, BFC, building smart data dictionary and CB-NL. Both engineers, experts and the literature notify IFC as a promising data format.

As IFC is still struggling it is not advised to start with IFC as main platform technology directly. According to the expert interview ifcOWL or Simplebim is suitable. Start with simple information structures and later on involve more advanced technologies.

2.2 Core concepts reusing construction products and materials

2.2.1 Analog reuse of secondary construction products

As reuse in the construction industry is early, it is needed to understand the analog process before designing digital tools. This chapter contains three parts: design for disassembly, deconstruction methods and the current supply.

Design for disassembly is an example of designing with re-usable components, where deconstruction methods provide information into the limitations for the supply. The materials and product chapter provide knowledge about the existing supply, which provides information on the full range of parameters and could support the strategic decision in which niche market to start.

Reuse projects lessons

The world of reclamation, reuse, and recycling is almost like a parallel universe that is virtually invisible to those familiar only with new building materials and components. Some background information is needed to enable project teams to overcome this unfamiliarity. (Addis, 2006)

Example projects have shown the possibilities and realisation of reusing products in new building projects. However additional time is needed, and the need for identifying and buying the reclaimed goods should be done in an early phase. The following projects are described (Addis, 2006);

Lessons learned: The C.K. Choi Building, Canada:
The main lesson learned during the design phase was that designing a building to be **constructed with reclaimed components is utterly different from the typical design process, in that suppliers need to be identified before the design is completed.**

Lessons learned Birmingham project:
The key lesson learned from this project was that reuse and use of reclaimed materials is a realistic option for many building elements, but a **significant amount of additional work is required** by the project team that would not be encountered when using ‘normal’ materials and goods.

Near Doncaster, The earth Centre:
It is essential to allow **enough time** in the construction program to arrange for disposal of goods and materials for reuse or reclamation and to acquire reclaimed goods and materials for a new project. **A better developed waste-exchange infrastructure will greatly help achieve these aims.**

Lessons learned Building 16, Garston, UK:
The structural performance of steel is relatively easy to assess, making its reuse straightforward. **The economics of the supply chain, including storage, trimming, cleaning and painting will be considerably improved if the operation is organized at a regional level, rather than locally**

Related to the costs in 1996 the Udden Project (Sweden) and thereafter in 1999 the Nya Udden. For both projects, using a significant degree of reused concrete elements cost roughly 10% to 15% more than building with conventional building practice. (Eklund, Dahlgren, …, & 2003, n.d.)

Recent projects include in 2013 the Karlstad Hospital (Sweden) and Gemeentehuis Brummen (Netherlands). Thereafter Alliander Hoofdkantoor, The Circle, Tijdelijke rechtbank Amsterdam and several BAMB pilot projects. These feasibility studies have also shown that, although challenging, the technical aspects of Reversible Building Design are not the biggest issue regarding the transition

towards a circular and dynamic built environment. **A shift in mentality and design culture seems to be an essential barrier to a circular economy in the built environment.** (Elma Durmisevic & Beurskens, 2017) in the D12 Feasibility report.

The current process of product procurement

In the current design process, the product procurement follows after the final design (see red to in figure 5), where the contractor has a list of the specifications. With this list, he can choose products and brands if they meet the specifications. Through this, most procurement is based on lowest price and current relationships between contractor and supplier.

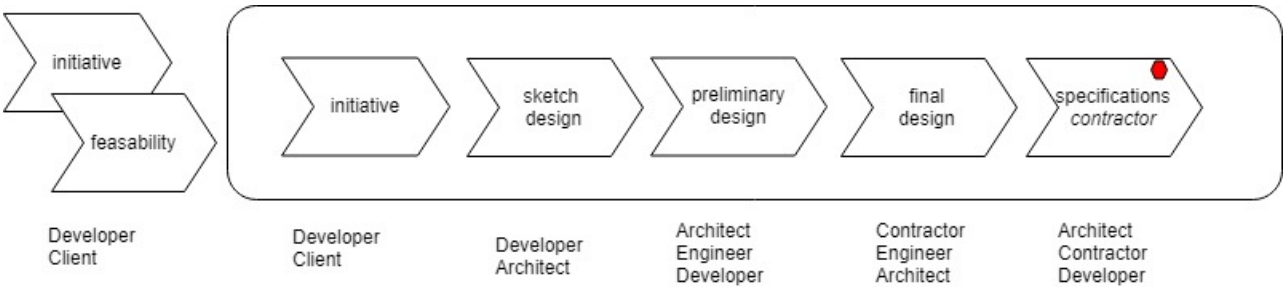

Figure 5: current process and product procurement (Own figure)

Personas – results

Before picking one or multiple participants, the possible participants have to be mapped. Namely; Client, Architect, Contractor, Supplier, and Engineer. This master thesis does not interview demolition companies (as potential users), as BAMB mentions the need for a demand-driven marketplace.

These personas are mainly based on the research of competitive advantage[4]. This chapter is a summary of their reports and findings during the interview phase. Important is to get an understanding of the personas motives underlying decision making. Also, some knowledge about age, gender, and current software is useful in understanding the different persona on designing solutions for them. The summary is shown below in table 3:

Table 3: persona summary

	Motives	Influencers	Statics (company)	Character / software use
Architect	Focus on user Sustainability / environment	Client Project Architect Expertises	85% < 10 staff 5% > 50 staff 25 % female	Planning, design and oversee Creative Sketch software and BIM (60%)
Engineer	Problem solvers Ensure safity Personal interest	Principle Engineer Project Architect NEN-codes	9% female 57% above 35 age	Analytical (but quick) Use of complex tables / charts FEM software, CAD & BIM
Client Public & private	Speed of construction Image and ROI Operting costs	Stakeholders Board of directors Architect / Contractor	4 miljard budget 23% will follow architect decision	Powerpoint
Contractor	Costs and availability Ease of installation Planning / profitable	Sub-contractor Architect Project manager	90% ZZP 100 contractors > 100 employees	Communicators Negotiator BIM & Excel & Gant chart

In the appendix more information about specific personas is set-out. They give an understanding of; the relationships between the different roles

[4] https://www.cadvantage.co.uk/researching-construction-personas/

Design for disassembly

Focusing on the demand size requires knowledge about the supply side. What is available in the market and what are the constraints in offering products on a marketplace. Therefore these chapters explore design for disassembly, deconstruction methods and the supply of materials and products. The interview with E. Durmisevic (PhD DfD) also confirms these topics' relevance to the demand side.

Tingley has done extensive research on barriers for deconstruction. These barriers are taken into account at the core interaction chapter.

Deconstruction of buildings (instead of demolition)

Disassembly or selective demolition is a process to recover and reutilize construction materials. Information on the deconstruction of buildings is limited as the number of deconstruction is limited in comparison to demolition. There are some developed guidelines to encourage deconstruction above demolition. Still, few buildings are designed with DfD principles (Rios, 2015). The literature also provides guidelines for deconstruction potential of existing buildings. These papers do not provide rules of thumb for deconstruction costs but do agree that structure size, transparency, available information (as-built files / IFC), and connections do play an important role.

What could we learn from the different reports to consider for the core interaction?

The most recent research (2018) “Analysis of Guidelines and Identification of Characteristics Influencing the Deconstruction Potential of Buildings” the following table (see attachment) is produced and provides insight into the characteristics of buildings that influence the deconstruction potential. And advice mechanically disassembly for large components, and manual disassembly for light components.

The paper “Decision tools for demolition techniques selection” (Abdullah et al., 2003) provides a hierarchical structure for a decision-maker with an overall view of the complex relationships inherent in the situation and the selection process. It allows the decision-maker to assess whether he or she is comparing issues of the same order of magnitude. This research does not affect the core interaction.

The third paper from Bill Addis’ book, who is an experienced professional dismantler (Addis, 2006).
Specific building characteristics simplify the job of the dismantler, reducing the time and expense of salvaging the building materials:

- Transparency: visible and easy to identify building-systems
- Regularity: similarity throughout the building and regular, repeating patterns.
- Simplicity: systems and interconnections that are understandable. Reducing different materials and component sizes.
- Large components above smaller members; larger members resist damage better
- Easily separable materials: Materials should be easily divisible into reusable components.
- Mechanical fasteners are preferable to adhesives

Conversely, Addis has found that some building types and materials are difficult or impossible to deconstruct or have no reuse value if deconstructable:

- Complex or mixed systems: complicated, hidden or mixed structures challenge de-assemble.
- Non-Standard Components: custom components are hard to reuse in other buildings.
- Composite Material: certain types of composite construction are impossible to deconstruct.
- Mixed Material Grades: similar looking materials with different properties have less value. Unlabelled materials grading is especially problematic and may result in grading them in the lower category for the sake of simplicity.
- Environmental: hazardous materials that require special handling and worker protection, such as asbestos.

Glias describes some solutions when dealing with concrete structures. Concrete is mentioned as a challenging material for deconstruction. Still, it is possible to reuse concrete parts and deconstruct existing buildings.

- Hack the connection: Hack with a compressor the concrete around the rebars, where after the rebars could be burned. This created the most damage and is time-consuming, but no reinforcement drawings are needed. Sawing is needed to modify the desired dimensions.
- Drill the connection: If it is possible to locate the rebar, drill it out of the connecting. After that the element can be lifted. This fast method also requires sawing afterwards.
- Saw the connection: In terms of damage and time, it is the best method. Difficulties and danger could occur when sawing on height. This method is the most expensive but can reduce modification costs if directly sawn to the new dimensions.

The last paper is looking further, and already combining the use of digital files (e.g. IFC) with the data processing and analysing of the deconstruction methods of buildings. (Akbarnezhad, Ong, & Chandra, 2014b)

Using BIM and data formats to score construction on disassembly potential and importing the needed products directly in the new BIM file. This is especially interesting for the added value of a marketplace as data warehouse and reducing engineering time.

BIM software (Tekla) enables assigning deconstruction properties to specific elements (see attachment). Different features are disassembly-ability, recyclability, visual condition, recommended disassembly technique and more.

2.2.2 Construction materials

Designing filters for engineers requires knowledge of construction materials. This chapter provides insights into the reuse volumes in the Netherlands and gives insight into the reuse properties of specific construction materials (wood, steel, concrete, and masonry).

Material volumes in the Netherlands

Analyzing the waste stream gives an idea of the reuse volume in the Netherlands. This is done in tons, while this thesis focuses on the reuse of products instead of recycling material volumes. The next chapter attempts to analyze the product details in-depth.

The most recent research done by TNO and EIB. It focuses more on the reuse (circular) potential of the existing built environment (Kootstra & Errami, 2018). The yearly potential is 0,6 megaton. Around 33% is concrete and mixed rubble. Infrastructure and housing are both around 32% of the sources for all the materials. TNO predicts that the amount of available material is 25% of the demand for building supply. As BAMB research mentioned, the bottleneck is the demand, while the current supply could not fulfil the need for the whole supply chain. With the increase in material costs, this is an opportunity[5].

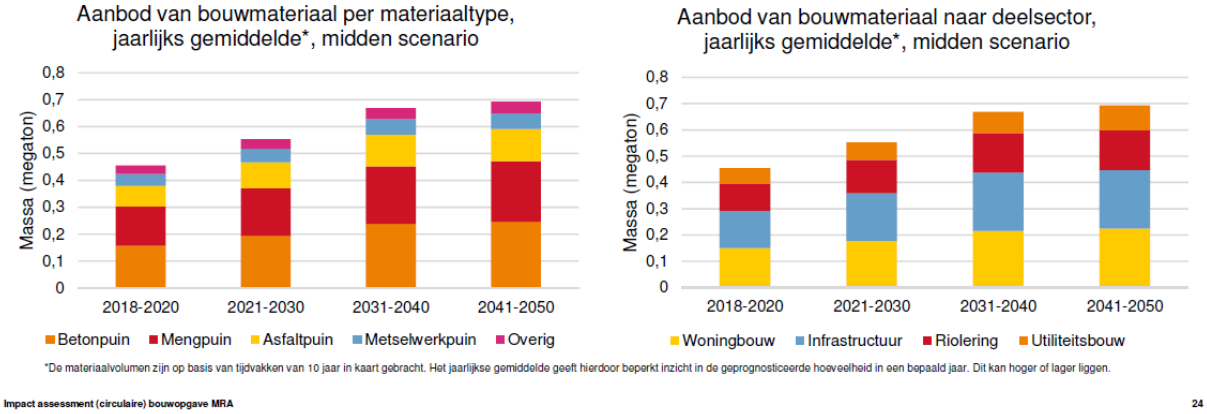

Figure 6: Availability of materials (TNO)

Material volumes Internationally

Digital platforms require scale; to overcome the chicken-egg problem and to have an ROI on high investment costs. Therefore an international view is relevant.

In the UK fifty thousand buildings get down each year, generating 45 Mt of construction and demolition wastes; the majority of this is concrete, masonry, bricks and steel (Adams, 2013). The same obstacles apply there; poor market conditions, low productivity and lack of reuse capabilities. Still the combined rate of reuse and recycling of steel increased from 93 to 96% from 2000 to 2012 (Sansom and Avery, 2014), dominantly by recycling, with reuse less than 4%. Estimations mention that 2-5 billion bricks in the UK (Kay and Essex, 2008) are demolished annually, although less than 5% of these are reclaimed for reuse.

Worldwide construction materials increased by a factor of 42; the same period saw a 23-times increase in the accumulation of materials within stocks of buildings and infrastructure (Krausmann et al., 2017; Wiedenhofer et al., 2015). In China, stocks account for 55% of cement global production in 2010 and

[5] https://www.cobouw.nl/bouwbreed/artikel/2018/05/stijging-bouwkosten-alles-wat-u-moet-weten-101261184

will double in the next 30 years (Herczeg, 2014). In Japan, 43% of in-use stocks are within buildings (Hashimoto et al., 2009). These studies show the same kind of reuse problems.

Structural Materials: steel, wood, concrete & masonry

After analyzing the potential of 0,6 megaton in the Netherlands, detailed information about the specific building materials is needed for the design cycle. The literature provides knowledge about these materials, where the interviews aim to filter on the essential parameters. To provide marketplaces users with clear interfaces and layering of information. Thereby the focus is on wood, steel, concrete, and masonry. Out of scope are bitumen, earth, and composites.

Wood

Wood is an anisotropic, non-homogeneous material meaning that the properties (strength, hardness) vary on and along the growing grain. A significant factor in the deconstruction of timber structures is the used type of jointing. Bolts and metal plate connectors are ideal for deconstruction with minimal damage to the timber. (Grantham, 2002)

Do:

- Screws and bolts instead of nails
- Keep services (plumbing, electrical, HVAC) separate from the structure
- Label members with species and grades
- Panelized construction to permit final deconstruction on the ground (particularly at roofs)
- New connection techniques. Industry-standard bolting patterns
- Re-certifying structural timber for structural purposes
- Old timber structures (80 years) are ideal for deconstruction as they use simple techniques

Don’t

- Avoid fragile members; engineered wood I-joists
- Avoid adhesives
- Damp, Moisture and insect infestations

Advantage

- Large amounts of low-quality or smaller sections of timber are recovered then these could be laminated together to produce longer, more usable lengths of timber

Overview based on (Crowther, 1999; Webster, 2005)(Tingley, 2012) (Neun & Grothe, 2001)

Wood examples.

In the figure 7 the darker parts are the reused wooden (beams and façade panels) parts. Connecting these parts to new wood guarantees safety.

Figure 7: Re-use of wood (deingenieur, 2020)

Wood and online marketplaces:
Currently, many suppliers offer wood on an online market. The difficulty is in searching for and selecting the right sizes and wood types. As the figure right under shows different sizes and wood types. Filtering on specific dimensions is not possible.

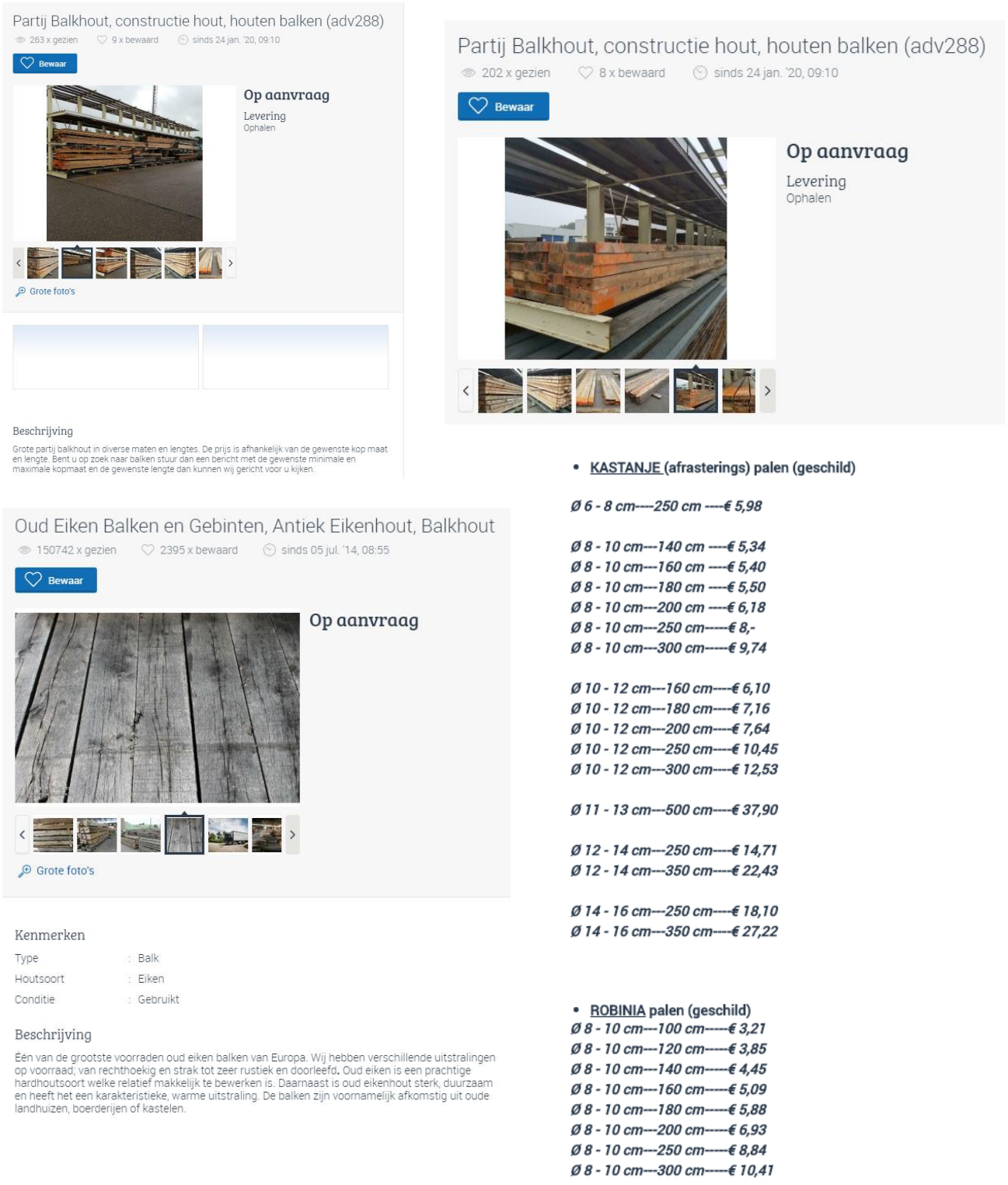

Figure 8: offerings on a marketplace: product information is not structured (marktplaats, 2021)

Steel (structural)

The issue of steel reuse and recycling is addressed by researchers worldwide, (Broadbent, 2016; Wang et al., 2017) (Diener and Tillman, 2015; Dunant et al., 2017). Steel reuse is possible with minimal reprocessing. The difficulty is in reclaiming steel from existing buildings. Webster and Costello (2005) recommended that it should be avoided in design for deconstruction.

Do

- Highlight similar issues and the importance of collaboration between stockists, contractors and fabricators to stimulate steel reuse economically
- Bolted connections are most comfortable to take apart without damage to the steel.
- Standardization: common shapes, regular spacing and precast decks (Sansom (2006)
- Mark steel grades and dimensions on members
- Alternatives to spray-on fire-proofing. Explore the use of clamps (as connections).

Don't

- Avoid composite floor systems that use welded studs and cast-in-place concrete
- Avoid short filler pieces

Advantage

- High technical lifetime/

Disadvantage

- Steel is attached to the concrete. Separating structural steel from concrete requires further research (Rehman et al., 2018).
- Research in testing and verification of steel material properties is limited. Fujita et al. (2014) proposed a non-destructive procedure for determining the steel grade. (also see Nebest)

Steel reuse example

Figure 8.1: IMD winkelpaden hoogstraat, reuse of structural steel (bouwen met staal 270, 2019)

Steel online marketplaces and information details
Steel offering on marketplaces (example marktplaats.nl)

Figure 9: steel on online marketplaces (marktplaats.nl, 2019)

Added tekst in the advertisement:

“IPE 120 MENIE GELEGENHEID
prijs incl btw 0,85 per kg
prijs incl btw 9,01 per m1
39 x 2240 mm prijs per stuk 20,19 incl btw.-
OF WE ZAGEN ZE OP DE MAAT DIE U WILT.

IPE 140 GEBRUIKT
prijs incl btw 0,73 per kilo.
prijs incl btw 9,60 per m1.
11 x 1700 mm aan 2 zijde koppelplaat prijs per stuk 16,32 incl btw antraciet.
5 x 2190 mm prijs per stuk 21,02 incl btw antraciet.-
4 x 2340 mm prijs per stuk 22,46 incl btw wit.-
1 x 3870 mm prijs per stuk 37,16 incl btw wit.-

IPE 140 2E KEUS ZWART ONBEHANDELD
prijs incl btw 0,85 per kg
prijs incl btw 11,22 per m1
84 x 6050 mm prijs per stuk 67,89 incl btw zwart onbehandeld
5 x 12100 mm prijs per stuk 135,77 incl btw zwart onbehandeld
OF WE ZAGEN ZE OP DE MAAT DIE U WILT.

IPE 220 gebruikt wit / creme.
prijs inc btw 0,73 per kilo
prijs inc btw 19,49 per m1.
5 x 2430 mm prijs per stuk 47,36 incl btw wit.-
2 x 2790 mm prijs per stuk 54,37 inc btw wit aan twee kanten een voetplaat .-
13 x 3075 mm prijs p stuk 59,93 incl btw wit aan twee kanten een voetplaat.- “

Concrete

Concrete forms a substantial proportion of the existing building stock (Leeuwen et al., 2018). However, concrete structural elements are hard to reclaim (Durmisevic, 2010); To transform from recycling to reclaim and reuse requires new techniques. Concrete is the most challenging of the three structural materials to design for future reuse (Addis, 2006). Methods/techniques for increasing the quality, durability and tension-stiffening properties of concrete are researched (Kisku et al., 2017; Rangel, 2017; Xiao et al., 2016). A summary of different research is given below:

Do

- Indelibly label each element, the label should include reinforcement and concrete strength.
- Fasten precast members with removable, durable, mechanical (stainless steel) fasteners.
- Develop new systems for connecting precast plank and tees to replace topping slabs. Use removable materials such as plywood on sleepers to provide a smooth sub-floor.
- Allow for thermal movement at connections, prevent cracked members.

Don't

- Precast slabs-on-grade, precast foundation walls, and shallow precast footings.
- Most cast-in-situ products. Or the whole structure should be reused.

Advantage

- Prefab / precast construction offers reusability options as it comes in standard sizes.
- New scan techniques could provide more information about reinforcement
- While concrete structures are generally not suitable for reuse, other concrete products like paving slabs and roof tiles are re-usable (Goodier, 2002, p.156). Goodier (2002) also states that some concrete flooring systems could be reused depending on jointing type.

Disadvantage

- Separating cast-in-situ elements requires to cut through the structure.
- Reinforced concrete does not have standards on dimensions, reinforcement amount and layout. Structural members are heavy to move.
- The "reuse" engineer lacks the information on strength and serviceability to reuse efficiently. (old drawings should be consulted)
- There is often no or minimal economic gain for reusing concrete products (Goodier, 2002)
- Elements that have been pre/post-tensioned are dangerous to de-stress, \
- Joints between units or elements are generally mortared, glued or tied with reinforcement which makes them difficult to separate
- Foundation walls and footings are unlikely to be reused.

There are, however, a few cases where reinforced concrete buildings have been deconstructed and the elements reused. In Middelburg in the Netherlands, the top seven floors of an apartment building were deconstructed and then reused to build two new, smaller apartment blocks. Deconstruction was possible due to the dry mounting jointing methods used (either steel strips or bolted connections) between all the concrete elements except the floor. The floor to floor joints was grouted, but these could be cut through once the wall elements above were lifted. Once the elements were removed some repair work was carried out on them before they were used in the construction of the new apartment buildings (Dorsthorst & Kowalczyk, 2003, pp.8-10). A more recent project is superlocal[6] in Kerkrade, The Netherlands.

There are no examples of concrete offering on online marketplaces.

[6] https://www.superlocal.eu/superlocal/

Masonry & Bricks

Papers on brick reuse address the recovering, dating and reuse of heritage bricks from the lime-based mortar (Hopkinson et al., 2018). Thormark (2000) reported that 85% of the bricks with lime-based mortar could be entirely separated. The following list is based on the research of (Addis, 2006; Hopkinson et al., 2018; Tingley, 2012)

Do

- Lime-based mortar degrades over time. Therefore, it will have little residual bond strength, and it is relatively easy to separate bricks with lime-based mortar. (BDA, 2014; Bouvier, 2013; Cristini, 2014; Gorgolewski, 2008; Pesce, 2013; Quagliarini, 2014; Serlorenzi, 2016).
- Use of mechanical fasteners to secure brick masonry. Renzo Piano's IRCAM façade uses this concept.

Don't

- No cost-effective technology is available to separate Portland cement mortar from the brick. (Addis, 2006)
- Avoid using grouted reinforcement. Investigate using unbonded post-tensioned reinforcement in hollow masonry construction.

Advantage

- Used brick is a popular material available in today's salvaged material marketplace. Salvaged brick has a warm and comfortable feeling that is difficult to recreate in mass-produced bricks.
- Rebrick (2013) shows the potential for recovery of bricks from lime mortar by an automatic brick-cleaning system. (Still not for Portland cement)
- Most bricks have standard sizes.

Disadvantage

- Building codes require reinforcement of structural masonry in a seismically region. The reinforcement is embedded in portland cement grout, making it impossible to salvage.
- Removal techniques of lime-based mortar require time-consuming manual labour, using a heavy/brick hammer, broad cold chisel (BDA, 2014) or brick cleaner machines (KHR Company Ltd, 2017).

Bricks and online marketplaces

Many public marketplaces offer reusable bricks.

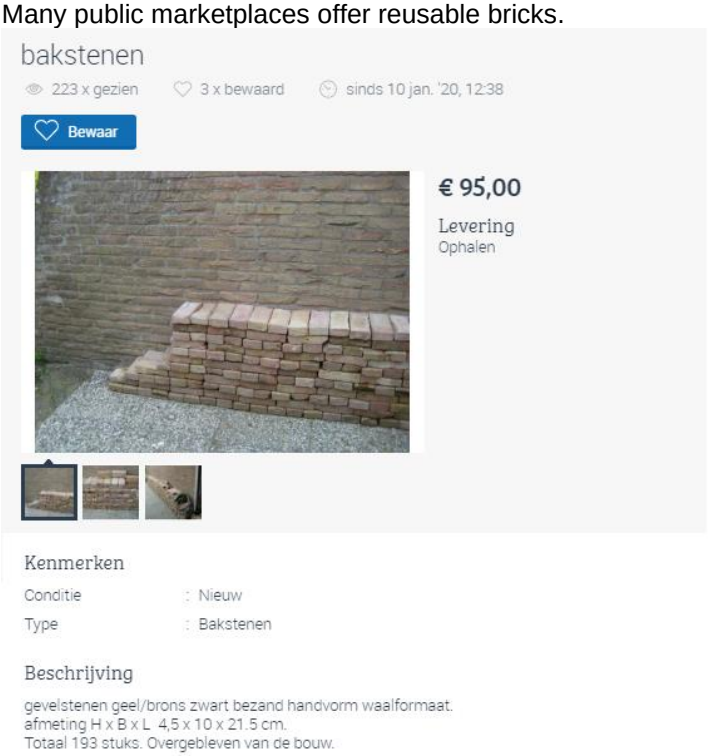

Figure 10: Bricks advertisement example (Marktplaats, 2021)

Conclusion materials

We need filters for quality that contain specific parameters related to the specific materials. A short overview of the three primary construction materials is shown below in table 4.

Table 4: Barriers and benefits for dis- & re-assembly

	Barriers	Benefits
Disassembly		
• steel	Rigid connection	Long technical lifespan
• wood	Technical lifespan, Moisture, insects, nails	Light, easy to cut and reuse in smaller parts
• concrete	Cranes, heavy and big, cut and sew, reinforcement. Recycle as aggregates	Huge supply in the Netherlands
Re-assembly		
• steel	Residual stresses	Welding
• wood	Spikes and deformations	Light-weight
• concrete	Hard with non-rigid connections	Prefab options

2.2.3 Construction products

Insight in the reuse potential of materials is exciting. But reusing products even more. This chapter uses the existing literature to show the potential of reusing products, both in the Netherlands as international. This product knowledge will support in selecting products for designing the core-interaction.

Products in the Netherlands

TNO made predictions of the current amount (in kton) of product types in the existing built environment (Leeuwen et al., 2018). Still, concrete is leading where floors take the most significant share. Within wood, this is ; roofs, interior walls and foundations are the main stakes. For steel, this is; ground floors, story floors, foundation and load-bearing walls. TNO also made predictions of the environmental impact of the products and their materials, although concrete is the most significant supply, steel and copper contribute significantly to environmental impact.

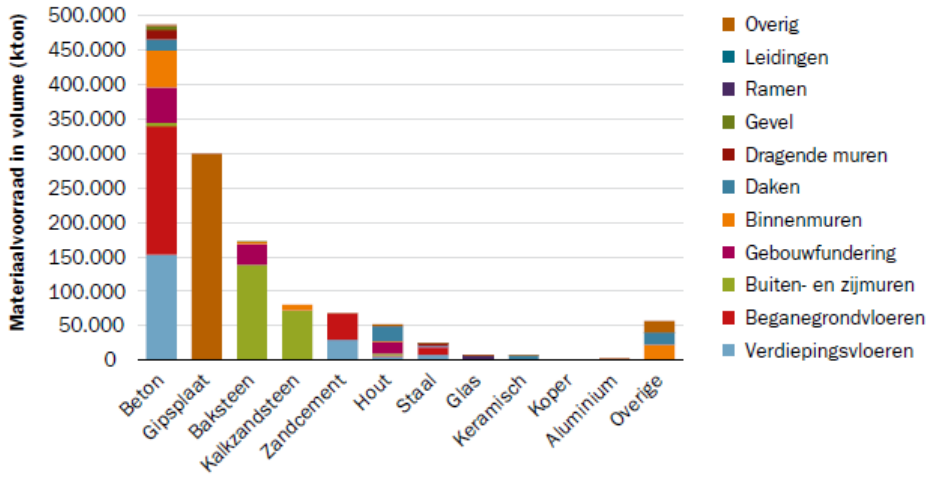

Figure 11: Volume of products (in Kton) in the Netherlands (TNO, 2018)

Products and international research

Several studies in Melbourne (Stephan and Athanassiadis, 2018), Rhine-Main (Schebek et al., 2017) and in the Rhine-Ruhr region (Oezdemir et al., 2017), offer a detailed material analysis of the buildings. Varying from concrete, bricks and metal these figures confirm buildings as a major stock of materials. Study in Finland shows the potential of concrete Reuse of concrete panels reduced the cost by 20–30% (Huuhka, 2010a, 2010b; Huuhka et al., 2015). However, Yeap et al. (2012), highlight the costs of handling and storing concrete building components, which could make the reuse uneconomic. Matching the supply of reclaimed products with local/regional demand could overcome the storing issue. This is done in Kerkrade, project superlocal. This innovative project aims at 100% reusing of products acquired from the demolition of an outdated high-rise block to create four new living units (UIA, 2018).

Finnish (Huuhka et al., 2015) research mentioned specific products as most attractive for reuse purposes. This could be exciting product categories to further develop for the start of a marketplace.

2.2.4 Go digital

The analogue chapter provides knowledge about the current supply and barriers of deconstruction. This is helpful in the design of the core interaction. As this research aims to design a digital artefact, knowledge about the digital side of the construction industry is required. The IFC appendix provides insight in data technology and her barriers. This chapter will provide information about the current building stock, and how BIM and scan technologies could play a role in digitizing these assets.

Nowadays buildings

In western economies, at least half of the buildings in use in 2050 have already been built. According to a recent survey by the U.S. Energy Information Agency. 72% of floor stock in the U.S belongs to buildings over twenty years old (Marnay et al., 2008). New-build rates in Western-Europe are low (1% annually) (Bell, Hinnells et al., Power, & van der Flier and Thomsen).

Incomplete, obsolete, or fragmented building information is predominating in many existing buildings. As existing buildings often lack as-built documentation due to omitted updating, limitations of BIM use in existing buildings (Volk, Stengel, & Schultmann, 2014). As mentioned before, deconstruction has social, economic, and environmental advantages. Despite all these advantages, people still prefer demolition in most of the cases (Kibert C.) & (Macozoma D.).

Existing data

The lack of valid data about the technical composition of the building and quality of the elements is a hurdle in the reuse of components. Therefore the coming parts explore different techniques and incentives to digitize the existing assets.

BIM for existing building

To need for BIM and IFC in the existing built environment for reusability plays a role in deconstruction costs. Several techniques exist to digitize building assets. In the literature, numerous reviews of BIM implementation and research approaches in new buildings predominate, while BIM usage in existing buildings is somewhat neglected (Volk et al., 2014). Therefore in practice, costly and mainly manual reverse engineering processes (scan-to-BIM, points-to-BIM) help recapturing building information.

It interesting is to combine the need for BIM for reuse purposes with the need for BIM on facility management. Maintenance functionalities require a high level of detail (LoD) of components, the installed services, equipment, and appliances (Bill & Carrasquillo-Mangual, 2013).

As-built BIM modeling is time-consuming and error-prone with the current BIM modeling software. Specialized software for reverse engineering, data capturing, and BIM processing does exist and allows rapid generation of floorplans. This software is far from (semi)-automated BIM modeling of existing buildings. Many publications deal with semi-automated modeling of building surfaces or components to their geometrical representations. This modelling does not include component properties or semantic information. These functional, semantic, economic or relational are interactively or semi-automated integrated into BIM. For example, service building components like ducts, pipes, or plumbing (MEP) can only be modeled with high user input yet (Dickinson, Pardasani, Ahamed, & Kruithof, n.d.). Due to an effortful BIM creation process, existing buildings' model creation either focuses on coarse building components or is not applied yet. The high LoD, required for maintenance or deconstruction considerations is not compatible with the current time and cost restrictions in the AEC/FM/D sector (Volk et al., 2014).

As skilled personnel and high efforts are necessary to model BIM of existing buildings, further research in automated capturing, processing and modeling could reduce building auditing cost and increase productivity in BIM-based maintenance and deconstruction processes.

Conclusion

Different techniques do exist to digitize the building assets. All with different benefits and costs, incentives such as facility management could reduce costs. This research is needed after the core interaction to get a critical mass of detailed secondary products on the marketplace.

2.3 Literature conclusion

The above topics do not directly contribute to the artefact's design but will affect the following iterations. With the current research and knowledge about BIM for existing buildings, these parts aim to contribute to the opportunities for reusing products when combining different research (problems) together. The enormous (non-digitized) supply of existing buildings could be overwhelming. Where should a marketplace start with, what should be reused in the near future and what needs further investigation? This thesis does not aim to answer these questions, but with its collection of other research into the materials and products flows it hopes to provide a kick-start for people who are eager to continue in this field of research and entrepreneurship. With the further development of a marketplace, it aims to provide information to stimulate new designs and reuse purposes.

To successfully develop a marketplace for building materials reuse, several key considerations must be considered. Firstly, user research techniques and interface design rules must be utilized to create a user-friendly platform that caters to the needs of potential users. Platform knowledge is also crucial, including understanding the core interaction (2.1.1.) and identifying champions within the Construction2Construction sector (2.1.3). Facet filtering (2.1.4) is an essential feature that can enhance the user experience, as exemplified by the bol.com platform. Additionally, insight into the current reuse marketplaces and their interfaces (2.1.5.) is crucial for identifying gaps and opportunities. An understanding of Industry Foundation Classes (2.1.6) can also facilitate the creation of a marketplace that caters to the specific needs of the building industry. Digital challenges and opportunities in the Architecture, Engineering, and Construction (AEC) industry must also be considered (2.1.6.). Knowledge about materials (2.2.2.) and products (2.2.3) related to reuse in the Netherlands and Europe is also necessary to make a roadmap/selection on a first set of products and materials. This information is product and material specific and needs to be integrated in filters and product information in later design stages of the potential marketplace. Finally, possibilities to digitise the current building asset (2.2.4.) can enhance the efficiency of the marketplace and enable effective material reuse. By considering these factors, and most of all by defining the core interaction, a successful marketplace for building materials reuse can be created.

Chapter 3: Research Design

After reviewing different scientific methods the information system framework is chosen. A conceptual framework to describe the boundaries of design science within the information system discipline and for understanding information systems research. This framework will be explained whereafter it will be applied to the research question.

This conceptual framework aims to position and compare the behavioural science and design science paradigms. In this chapter to framework will be explained. Before applying the framework to the given research problem, the framework itself and her cycles are described to get a better understanding of its use. Making use of the book Design Research in Information Systems (Hevner & Chatterjee, 2010).

The relevance cycle (business needs) bridges the contextual environment of the research with the design science activities. The Rigor Cycle (applicable knowledge) connects the design science activities with the knowledge base of scientific foundations, experience, and expertise that informs the research project. Where the design cycle iterates between the main activities of building/designing the artifacts and evaluating them.

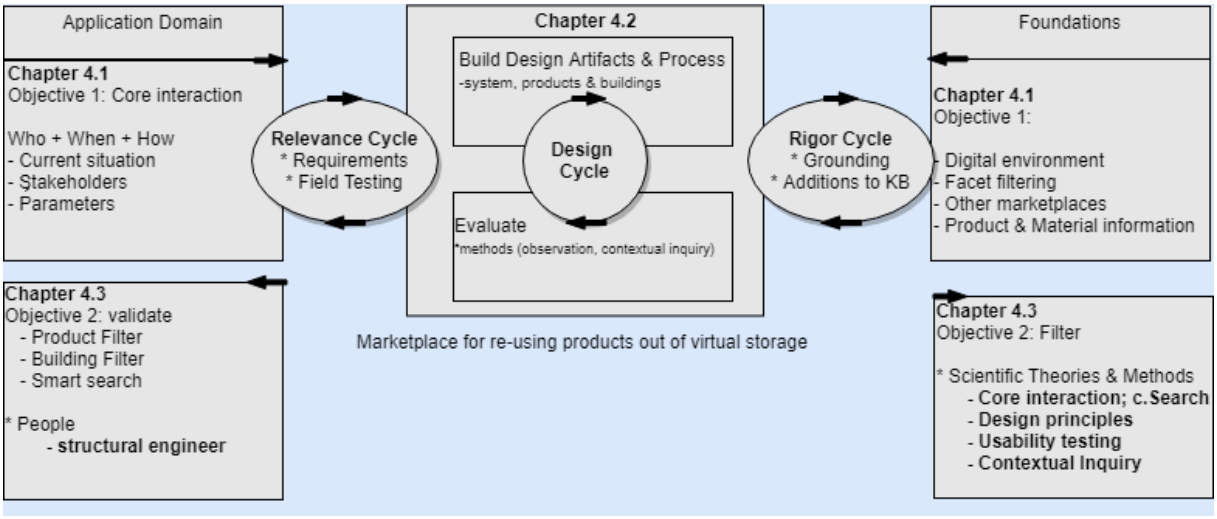

Figure 12: Overview of the research design

Mitch Kapor wrote that good software should be like well-designed buildings. They exhibit three characteristics:
• Firmness: A program should not have any bugs that inhibit its function.
• Commodity: A program should be suitable for the purposes for which it was intended.
• Delight: The experience of using the program should be a pleasurable one

3.1 Research question: How should a secondary construction marketplace function?

After answering research question 2 with a literature study, research question 3 can be split into multiple steps.

Question 3: How should a secondary construction marketplace function?

Step 1: Input for artefact (participants + filter)
1.1: who should be the users of the artefact?
1.2: how should they search for products (usability)?
1.3: how should the design culture change?

Step 2: Design
2.1: culture design, suggested change in procurement
2.2a design a solution when less data is available (building search)
2.2b design a solution for the brand layers (structure, skin, services, space & stuff)
2.2c design a solution for smart search (future technologies and huge amount of data/products available)

step 3: validation of the artefact (value)
3.1: champion validation, is the chosen champion able to search and influence the design(culture)?
3.2: is the artefact useable?
3.3: does it solve the problem, and challenges of reusing product in the design?

First, a more holistic understanding of the comprehensive system should be used to know how something should be used as this step is two-folded. High-level, it tries to find opportunities and barriers in re-using (circular) construction materials & products in the (construction) design process. How an artifact could influence and change this process change the design culture (Elma Durmisevic et al., 2017). The literature gives answers to this question in combination with the interviews.

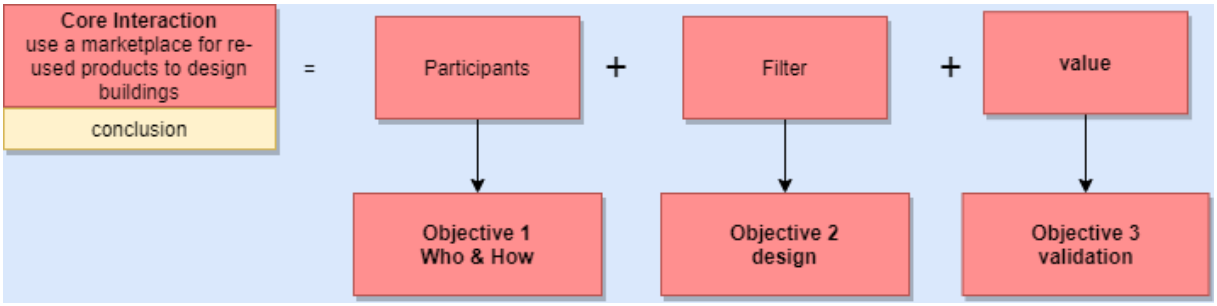

Figure 13: core interaction and related steps

The second part is more detailed and explains how a "specific" marketplace should be used and by whom. To overcome the barriers identified in the first more holistic part of applying a circular economy in buildings' design process. As overcome, the additional time needed to find and ensure “re-used” building materials (Addis, 2006). We need to find out how designers could use this information and what exact data is needed.

Step 1 focuses on the opportunities and problems that arise during circular buildings' design, where step 3 focuses on the validating part of the e-marketplace. A fundamental lesson learned from economics and platforms is that electronic markets' conscious design is crucial for their working.

3.2. Steps and IS framework

Figure 14 shows this research design mapped on the IS framework. The phases are described in the next part.

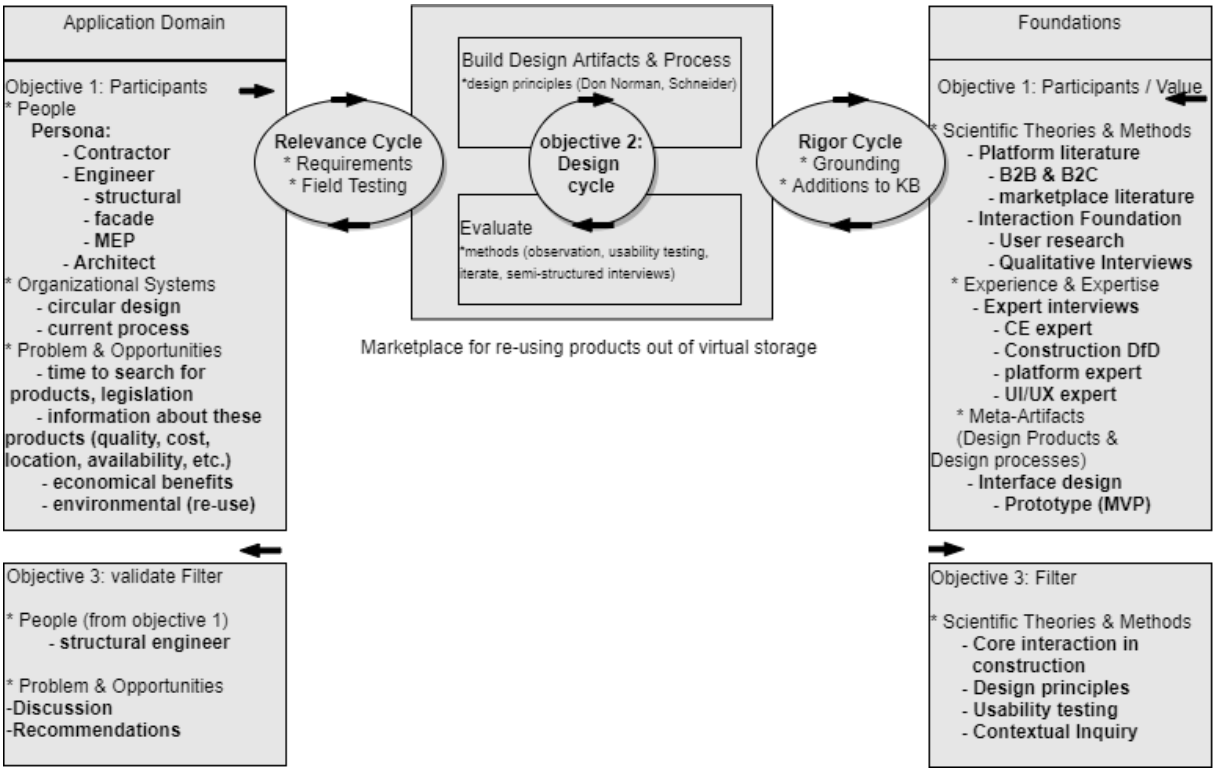

Figure 14: Information system framework for this thesis research

The IS framework is cyclic and dynamic. The following sequence is used to structure the report and make it more readable. The first part (step 1) is oriented toward the middle (requirements and grounding literature). This contains empathising with participants, defining and ideating solutions. It will also solve step 1: **To find out who and how virtual storage will be used how they need to see data.**

Phase 1: Interviewing to discover opportunities, obstacles, and business needs. (Application Domain)
Phase 2: Rigour this with research (about platform design, circular business needs) and expert interview with other researchers. (Foundation Domain)
Phase 3: Summarize literature and interviews in a thematic analysis.

The second part (step 2) is at the heart of the IS framework and is turned inward and contains design iterations.
Step 2: Design of the prototypes (Design Cycle). This design part is split out in a culture change and three digital artifacts.
The third part is oriented outward (field testing, additions to the knowledge base, and evaluating artifacts). Continue prototyping and testing with participants. And will solve step 3: **To find out if the marketplace is valuable and what else should it do**

Phase 4: Interviewing to validate and evaluate suggested artifact. (Relevance cycle)
Phase 5: Additional scientific methods or literature. (Rigour Cycle)
Phase 6: Results and next iterations (Recommendations)

After that, the discussion and conclusion take place.

3.2.1 Step 1 Who & What

To understand the core interaction, we have distinguished three parts, namely; the participants, the value and the filter (see literature). Step 1 starts with the participants. Who are the participants, how do/should they use the marketplace? This part begins with possible filters and ways of interacting with the object.

The move towards sustainable practices in the supply chain involves various challenges. One of these challenges is the additional time required to search for suitable materials and products that align with sustainability goals. Additionally, there is a need for more information about reusable products, but currently, there is a lack of such information. The economics of the current supply chain is another factor that complicates the shift towards sustainable practices. There is a need for a change in design culture to incorporate sustainability practices into product design. Lastly, there is a lack of filters and knowledge about champions for design with reusable products, making it difficult to identify those who prioritize sustainable practices in their design process. These challenges require collaborative efforts among stakeholders to overcome and drive progress towards a more sustainable supply chain.

In this phase, different methods are used to have input for the design cycle. These are semi-structured, personas interviews and thematic analysis. The artefact field study can be executed by means of appropriate technology transfer methods **such as action research** (Cole, 2005). User Research follows more specific techniques such as semi-structured qualitative interviews (Blandford, n.d.).

These interviews are suitable for creating insights into design projects—because design challanges are not exploratory; instead, they aim for solutions to specific problems. Conducting usability interviews in this way will allow you to collect valuable information without asking the participants directly what they think about your concepts. Combine the two methods by presenting your thoughts during the last part of the interview. See the appendix for the interview form. “Be aware of the questions that will be added after the rigour cycle which will lead the new insights into the application domain.”

Step 1 input of projects and personas:

As the circular economy is still a relatively new topic. Interviewees should fit the persona. As the topic and step are about a potential artifact in a new way of designing buildings (with re-usable elements). It could be hard for the interviewee to think and talk about a potential tool that is used in a situation he has not experienced before. Therefore, projects in the Netherlands that applied some principles of the circular economy are selected. Interesting are the ones that have re-used products and could potentially have used an online marketplace.

Table 5: Selected projects that have reused (structural) products

Date	Project	Re-used products
2015	Alliander Duiven	Steel construction (through heaping up) Waste wood to cover interior facades Work clothing processed into insulation
2016	The Green House	Façade panels including glass, Inner Walls Vowels and paving stones
2017	Hoogstraat, Rotterdam	27 tons of steel: Approx. 100 steel profiles
2017	Hof van Carthesius	275 wooden beams, Sandwich panels Partitions, doors, windows, stairs Wall sockets, shutters Attempt to concrete donor skeleton
2019	Erasmus hospital	Stocktaking for circular demolition (bureau Boot)

From projects to people

The research question aims to develop a tool that will change the design culture. A logical step is to start interviewing architects and engineers that influence the design. Engineers include structural-, building physics & systems and façade engineers. Their roles relate to many other functions that influence their design choices, it is crucial to consider these as well. This thesis named the support group; the contractors, clients, demolitioners and stockist (buyers). Due to the time limitations this consideration is made.

See below the overview of the personas, their function, and their relation to a project.
The category foundation is related to the rigor cycle and aims to understand the topic better to interview experts in the field. In this case an expert in design for disassembly, TNO as a research organisation and an expert in the field of BIM and IFC. The UI/UX field is related to the methodology used for user research and interface design. The column marketplace is added as during the research several initiatives of product marketplaces showed up. These are relevant for the application domain as these are perfect examples and are insightful when designing the new artifact. The inspiration for creative design activity can be drawn from many different sources to include rich opportunities/problems from the application environment, existing artifacts, analogies/metaphors, and theories (Iivari 2007).

Table 6: Persona selection for chosen subject or project

Project \ Role	**Architect**	**Engineer**	**Support Group**	**Science & Professional**	**UI /UX**	**Marketplace**
Foundation		Structural		Researchers		
Professional & experts				BIM expert	UI/UX Circular	
The greenhouse			Purchase& Developer			
Alliander	Architect & technical architect		Manager Contractor			Contractor
Hoogstraat	Designer/ advisor sustainability	Structural				
Hof van Carthesius	Architect	Structural				
Erasmus			Stocktaking			
Merosch		System				
No specific project	Senior Architect	Façade & Structural	Supplier			
Marketplace			demolition company		Three different marketplaces	

How many interviews

Three to five users are interviewed per group as these will cover 80% of the usability problems as stated in a mathematical model of the finding of usability problems (Nielsen & Landauer, 1993). Sauro also proves five users: more specifically, five users are likely to find problems that impact 30 percent or more of users (Sauro 2010). However, after five users, it is less likely to detect problems that 10 percent or 5 percent of users will have. In some cases, a problem that affects 10 percent of users can be substantial. Be aware of the limitation, explain it coherently to stakeholders, and tell them that more interviews are needed if the less obvious problems need to be found. (Sauro 2010).

After these interviews, the thematic analysis is done. Keep in mind that the information system framework can change or provide extra input after some interviews are conducted.

Supplier
Because of the full range of products, different procurement contracts and the fragmented supplier market, it is hard to decide on which suppliers should be interviewed. However, the movement of lease products within a circular economy affect the suppliers. Since there are experiments with lease facades, the link with a marketplace for reusing facades (and other elements) is impressive. For time sake, there is one interview with the branch organization for façade suppliers.

If a picture is worth 1000 words, a prototype is worth 1000 meetings
-- User experience researchers, 2019

3.2.2 Step 2 Design

Step 2.1 is about the change in design culture to increase the matching of consumers (champions) and producers(re-usable products)

Step 2.2 is about the digital artefact itself. This phase has three parts; product search(2.2a), donor building search (2.2b), and smart search (2.2c). The research aim started with the core interaction and filters for reusable products. But during the first phase, different obstacles occur; the lack of data and the need to change the design culture whereby a more logical (temporarily) solution is needed. Therefore a marketplace for donor buildings offers changes in creating awareness and gathering data. A more smart and futuristic solution is proposed, namely; smart search and tries to explore how preliminary design phases could use tools to automate and a more flexible approach to search for products.

Step 2: Design
2.1: culture design, suggested change in procurement

2.2a design a solution with less data available (building search)
2.2b design a solution for the brand layers (structure,skin,services, space & stuff)
2.2cdesign a solution for smart search (future technologies and huge amount of data/products available)

3.2.3 Step 3 Validation

The value (Validation)

After the design of the donor and product marketplace phase 4 validates those designs. This is part of Step 3 and is oriented outward (field testing, additions to the knowledge base) and answers the following questions (**is the marketplace valuable and what else should it do?)**

Phase 4 validates the artifact with three structural engineers and a professional with experience in the reuse market. The validation focusses on the structural (Brand) layer. As phase 1 discovered some significant barriers to the direct use of a product marketplace, a donor building marketplace solution is proposed. This is validated and further developed in phase 4 and 5.

step 3: output of artefact (value)
q 3.1: validate the champion / user
q 3.2: is the artefact useable
q 3.2: does it solve the problem, challenges of circular design (related to digital search)

Usable / Valuable (specifically related to the filter)

The new interview questions focus on different demolition techniques, the potential of product types, and the differences within the building materials. During this validation, the design is iterated as well. See the appendix for the questions during the interview. The rigor phase 5 offers room for further literature research for questions raised during the validation phase. The same principles of 3-5 users (Sauron, 2010) do apply here. After the design phase those will be selected, see chapter 4.3 for more information.

Summary steps & Research flow

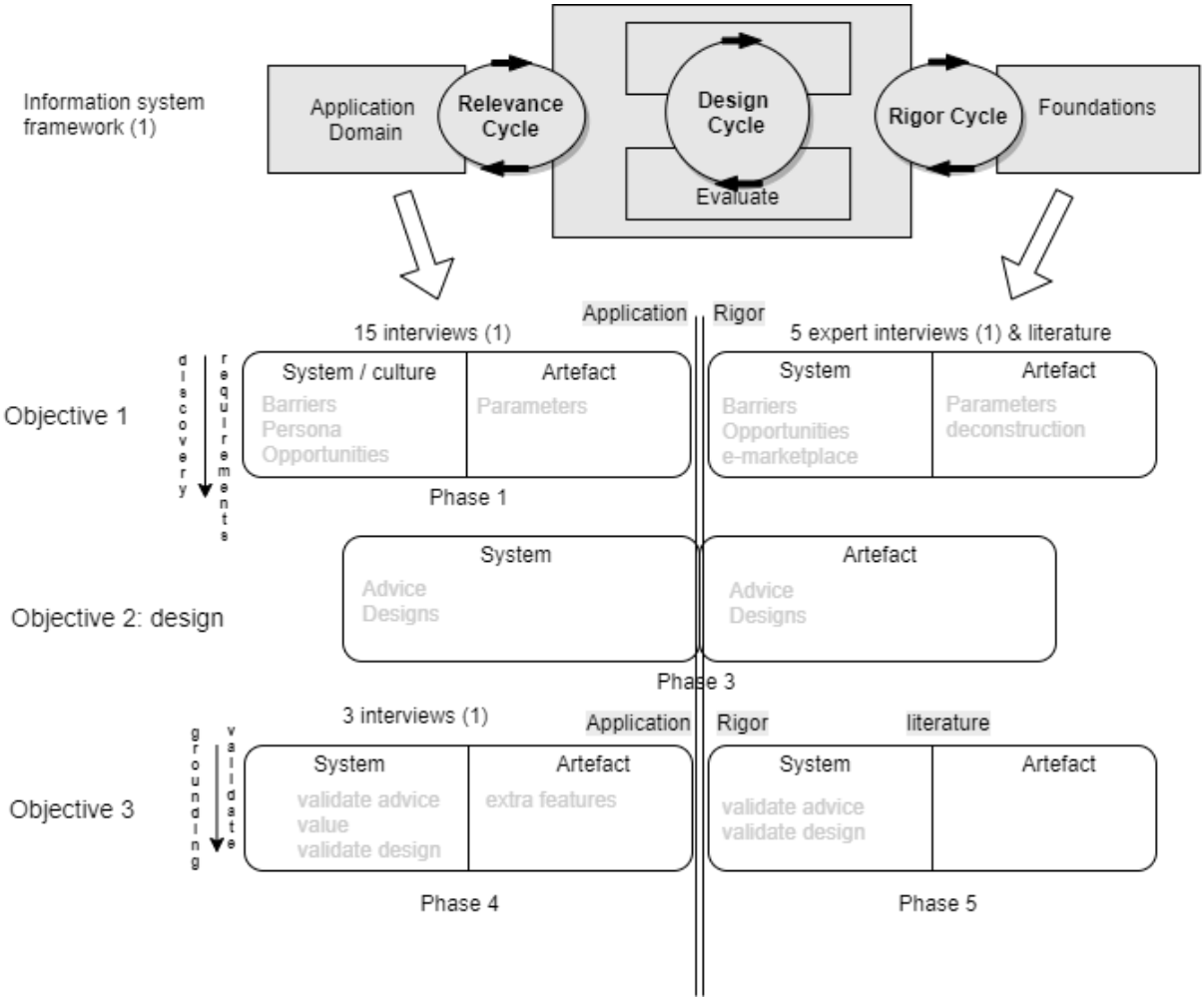

Figure 15: Complete overview of the research design

In figure 15 the word ‘System’ relates to the design culture/customer journey with wherein the ‘Artefact’ operates, where ‘Artefact’ relates to the digital marketplace for secondary construction materials.

Chapter 4.

Introduction

This chapter presents the results of the research question 3: Question 3: How should a secondary construction marketplace function? As described in the research design this question is split into three steps. The part answers step 1.

Step 1: Input for artefact (participants + filter)
q 1.1: who should be the users of the artefact?
q 1.2: how should they search for products (usability)?
q 1.3: how should the design culture change?

First, the personas and a discussion about the champion role are presented. Then the obstacles, barriers, and search method per persona are summarised. After that, the specific parameters per Brand layer per persona give an overview of all the different product parameters. With all this information, rigour research (phase 2) supports the more fundamental design (phase 3).

Table 7: persona summary after all interviews related to step 1

	Motives	Influencers	Statics (company)	Character / software use
Architect	Focus on user Sustainability / environment	Client Project Architect Expertises	85% < 10 staff 5% > 50 staff 25 % female	Planning, design and oversee Creative Sketch software and BIM (60%)
Engineer	Problem solvers Ensure safity Personal interest	Principle Engineer Project Architect NEN-codes	9% female 57% above 35 age	Analytical (but quick) Use of complex tables / charts FEM software, CAD & BIM
Client Public & private	Speed of construction Image and ROI Operting costs	Stakeholders Board of directors Architect / Contractor	4 miljard budget 23% will follow architect decision	Powerpoint
Contractor	Costs and availability Ease of installation Planning / profitable	Sub-contractor Architect Project manager	90% ZZP 100 contractors > 100 employees	Communicators Negotiator BIM & Excel & Gant chart

4.1 results Step 1

step 1: Input for artefact (participants + filter)	
q 1.1: who should be the users of the artefact?	Chapter 4.1.1
q 1.2: how should they search for products (usability)?	Chapter 4.1.2
q 1.3: how should the design culture change?	Chapter 4.1.3

4.1.1 Who should be the users (champion) of the artifact?

The different parties mention the contractor as the champion for choosing the product in the initial design process. **Where the engineers and architects decide on the specifications for products, contractors still have the right to obligate for specific (reuse) products.** For a change in the design process, the designer and structural engineer play the most crucial role (on the demand side). Engineers mention their advice-giving role in such a project and their ability to be more creative and solution-driven in reusing specific materials. In the end client and project developers

Recent Dutch research into construction marketplaces asserts this: “From interviews and practical test it seems that the five most influential construction disciplines, in terms of reuse, are: specification writer, demolition company, contractor and the engineer companies” (Slager & Jansen, 2018)

A new champion (key user)

There is a need for a new persona, as current persona’s do not take full responsibility in the reuse process. Already in the Roman period, there was demand for second-hand building materials. Re-use was an organized process that constituted a large number of practices, which were performed by diverse and skilled laborers – epigraphic sources, even mention a *collegium subrutorum* or a guild of demolition experts (Barker & Marano, 2017). None of the existing legislation, at that time, limits the sale of second-hand material taken from legitimate demolition or refurbishment projects, or even excess material from new or unfinished building projects (Fant, Russell, & Barker, n.d.)

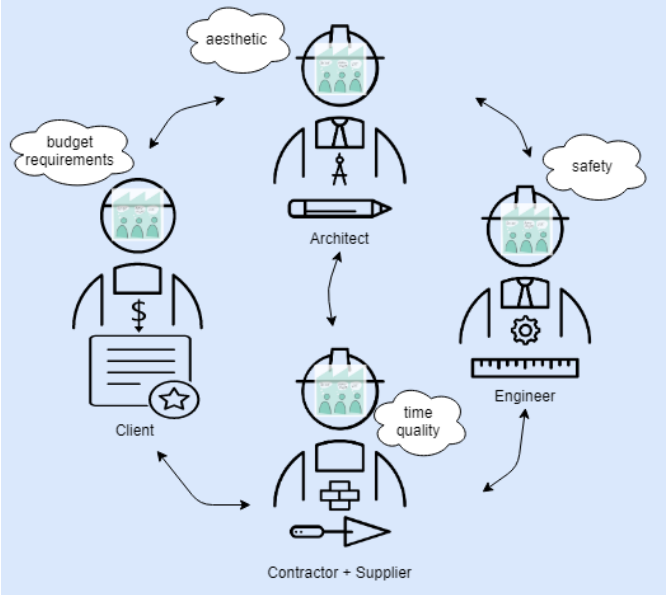

Figure 16: Design team as champion (Own figure)

4.1.1 Opportunities, barriers and search methods per user group

The results of the thematic analysis after the interviews is presented below. The search column in this overview provides information on how a person would like to search for products.

Tabel 8: Summary of results divided in opportunities, barriers and wanted search methods

	Opportunity's	Barriers	Search
Foundation	Ease of searching > business Challenge of architect Environment	Lack of market strategie Lack of decision making Cost of dis assembly Cooperation of marketplaces	**Depending on phase** (DO,VO) Location, sizes Material, colours, photo
Architect	Products with high turnover **Usefull for inventarisation** (VO) Return product to supplier	Guarantee and quality Rigid connection Architect is not product trader Element have holes, spikes etc.	Maintainability Estethics (colour, look & feel) Photo's Specific paramters: Fire etc. pinterest
Engineer	**Technical feasibility** In VO **less information required** Marketplace could be used!	Earlier investment in design phase PO / Architect is in the lead Information about reinforcement To many different products	Moment of inertia / resistance **Grid size** tables
Marketplaces	Reuse of doors is profitable **Easy demountable stuff** Uploading information	**We need one language** Government should start with regulation	NL-FsB / Stabu or Shear layers
Support group	Start with low-haning fruit Marketing and PR Could be financial beneficial	**Not for big complex projects** Role of suppliers No return of investment Pricing not clear or expensive	PO will use supplier Financial Extra costs: demolition, transportation and assembly

After conducting the rigour phase 2, several critical themes emerged in relation to the use of different types of product information in early design (VO) and definitive design (DO). One key finding was the need for material information and additional testing, which could be performed by organizations such as Nebest. It was also noted that financial investments required to claim products should be made earlier in the design process to ensure timely delivery.

Smart search options were identified as a valuable resource for users, but there was no clear consensus on a single champion for this. Different search options for architects, contractors, structural engineers, engineers, and building physics specialists were explored, with criteria such as style, stability, transportability, availability, cost, load factors, grid size, system type, height, and service capacity being considered. The timing, availability, and guarantee of products were identified as significant challenges. However, potential solutions were proposed, such as the circular economy, which could replace products with long delivery times. Uploading product information was found to be labor-intensive, but simplification was possible with Industry Foundation Classes (IFC).

The contractor's ability to choose products or the developer's interest in circular economic principles were seen as important considerations for design culture, given that current building codes were not deemed suitable. Collaboration between marketplaces was suggested as a way to overcome critical mass and reduce search time. Another challenge related to the existing built environment was found to be non-digital and characterized by rigid connections.

Finally, the issue of the champion role was explored, with engineers suggesting architects or product owners as champions, while architects argued that they were not product traders. Contractors were hesitant to take on this role due to perceived risks and a lack of regulation, while project developers saw it as the supplier's responsibility. Suppliers suggested that the government should regulate this issue

Quote:
My mantra has been that preventing old materials from being recycled or sent to landfill, and reusing reclaimed materials in buildings and landscapes, are both client-led. If the client is keen, professionals and their contractors will make it happen. I believe it will still be a long time before professionals will feel comfortable about reuse and keen to promote it to clients. A move in that direction must start somewhere. The acceptance of materials reuse in mainstream professional construction is in its infancy and needs exposure and the reassurance of its peers. –Bill Addis, 2016

4.1.2 How should the user search for products?

The engineers, architects and contractors are asked for different parameters to search for products. This gives input to design "the filter," which increases the matching between product and user. The result below shows every parameter mentioned. In the design phase (of this research), the filters are designed according to the first and most mentioned parameters. Step 2 will validate the design of the filters.

Table 9: Parameters / search criteria mentioned of relevant persona's related to the Brand layers.

	Structure	Skin	Services & Systems	Space plan / Stuff
Engineer	Material type Strength / quality * Amount & length Technical condition Profile Connection type Demount ability Price Fire resistance	Type of façade (+producer) distance between track-centre stijl & regel, h.o.h.& diepte Amount sound resistance thermal conductivity coefficient waterproofness airtightness fire resistance smoke resistance Rc & U values	Type (air, water & energy) --box / machine Capacity Connection type Energy consumption --canal / transport Length / Amount Form / Size / Capacity --exhaust / distribution Capacity / Size	**Space plan** Function Load-bearing Geometrical **Stuff** Type of product Capacity
Smart search	Moment of inertia Moment of resistance *in combination with grid size, load and material	Size Type	User requirements **systems change too fast	related to user requirements such as square meter
Architect	Colour Texture / look & feel Maintenance sensitivity Amount Aesthetic Condition	Colour Texture / look & feel Maintenance sensitivity Amount Condition	Colour Texture / look & feel Maintenance sensitivity Amount Condition	--Product Colour, texture Aesthetic Maintenance sensitivity Amount & Condition
Contractor *more research*	Availability & Price Demount ability Alternatives	Availability & Price Demount ability Alternatives	Availability & Price Demount ability Alternatives	Availability & Price Demount ability Alternatives
Extra	C02 impact Shadow costs Extra costs** Transport Dis-& Re-assembly Testing Repair/Adjustments	C02 impact Shadow costs Extra costs Transport Dis-& Re-assembly Testing Repair/Adjustments	C02 impact Shadow costs Extra costs Transport Dis-& Re-assembly Testing Repair/Adjustments	C02 impact Shadow costs Extra costs Transport Dis-& Re-assembly Testing Repair/Adjustments

*Strength, stiffness and toughness could be replaced by the material property. For example, S235 or S355 in steel. In concrete C30/35 classifications says enough for structural engineers.

** some interviewees mentioned that the extra costs are around 15% of the normal price. But this a rough estimation.

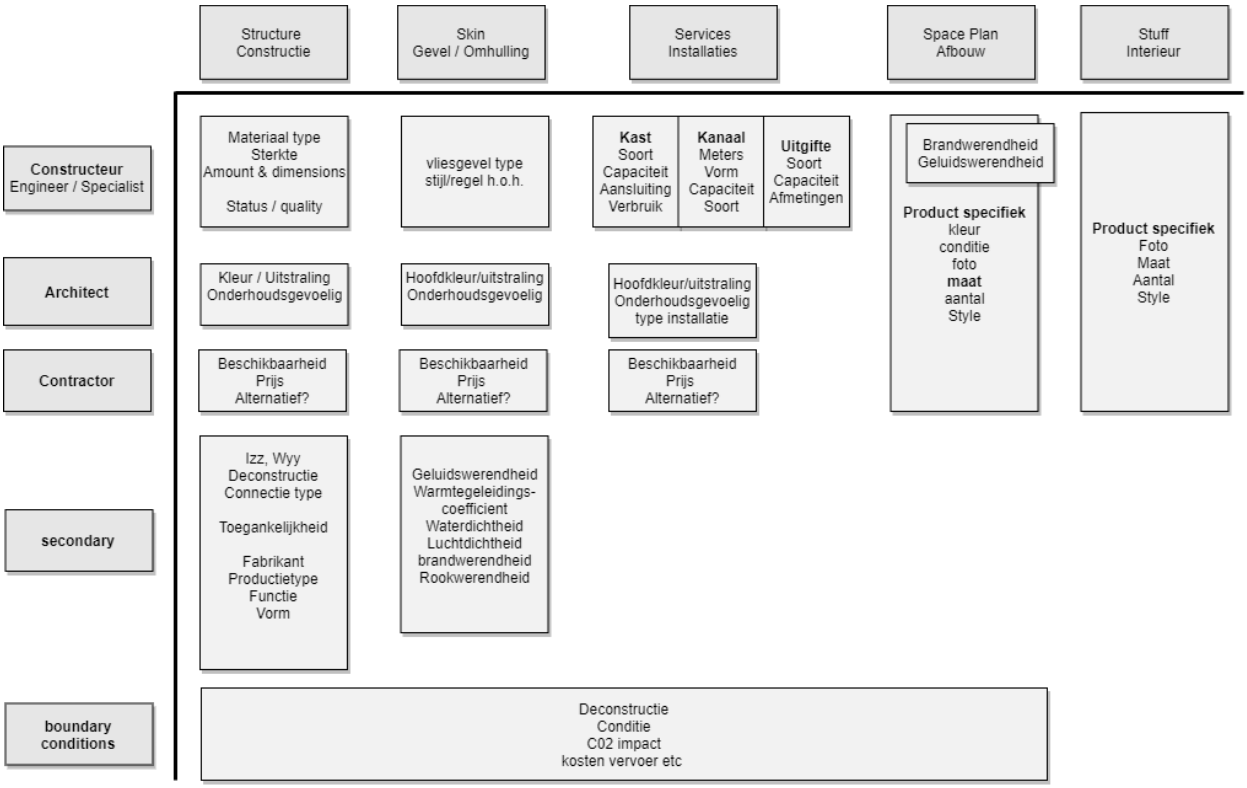

Figure 17: simplification of table 9, in Dutch due to jargon. (Own figure)

NL/SfB and Stabu

During the interviews, the relevance of Stabu and NL/SfB came forward. Simplified: engineers use NL/SfB and architects stabu for the procurement (dutch: bestek). Below a mapping is made on the six brand layers. Most engineers and architects did not mention the need for such a mapping. It is a “nice-to-have” function in a more advanced marketplace but not directly relevant for the core-interaction.

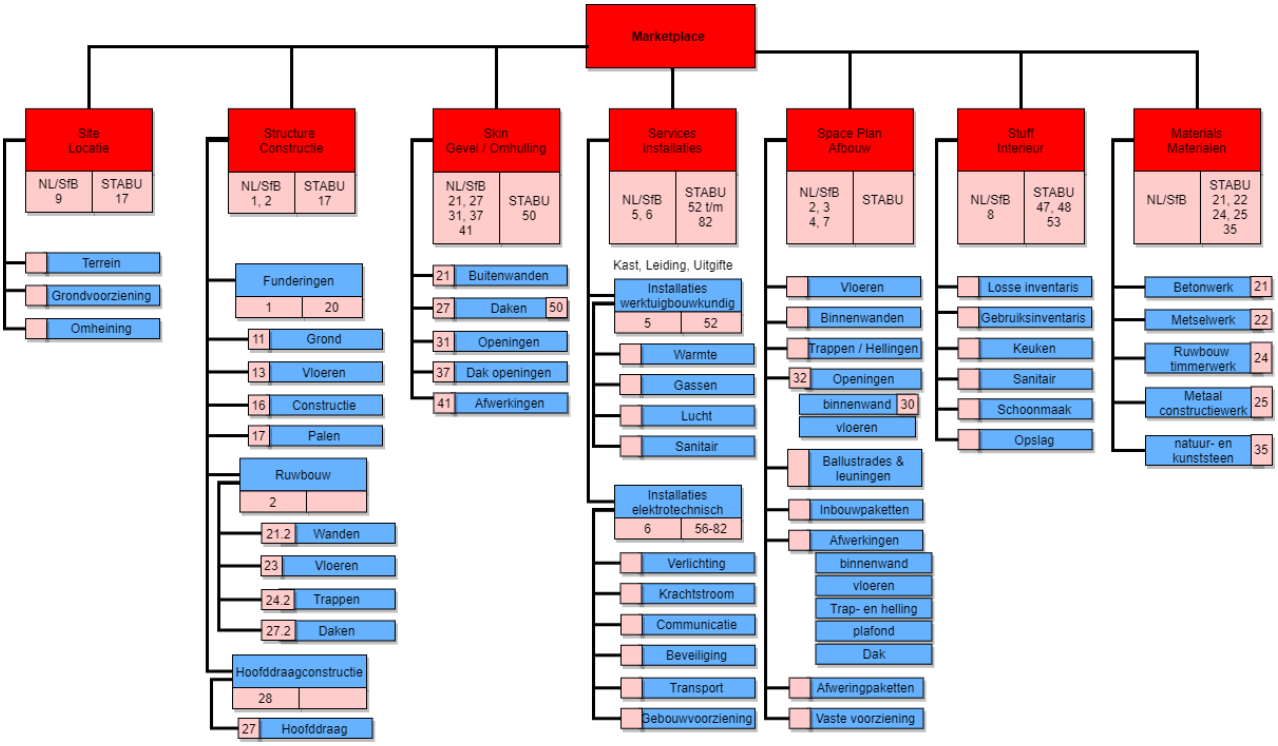

Figure 18: mapping NL/SfB and Stabu on the brand layers (Own figure)

Other parameters

(Disassembly, transport, re-assembly & environmental impact)

Parameters that are of secondary interest do relate to the filtering of products. If rules of thumb, e.g. estimating economic and environmental impact, then decision-making for reusable products would be more comfortable. However, these do not exist yet (rigour interview). The information of disassembly, transport, repair, re-assembly, and environmental impact depends on local circumstances. This local information could be linked to e-marketplaces, if more information is collected about product types, assembly hours, and local numbers of loans and transport. For parameters about the environmental impact, different LCA's do exist, but all with different outcomes and methods. Comments on e.g., BREEAM for reusing materials out of existing buildings shows that reuse is not positively scored in this method. In contrast, reuse has both a positive environmental and economic impact. A request is made to increase the point for reuse, so clients get the reward they deserve. As the mentioned parameters are not of interest to the core interaction, this is out of scope.

4.1.3 How should the design culture change

The thematic analysis separated the different challenges of a reused material marketplace into three broad themes; supply, demand, and the core-interaction. This thesis tries to find a solution for the core-interaction of a reuse material marketplace. Parallel to this, the literature research and the interviewees mention the need for a change in the design culture. This is also mentioned in other researches. 'Worldwide construction industry purchases exceed 3 trillion dollars annually. The concept of many-to-many marketplaces is powerful, but the scope of this transformation will require years of small steps and incremental changes in business processes to realize the vision fully' (Becerik, 2004). And 'the shift from recycling to reuse, however, is not just merely a technical challenge but requires analysis of whether the effort is justifiable (Hopkinson, 2019) concerning environmental savings.'

A digital platform itself does not solve the gap between supply and demand. Therefore, advice is given on how it should operate within the broader system. The system design has three parts -- Firstly, the role of the marketplace. Secondly, the change in design culture and thirdly, business models and niche markets.

What is the marketplace?

The current marketplaces for reused materials change/offer commodities. Some are offering transport services but nothing more. The need to integrate services and knowledge is an excellent way of improving such a marketplace's value. Some pioneering venture capitalist blogs do explore different roles of marketplaces.[7] "Managed marketplaces are a tactic to solve a broader problem around accessing high-quality supply, especially for services that require greater trust and entail high transaction value."

Research describes different marketplace models and strategies, such as a Review of The e-marketplace: Strategies for success in B2B eCommerce (Warren D. Raisch, McGraw Hill, 2001). It is important to consider the need for a broader ecosystem to overcome the reuse barriers mentioned in table 8. Current marketplaces like eBay and marktplaats.nl do already offer (construction) materials, but this is not efficient enough to serve the broader construction industry. Starting with a buy-side model would convince the demand-side to re-use products. The marketplace could evolve into a procurement marketplace that integrates vertically (transport, dis- & re-assembly).

[7] https://andrewchen.co/how-marketplaces-will-reinvent-the-service-economy/

Change of design culture & product procurement

In the current design process, product procurement takes place after the final design. The contractor has a list of specifications. With this list, the contractor can choose their products and brands if they meet the specifications. Through this, the procurement is based on the lowest price and current relationships between contractor and supplier. The interviewees mention that it is tough to use second-handed materials in this phase (see the first red dot in figure 5). To increase the range of possible reusable products, recommended is to start early in the design process (see the two red dots below).

In an ideal design flow, a feasibility study into reusable products is done during the sketch design. After this feasibility, some design decisions are made, for example, to design the main structure in wood as this offers the highest chance for reuse. If possible, the products are claimed. However, if, the risk or obstacles are too high, the contractor can use its supply channels to buy new products.

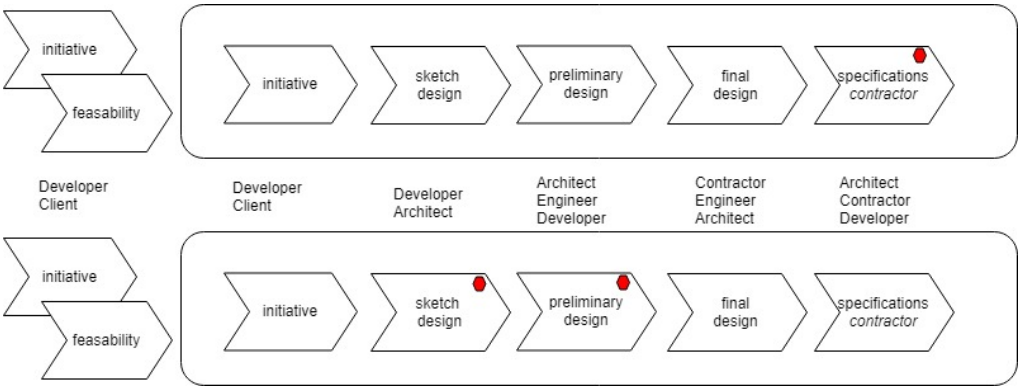

Figure 19: Change in buying moment during project phases to improve reuse possibilities.

When changing the design culture, there is also a shift in champions of the product decision. Some interviewees mentions the importance of the role of architects and engineers.

Demolition expert: "It is better if an architect makes his design fit for reused construction materials."[8]

Architect: "We prefer to take responsibility for a bigger part of the construction chain."[9])

A few studies have started to describe this change as well; In their means-oriented approach to design, the available materials provide a starting point (Pereira et al., 2016). A harvest mapping tool is used to discover what is available (Jongert., 2011; van Hinte, 2007). In the initial design, the area around the site(25km) is scouted for available waste streams. Providing a material catalog to assist the design team and a means of communicating material choices to the client (Jongert, 2011). (Stegemann, 2018)

[8] https://www.cobouw.nl/bouwbreed/artikel/2018/06/marktplaats-voor-herbruikbare-bouwmaterialen-101262133

[9] https://www.trouw.nl/groen/comfortabel-leven-tussen-het-afval~aaf28982/

Niche market

Starting a marketplace requires strategy on where to start. This could be described as the bowling pin strategy. Start in one niche, be fruitful and continue with others. Next to this bowling pin strategy. To better understand this problem field and have one language, Steward Brand's theory is used.

Steward Brand about building types.

Stewart Brand identified three types of buildings related to three kinds of segments. Namely commercial, domestic, and institutional buildings. All three have three types of roads; low-, high- and no-road. Commercial buildings adapt quickly due to competitive pressure, while domestic buildings change gradually to meet the needs of families. Institutional buildings aim for timeless reliability and can be reluctant to change, which can cause significant disruptions. Low road buildings have low visibility and high turnover rates, while high road buildings are characterized by exceptional design. "No road" buildings are inflexible modern structures considered works of art.

When institutions try to make High Road buildings, they go for monumentality over flexibility. When, say, a decade later they need to expand, they often end up with Low Road extensions: portacabins rented space in nearby buildings like people working in storage rooms.

Table 10: Potential re-use projects related to building tuypes

	Low Road (budget)	High Road (investing)	No road (art/magazine)
Commercial (adapt quickly)	Future	Very Interesting	pioneering
Domestic (change most steadily)	Far Future / not	Interesting	pioneering
Institutional (change reluctantly and rarely)	Not at all	Future	pioneering

Durmisevic is combining different types of buildings with destination and disassembly strategies. Here, Brand and Durmisevic agree with each other, saying that the need for change is frequent for time-independent (domestic and partly commercially). And thereby, DfD and reusable products are attractive.

Business models for reusable products

The economic part of a marketplace and re-usable products is vital to take into account as well. The literature on potential materials and products provides information on potential markets. A marketplace will increase direct re-selling if products or buildings are on the marketplace before demolition. This could be beneficial for better deconstruction techniques and less transportation of the products. However, if quality needs to be ensured, tests need to be done. Coming ecosystems could support this process, but this quality guarantee is expensive nowadays.

Other business models, more related to the producer's responsibility, could be beneficial. The producer takes back his product after demolition and put it back in the market after testing, repair, and new warranty conditions. This could be done with buyback guarantee or lease constructions. Still this raises some new challenges relating to the existing built environment and the lack of product ownership. In both existing and new situations (supplier responsibility), a reused product marketplace brings together supply and demand. Search and filter function could change depending on the ownership of the products.

Dunant et al. (2018) highlighted that the supply chain should include specialized stockists to make the market for steel reuse more favorable.

Results phases 1-3 (summary)

For the whole thematic analysis see appendix 'summary step 1' this is the sub-set of the core interaction items by leaving out supply and demand issues. Supply and demand is not something that can be directly changed by a digital platform. But the core interaction has a direct relation to the functioning of a 'digital' marketplace.

Table 11: Core interaction items from literature research and interviews during step 1 (subtracted from appendix table 8 that concerns all issues related to reuse of construction products).

		Phase 1 - application		**Phase 2 - rigour**
Theme's	**By whom**	**Application Interviews - Challenges**		**Rigour Literature - Challenges**
Core interaction	**Engineer Architect**	Time to find re-used products on websites. Unclear info (on current marketplaces)		B2B usability (in construction)
Core Interaction	**Champion**	A different need for information and search methods per persona Architect: aesthetic | Engineer: Functional | Contractor: Practical		No literature found related to champions for reuse products in construction.
Core interaction	**Rigour interview Architect / Contract**	A different need for (procurement) information is needed in different phases of the project, especially for reuse.		No literature found
Core interaction	**Engineer Architect**	Different materials have different reusability challenges and environmental performance. How should a marketplace show this?		Webster, Tingley, Bill Addis
Core interaction	**Marketplace**	One language (e.g. IFC, STABU & products)		Interoperability of Data. (van Berlo, 2015)
Core interaction - champion	Architect Engineer	Responsibility: an architect is no product trader Contractor right to choose own product with same requirements "Circular design is a quite new" Who takes responsibility?		User research: Who is the champion? Difficult to make journey map and have one clear "end-user." Activity-centered-design?
Core interaction	**Engineer Architect**	Different websites, different in usages. Therefore, it takes more time to find products online.		Variety and heterogeneity of different e-commerce websites (Kong, 2003) & Research bouwmarktplaats (Slager, 2018)
Core interaction	**Marketplace**	General constraints of reuse marketplaces in the Dutch construction sector. (Timing, aural coordination is needed, different interfaces)		Bouwmarktplaats onderzoek (Slager & Jansen, 2018)

"Milestones of civilization are always initially regarded as utopias. Albert Hirschman, one of the greatest sociologists of the last century, wrote that utopias are initially opposed on three grounds: futility (it cannot be done), danger (the risks are too great) and perversity (it degenerates into its opposite). But Hirschman also wrote that utopias, shortly after they are introduced, are often considered dead wrong." – (Rutger Bregman, 2018)

4.2. Design of the marketplace (Step 2)

The trick isn't adding stuff. It's taking away.
—Mark Zuckerberg, founder and CEO of Facebook

Goal of this step is to design the interfaces of the digital marketplace so that in the next step the filters could be validated.

Step 2: Design
2.1 design a solution for the brand layers (structure, skin, services, space & stuff)
2.2 design a solution with less data available (building search) –
2.3 design a solution for smart search (future technologies and huge amount of data/products available)

Key learnings

Before starting with the design, the most relevant information is summarized: Core interaction = Participant + (Design team, Engineer & architect) + **filters** + Value (less time)

Design team

Construction2Construction (instead of B2B persona's) focus on the champions in design teams. In previous re-use project, the experts were willing to explore re-usable products and prove their structural safety (e.g., Hooghstraat by an interviewed engineering company).

Platforms and facet filters

Jargon or knowledge about categories is needed; the facet navigation presents a controlled vocabulary with the number of search hits matching each vocabulary term.

Usability

B2B websites typically provide a wide range of information and more detailed information on products and services (in-depth white papers and specifications). Usability is essential in B2B systems (Konradt, Lückel, & Ellwart, 2012). B2B also requires supporting more sophisticated procurement journeys.

Digital construction

Current marketplaces have difficulties. IFC seems promising, but many steps need to be made in construction ontology to open the re-use market internationally. External factors are fragmented markets. Therefore, the need for one marketplace that offers enough detailed information for every niche (brand layer). **"**The step for these online tools is to use information from corporations' knowledge management systems so that even those who do not work on a particular project can benefit from the knowledge gained (Becerik, 2004).

Re-use potential

Materials have each their specific challenges and cost. After searching for products, the marketplace should provide this information to speed up the decision process. Literature provides information into material types, their supply in megatons, and their specific challenges. There is a considerable concrete supply but better to start with wood/steel and space/service layer with more accessible demountable products.

Go digital

After realizing small steps of a marketplace, more challenges arise. Potential solutions are described to digitize the current assets of buildings. Currently, these solutions seem too expensive. After interviewing Nebest, more solutions in identifying material properties were shown. However, these are less relevant for the core interaction and the start of a marketplace.

Table 11: Summary step 1

Theme	Whom	Application Interviews - Challenges		Rigour Literature - Challenges
Core interaction	**Engineer Architect**	Time to find re-used products on websites. Unclear info (on current marketplaces)		B2B usability (in construction)
Core Interaction	**Champion**	A different need for information and search methods per persona Architect: aesthetic | Engineer: Functional | Contractor: Practical		No literature found related to champions for reuse products in construction.
Core interaction	**Rigour interview Architect / Contract**	A different need for (procurement) information is needed in different phases of the project, especially for reuse.		No literature found
Core interaction	**Engineer Architect**	Different materials have different reusability challenges and environmental performance. How should a marketplace show this?		Webster, Tingley, Bill Addis
Core interaction	**Marketplace**	One language (e.g. IFC, STABU & products)		Interoperability of Data. (van Berlo, 2015)
Core interaction - champion	Architect Engineer	Responsibility: an architect is no product trader Contractor right to choose own product with same requirements "Circular design is a quite new" Who takes responsibility?		User research: Who is the champion? Difficult to make journey map and have one clear "end-user." Activity-centered-design?
Core interaction	**Engineer Architect**	Different websites, different in usages. Therefore, it takes more time to find products online.		Variety and heterogeneity of different e-commerce websites (Kong, 2003) & Research bouwmarktplaats (Slager, 2018)

4.2.1 Design product search

The next parts will focus on the design of the product filters. First a decision is made on the structure of the general menu.

General menu

The brand layers are used for the general menu. Current marketplaces use NL/SfB, Stabu indexation, or the Brand layers to categorize different product groups. StaBu is used in the specification phase of a project, the SfB is useful in the design phase. The SfB has international usage in Denmark, Sweden and the United Kingdom.

The proposed designs within this thesis use the Brand layers as it is the most common in literature. The interviews confirm that Brand layers are useful to separate the different champions and, thereby the related product filters. Different types of engineers and architects could use their Brand layer so that their specific segment will have specific filters that relate to their needs. See Figure 20 for the design.

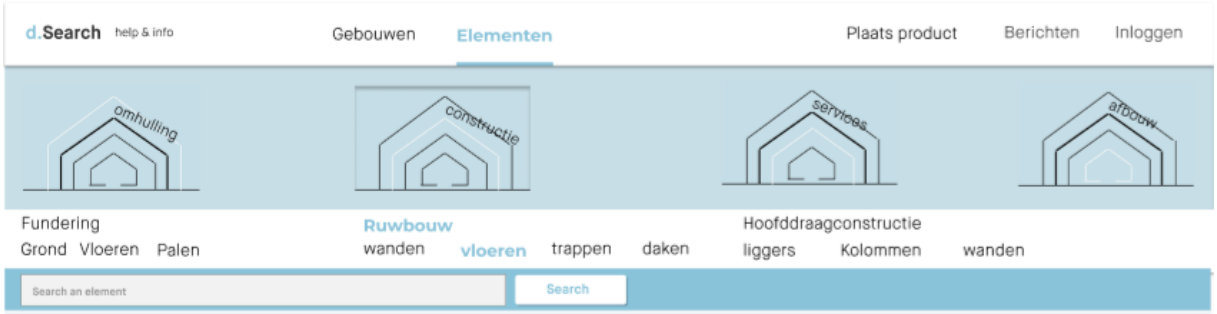

Figure 20: Brand layer and possible product categories for the home page navigation. Included NL-FsB/Stabu mapping. (Own figure)

Figure 21: Brand layer and selection of structure, home page navigation. (Own figure)

A different need for information in the preliminary design and the final design stage is mentioned several times. The previous chapter suggests earlier involvement of reusable product selection and thereby the use of a marketplace during the (sketch) design phase. This suggestion stays central during the design and validation of the filter. Therefore, the engineer and the architect are the main users of the core-interaction.

Core interaction: Participants + Value + Filter
Architect + opportunities and design decisions + aesthetics & product filter
Structural Engineer + grid size and material type decision + functional, physical capacity filters
Engineers (façade, service) + functional design decisions + capacity & type filters

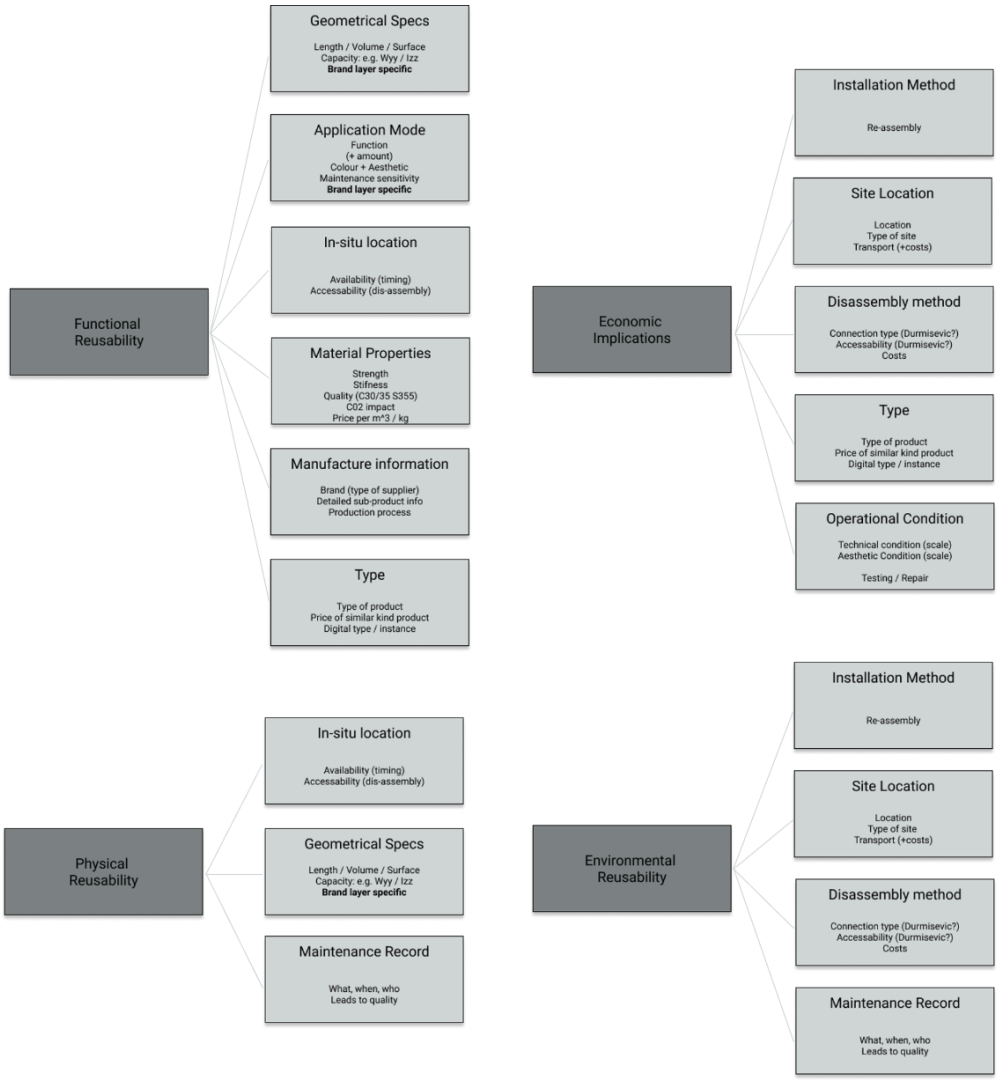

Figure 22: Parameters of Step 1.2 mapped on Swift 4 reusability groups (Own figure)

Structure, Skin, Services and Space filters

Using a marketplace for inspiration is mentioned by several architects. Therefore a Pinterest alike function is valuable with possibilities to filter on different kinds of styles. Architects want to see the pictures related to a specific Brand layer, where the engineers prefer clear tables. In the following parts contain the Brand layers and their filters. In the validation phase, the champions validate the filters. However, with the search bar, it is still possible to search within the whole marketplace. As the search for products from search bars and search engines like Google is mentioned as well.

The obstacles availability, timing of deconstruction related to reassembly are out of scope. During the interviews, claim buttons are discussed as a feature to overcome such obstacles.

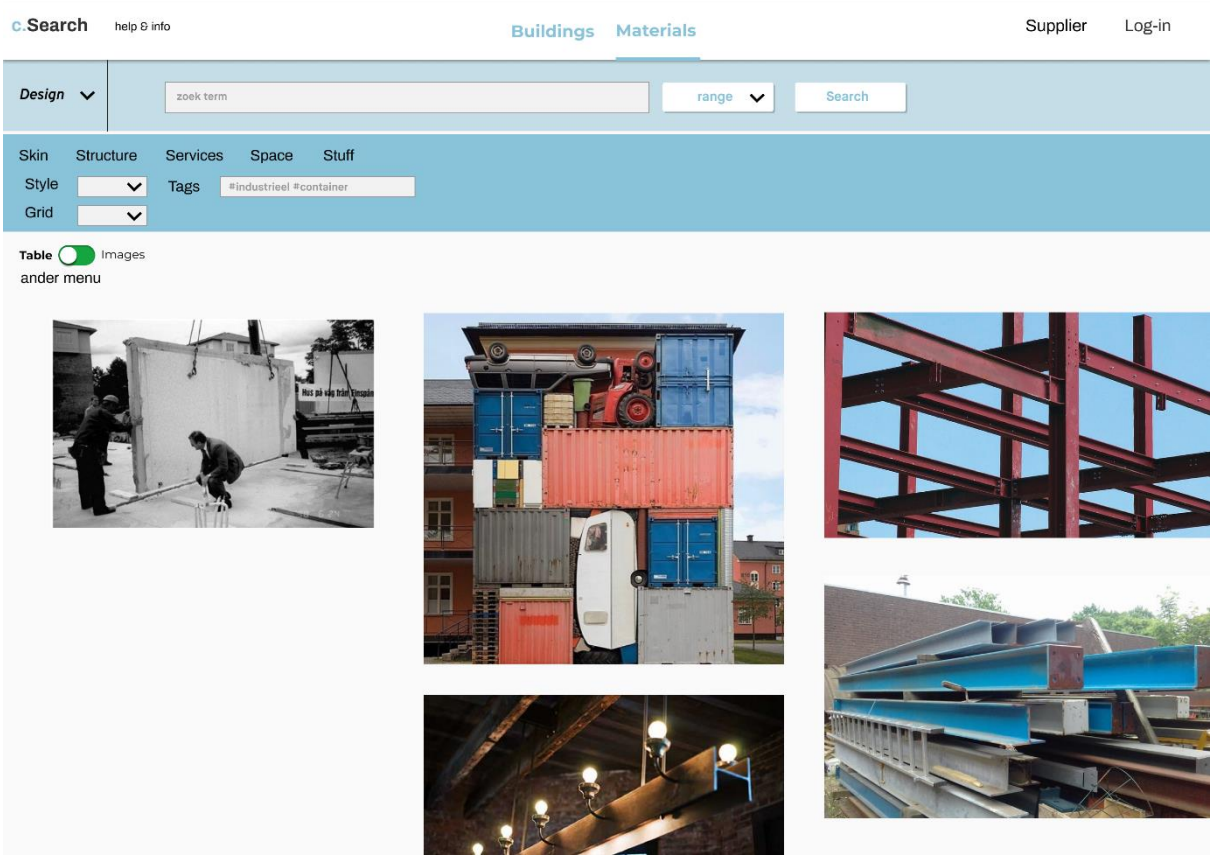

Figure 23: Marketplace with a search bar, and inspirational Pinterest like pictures having a style filter. (Own figure/design)

Structure

Figure 24 on the right shows the mentioned parameters related to each role. The most important are resistance, grid, Moment of Inertia (or Wyy) and material type. The extra information required: Dimensions, amount, availability and price.

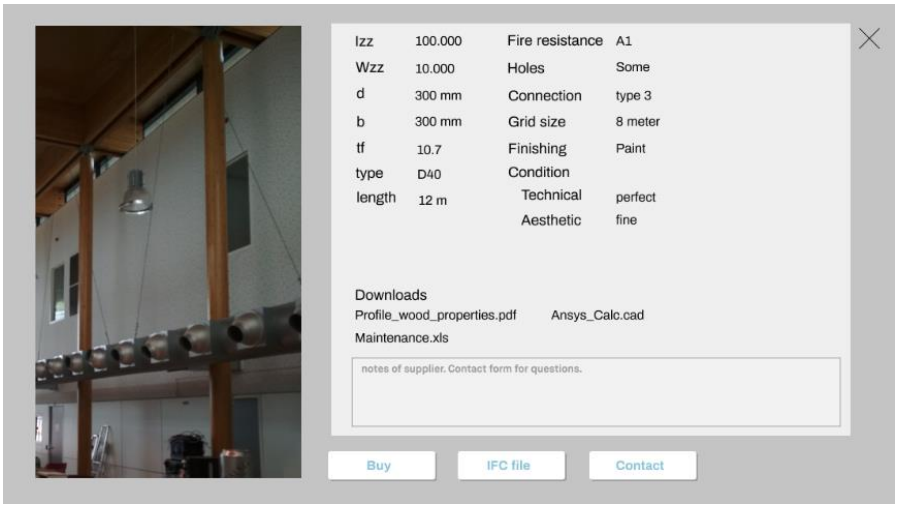

Figure 24: Information modal for a structural element (Own figure)

The structural layer relates to the different structural materials (wood, steel, and concrete). Therefore, the primary filter is related to the structural material. Whereafter grid size and profile dimensions could be filtered. These filters are the same for the three structural materials. More in-depth research is required to design better filters on the re-use quality aspects of the materials. The next table is derivated from the literature and is useful in the next design steps.

Tabel 12: overview of the three main structural materials

	Barriers	Benefits
Disassembly		
• steel	Rigid connection	Long technical lifespan
• wood	Technical lifespan, Moisture, insects, nails	Light, easy to cut and re-use in smaller parts
• concrete	Cranes, heavy and big, cut and sew, reinforcement. Recycle as aggregates	Huge supply in the Netherlands
Re-assembly		
• steel	Residual stresses	Welding
• wood	Spikes and deformations	Light weight
• concrete	Hard with non-rigid connections	Prefab options

Structural engineers recommended the possibility to attach documentation to the specific products. After filtering on products, the first analysis for structural safety is done. If previous calculations or more in-depth documentation is available, fewer products test are needed.

Design Structural layer:

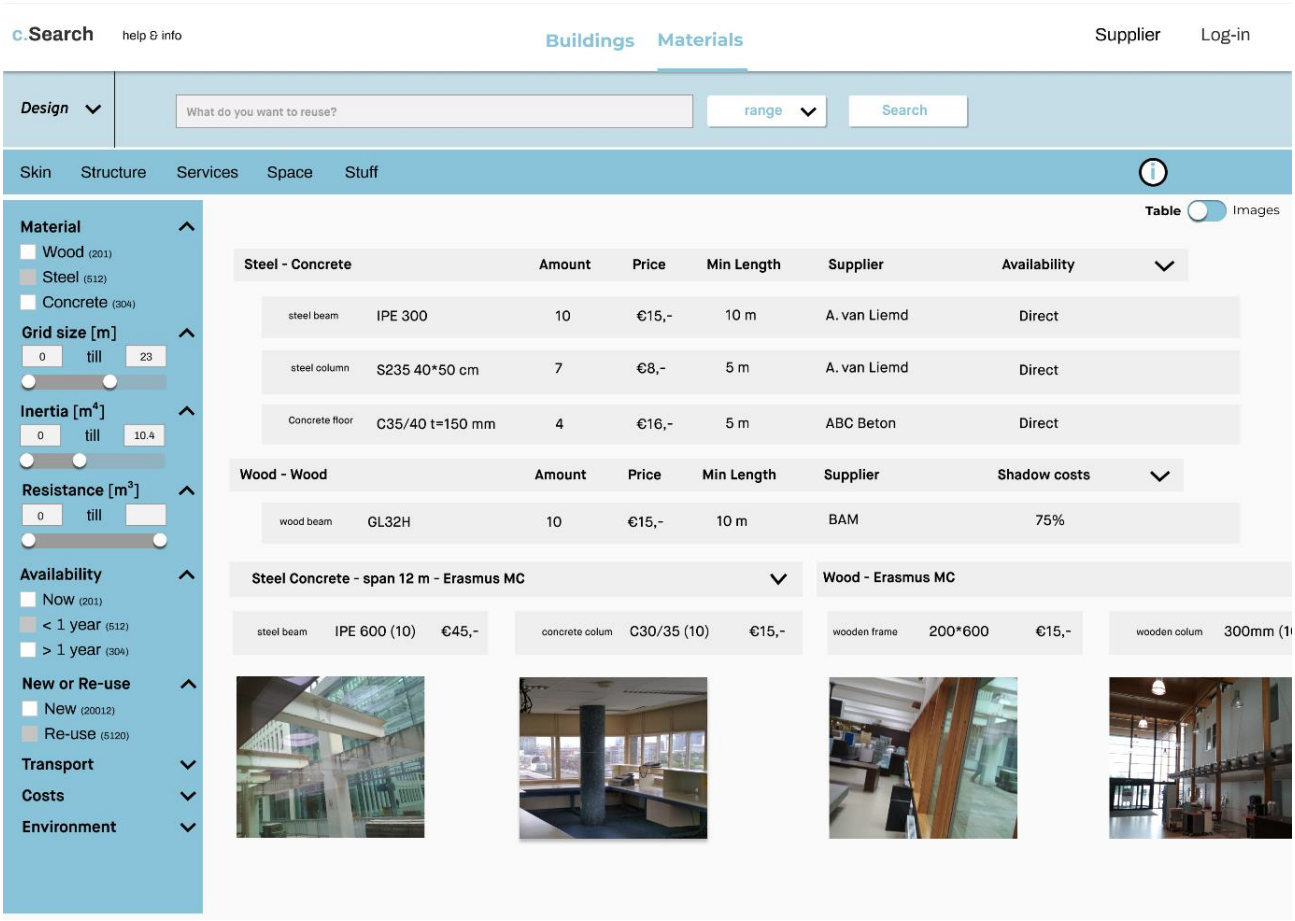

Figure 25: overview of structural layer and her facet navigation (Own figure)

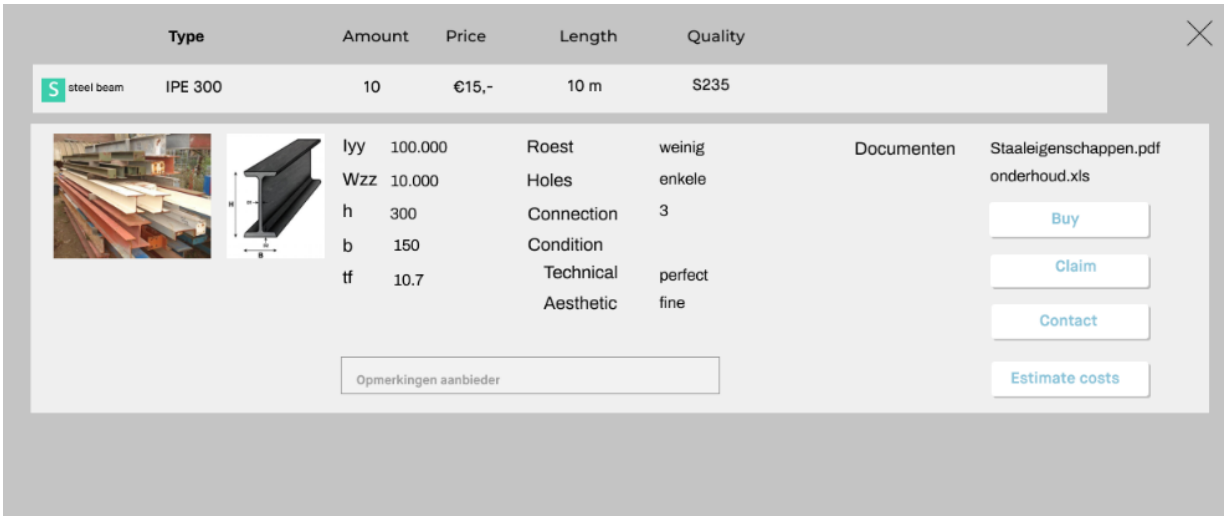

Figure 26: detailed product information: including documentation (Own figure)

Skin

The facade layer is hard due to the different types of façades that exists. All have many properties that vary depending on the function of the building. Interviews confirm that the size and type of facade are the primary filters. Architects need to see pictures and filter on aesthetics like color, transparency, and possible style.

The engineer is interested in functional reusability and could use filters if there is a particular need in the design requirements, such as high sound adsorption.

For the donor building search similar kind of building types are interesting as they have similar facade properties. When the platform has reached a critical mass, more advanced search option are proposed. A minimum amount of square meters façade could be requested where the platform search within the market supply and does several recommendations.

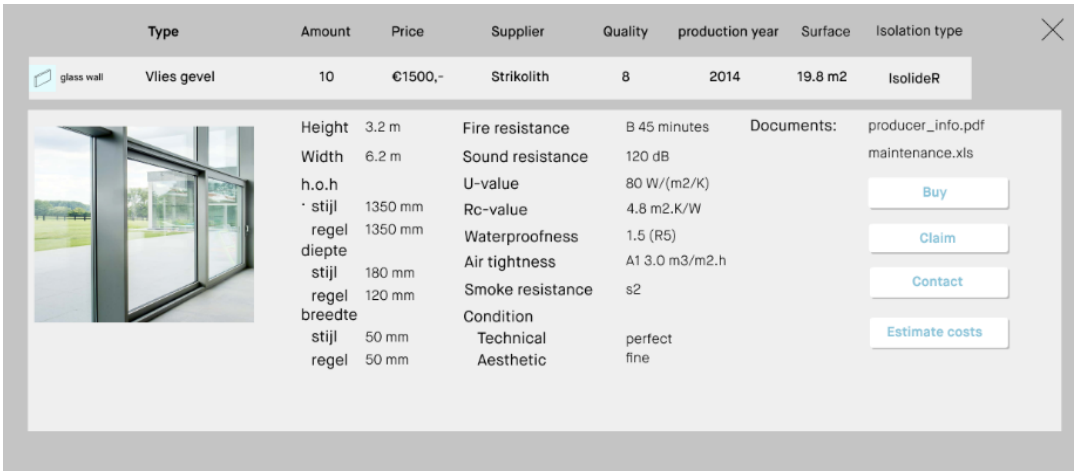

Figure 27: product details of a re-usable façade (Own figure)

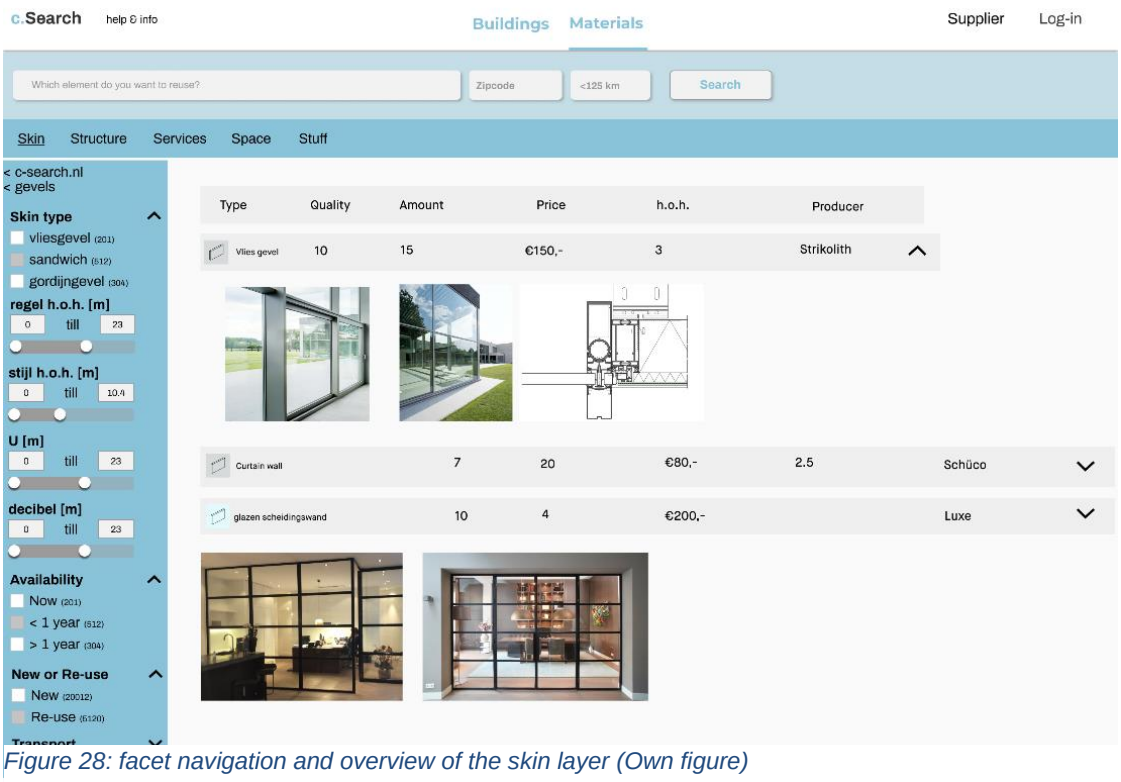

Figure 28: facet navigation and overview of the skin layer (Own figure)

Services

The user for the service layer would be the engineer and would filter on three categories. Namely the **machine** (heating, cooling and, air machines), the **distribution point** (ventilation grille, water tap, heating element) and the **transport** (cable tray, pipe and wires). The machine has a more dynamic environment with a significant change in regulation, expecting a low reuse pattern. The other two categories, distribution and transport are more suitable for reuse; these filters contain service type, (energy, water, air, data and heating), minimum length, the capacity of distribution and transportation.

Further specifications

Further interviews should give more structure into the specific filters of each category (box, transport and exhaust related to the service type). Where the box should filter on the capacity/power, the transport will filter on physical requirements (length and sizes) the exhaust will contain an aesthetical aspect and a minimum capacity.

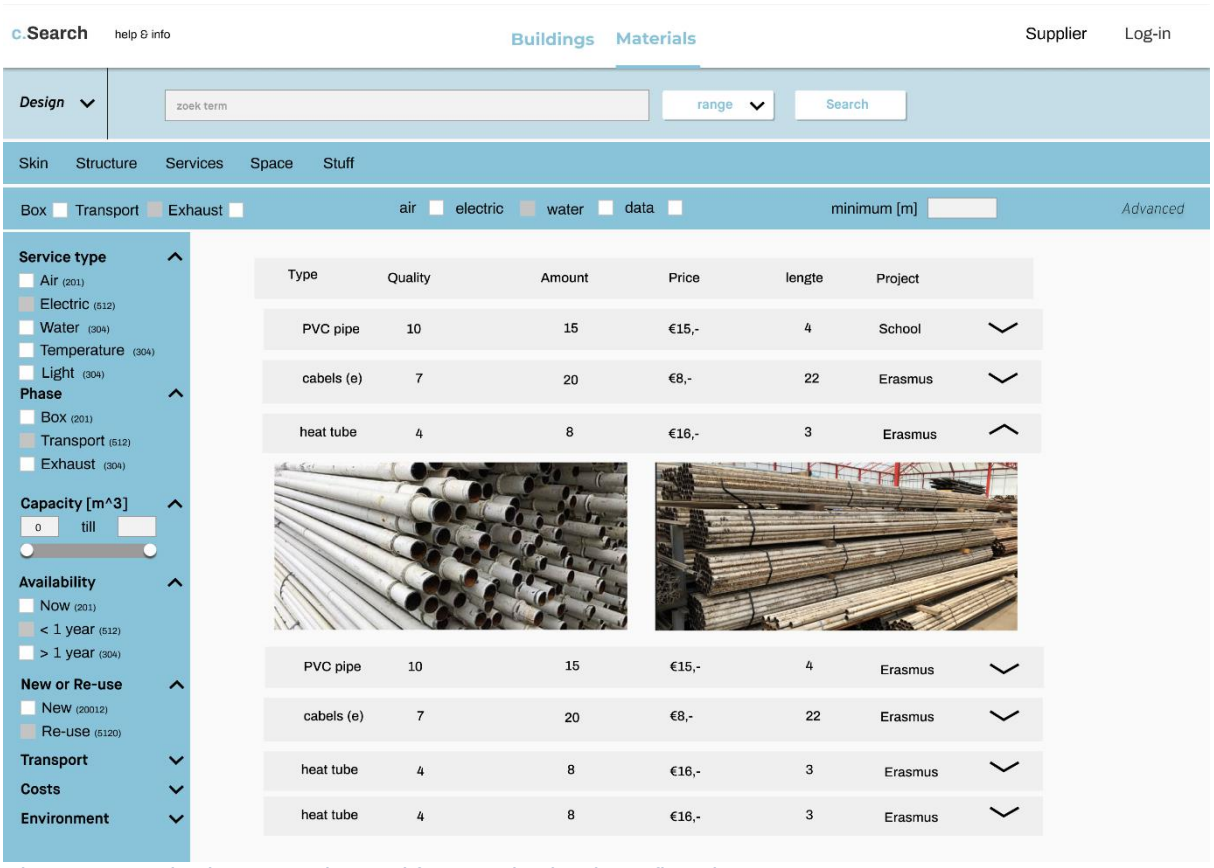

Figure 29: Service layer overview and facet navigation (Own figure)

Space

The space layer is not the most important in design decisions or environmental impact. Mostly structural engineers do not influence this layer. Architects will use Stabu to filter on specific categories. Related to these categories different filters are relevant. For example, indoor walls or doors need to filter on floor height and soundproofing. Next to that, the aesthetic part is considered an influential filter as well. Therefore, a style filter is designed and seeing pictures plays a considerable role.

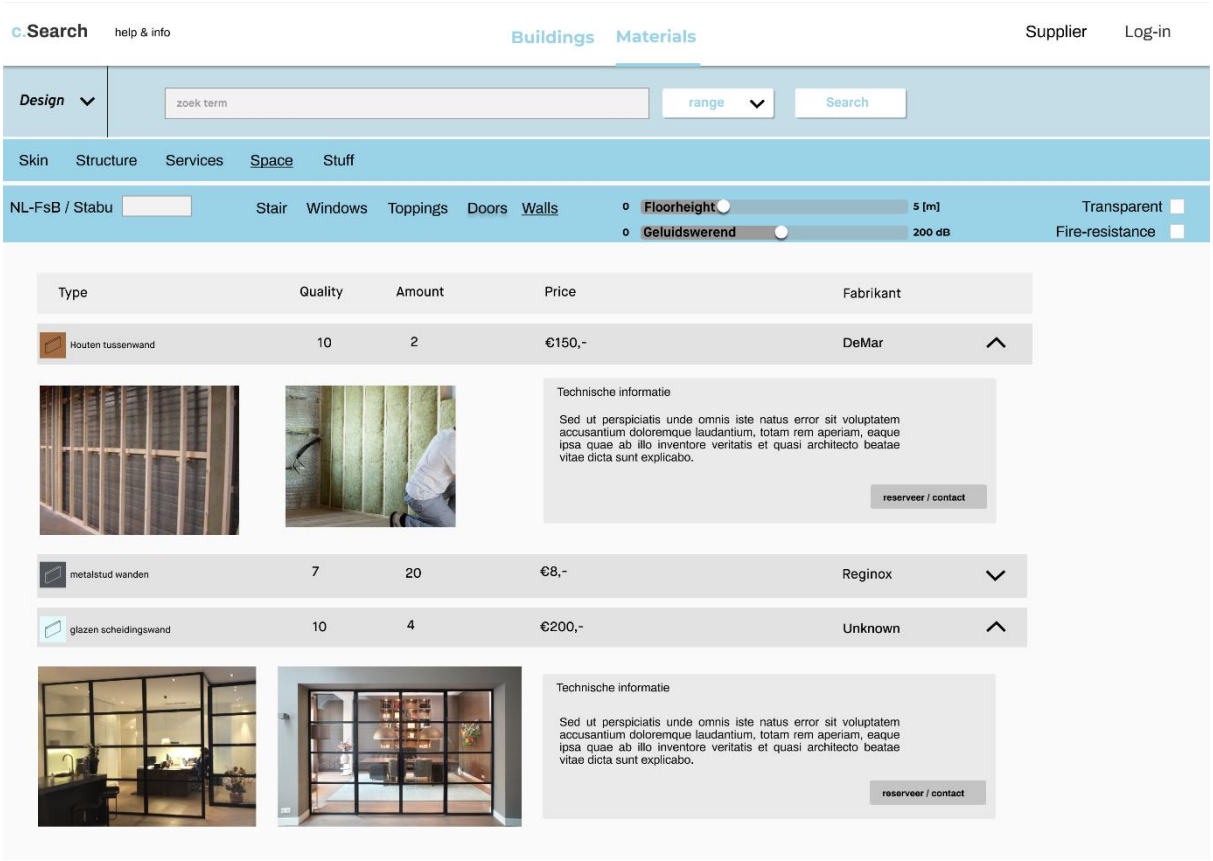

Figure 30: Space layer overview and her filters (Own figure)

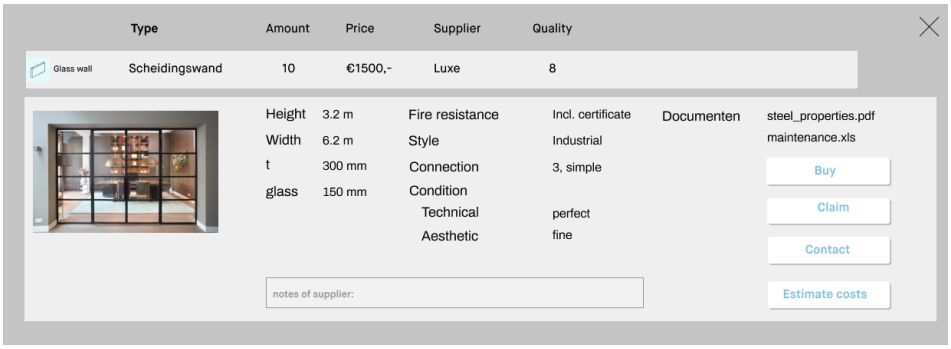

Figure 31: Example of products properties of an indoor wall (Own figure)

When reusing an existing "to be demolished" building recommended is to filter first on the other layers, and if they could be reused than also see if the space layer is interesting, the fit within the design is with this approach more significant. Therefore, next to the functional filters, a project selection is useful.

4.2.2 Design “donor” building search

The obstacle of digital information of reused materials, critical mass and the rigidness of the existing built environment all block the usage of a reuse material marketplace. To overcome this stage, a “temporary” solution will be designed. As most of the supply of reusable materials are out of the existing built environment, a donor building marketplace is proposed. This does provide building-specific information about the re-use potential of the products within a specific building. However, with less information and work, there could be ways of getting more insight into the re-use potential of existing buildings and their products.

Research into common product types such as pipes and different floor types could benefit the assessment for reuse potential of a building. For more insight into the material and product potential in the Netherlands, see phase 5. With information on building level instead of product level, design and demolition decisions could be made. Thereafter more data should be collected at the product level. Different BIM and data capturing methods are described in phase 5. This will reduce the risk of digitizing a building. According to the interview with Nebest steel test could be carried out on location. If possible, a connection could be made with biedboek.nl an official auction site for buildings which contains information, drawings and sometimes calculations about the buildings.

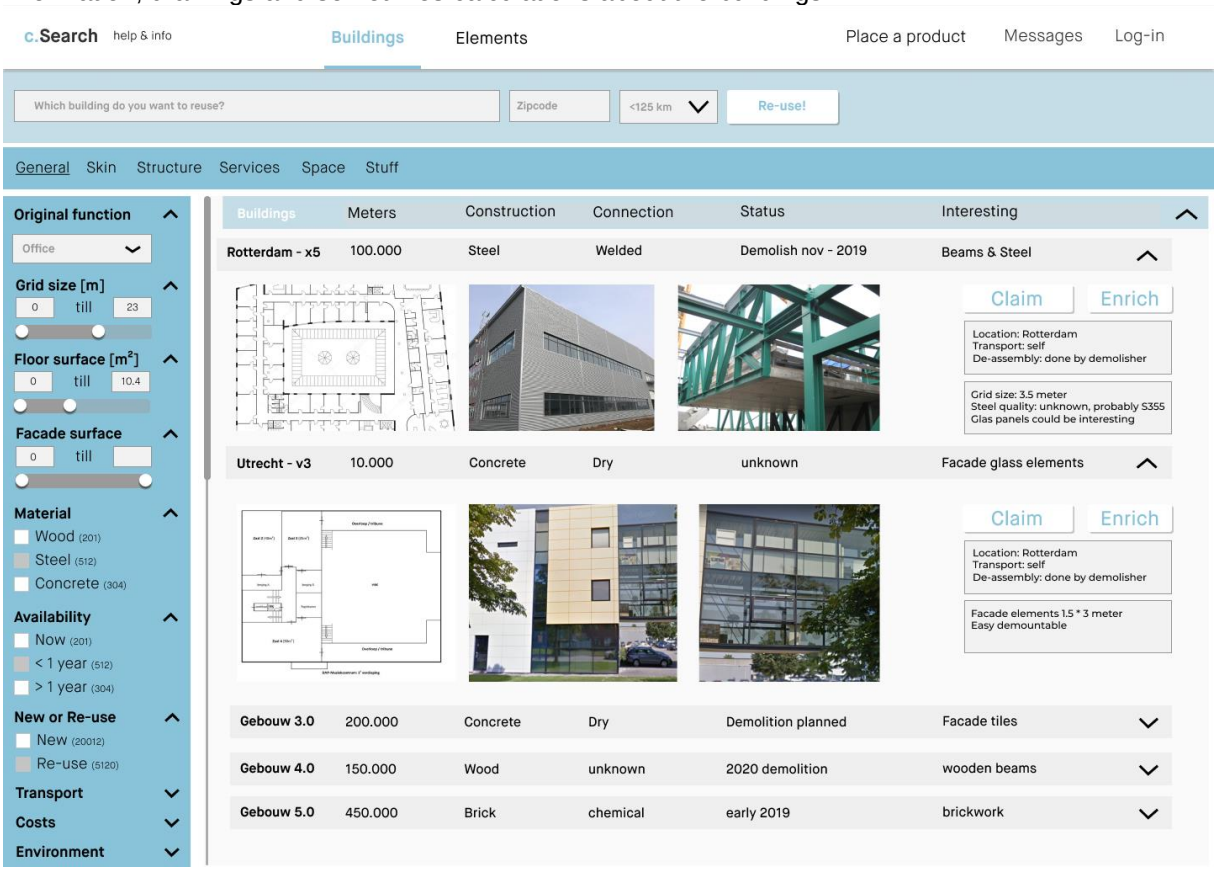

Figure 32: donor building search (Own figure)

In phase 4 the layering of information need is further investigated. This contains the design of different filters, claiming of building components/parts and possibilities to enrich the building with needed information. This could be combined with BCF, BIM for facility management, cheap scan techniques etc.

4.2.3 Design smart search

Instead of designing (physical or functional) filters that search for specific products a different approach is suggested. The vision is that an engineer/architect/design team search for a requirement instead for a product. For example: a structure that could resist a load of X. This requirement is used by the marketplace system that will recommend different solutions. Such as ten types of wooden beams or six iron beams with a certain profile. This approach requires more knowledge of the system but aims to increase the change in re-using products. In the validation phase this approach is validated as well.

Smart search could contain full structural analysis but will start with basic stiffness and strength calculations.

The first checks that are discussed within smart search are:

- Normaal kracht (sigma = F / A) sigma < trek/druksterkte (incl. factoren)
- Moment (sigma,m = M / W) sigma,m < trek/druksterkte (incl. factoren)
- Doorbuiging? W = 5/384 * ql^4 / EI (vrij opgelegde ligger) < 0,002*L (of 0,003)
- Dwarskracht (tau = V / Aeff) of VRd,c=[CRd,c*k*100*ρl*fck)^(1/3)+k1*σcp]*bw*d

And thereby leaving out:

- Kip
- Knik
- Wringing / Torsie
- Taaiheid en vermoeiing
- Hardheid en broosheid
- Kruipeffecten
- Secundaire effecten
- Inhomogeniteit?

When architects or project developers are using a marketplace simple input parameters such as q-load for different kind of buildings functions are needed as well. Therefor we suggest a simple input field (figure 33) that contains the information in figure 34 (right).

Figure 33: input field

CATEGORY IN EC1	FUNCTION	UNIFORMLY DISTRIBUTED LOAD q_k (kN/m^2)	POINT LOAD Q_k (kN) 100x100 mm
	HOUSES		
A1	Floors	1,75	3,0
	Stairs	2,0	3,0
	Balconies	2,5	3,0
	OFFICES		
B1	Offices generally other than B2	2,5	3,0
B2	Offices at or below ground level	3,0	2,7
	FACILITIES (education, culture, kindergartens, sport, etc)		
C11	Cafes and Restaurants	2,0	3,0
C12	Reading rooms with no book storage	2,5	4,0
C13	Classrooms	3,0	3,0
C31-C32	Corridors, hallways, stairs, landings	5,0	7,0
C39	Museum floors and art galleries for exhibition purposes	5,0	7,0
C 41	Dance halls, studios and gymnasia	5,0	7,0
E12	Reading rooms with book storage (e.g. libraries)	4,0	4,5
C21	Assembly areas with fixed seating	4,0	7,0
C51	Assembly areas without fixed seating, bars, etc	4,0	7,0
	CATERING		
C11	Cafes and Restaurants	2,0	3,0
	HOTELS		
A3	Bedrooms in hotels and motels	2,0	2,0
C11	Cafes and Restaurants	2,0	3,0
C51	Assembly areas without fixed seating	5,0	3,6
	RETAIL – PDV – GDV – Outlets		
D1	Areas in general retail stores	4,0	7,0
D2	Areas in department stores	4,0	7,0

Table 4.3 - Design values q_k and Q_k for imposed loads on floors (Source: EC1)

Figure 34: input q-load related to building function

This concept could be extended in a further vision where algorithms design buildings with re-usable components. Before researching and designing this view any further, a first validation is done with structural engineers.

If you want to teach people a new way of thinking, don’t bother trying to teach them. Instead, give them a tool, the use of which will lead to new ways of thinking.
— R. Buckminster Fuller

4.3 Step 3: Validation of the artefact

Theodore Levitt put it, "People don't want to buy a quarter-inch drill. They want a quarter-inch hole!"

This chapter measures the usability of the designed artefact by interviewing the key-user of the artefact. Every brand layer should be validated by different key-users. This thesis focuses on the structural engineer and the structural Brand layer. If this seems valuable, it is recommended to extend this research for the other layers. All four interviews validate the three desings; building-, product- and smart-search. Within these three designs, the focus is on the structural part of the building. See the attachment for the validation questions.

Step 3: validation of the artefact (value)
3.1: champion validation, is the chosen champion able to search and influence the design(culture)?
3.2: is the artefact useable?
3.3: does it solve the problem, and challenges of reusing product in the design?

Interviewees for the validation

Three engineers from three different engineering companies have participated in one-to-one sessions. The fourth person is an expert in advising design teams for re-use. Decided is only to interview one champion role first as the initiative is still at the people who want it. The current market circumstances show some pioneering engineers. Interviewing a design team does not make sense if a marketplace is used by a single person who provides such a design team with the marketplace's information. The expert in re-use could be seen as a Collegium Subrutorum pioneer.

4.3.1 Champion validation

Are engineers currently the ones who should use a marketplace for re-use.

(Engineer 1)**:** yes, it could be the structural engineer, but in cooperation with the supplier.

Example: The supplier take a big rol in the design of the pavilion. He contacted us and said you can borrow this amount of material (instead of buying), if you bring it back in this condition. As engineers we got C20/C30 wood with different length. Those included the standard trading lengths. Next to that we asked a demolition company for wind bracing. We measured them all and brought them to the contractor.

Who should be the champion (key-user)?

(Engineer 1) Ideally, at the engineer. However, mostly we do not get the time to visit different buildings. This was partly due to the architect. Collaboration is key in re-use and research to re-use. To convince the desing, team we organized a session where everyone could pitch ideas. In the end we tried to re-use reinforcement bars for the wind bracing. So, in the end the whole team should be there, but probably an expert is picked to really search for potential products.

(Engineer 2): The supply side should offer useful information and data about the existing buildings. The structural engineer could search for donor buildings if the client is willing to pay. It is better to start early in the process but is not necessary

Champion (Engineer 3):

As an engineer we are advisers but not deciders. As a big company we also have façade and building services engineers at our disposal. It would be advantageous if we could involve them when researching reusable building or products. This also means that the design team subsidiaries function in the design. I am not sure yet if that is desirable, maybe if there are substantial economic or environmental benefits.

Re-use expert: Probably a “circular” ecosystem around the traditional industry will occur. I am not sure if engineers and architects should take the frontier role (in searching) in the design team. More practical is to let reuse experts participate in the pre stadium of the design job.

4.3.2 Artefact validation

Validation Product search

General structural layer

The marketplace should contain drawings or calculations. Furthermore, (overview) tables over pictures. Engineers validate the crucial filters: Wyy (profile dimensions) and physical properties (length) related to functional re-use capacities. E-modules, own weight, sigmas are of lesser importance as these are common knowledge for engineers. Lists of all the material types and profiles are of great value. Pricing is useful but not the most important in an early design phase.

Remarkably, connection type or details are not mentioned as needed filters (for steel or concrete). Because when bolted connections are disassembled, the head and footplates are not re-used. As these connections will be different in the new building. Connections in concrete buildings will mostly be sawn off the beam.

Steel

Steel only needs profile type, length, and steel quality (S235, S355) filters. For steel pricing, comparison with new products is beneficial to convince the client.

Wood

Filters that are essential for “structural” wood products are:
Wood type, dimensions, wood quality and numbers. After the first filter, more information about the quality is essential. This quality is related to moisture, nails and more (see literature). Different strategies need to be defined to decide if the wood is qualitatively re-usable.

Concrete

All engineers conclude that concrete requires information about the reinforcement. The outside columns are different from the insides one, so engineers need to check multiple columns to be sure of the reinforcement situation. Concrete product information should contain drawings/calculations of the reinforcement. Scan techniques could provide information as as-is situation does differ with the as-designed situation. (e.g. contractor decide to use 3m or 7m reinforcement strings). The archive drawings could support in deciding the capacity of the buildings. Hollow core slabs are quite standard but pre-tensioning makes it different.

Still challenging.

Timing in disassembly and reassembly stays difficult and causes more engineering time if products are not available on time. E.g., (IMd) hof van carthesius where the re-use building was not available on time. So we made a new design to reuse different elements.

Secondary filters and toolings

Shadow costs are useful as they take different environmental categories into account (C02, nitrogen, particulates). Some companies use MPG while other LCA. Thereafter cost indications of transport, disassembly and reassembly are needed. If engineers could search within a 110% price range of the newbuilt price that would support decision making. A next step would be to design filters for cost experts and calculators. So that could easily make different cost estimations related to the design variants.

Brand layers / Stabu or NL-SfB

A structural engineer does not make use of Stabu or NL-FsB. That is more interesting for the architect of BIM engineer. The structural Brand layer would fulfil our search purposes.

Validation Building search

This first scenario is developed as the literature study discovered the lack of product (data) to search for products. So, in an early stage, engineers will search for buildings that could be of interest to re-use in their existing design challenge.

Donor building search criteria

During the validation phase structural engineers mention the following building parameters (filters):
Grid (in centimeter), age of the building, floor systems, stability system, the function of the building, span sizes, location, beam treatments (e.g., coatings), square meters (floor), date of demolition.

Core search (what would you search on first)

(Engineer 1) First material type as is standard in the design process. A client has wishes/requirements, and after that, a first design and thereby a material choice is made. Unless it is a unique project where re-use is central. Secondly age (building year), mostly the newer the higher re-use potential. Actually, the type of building(function) relates to that. Mostly it says a lot about the used floor type (e.g. housing is more acoustic and therefore thicker floors). Next to that, if you could re-use a building into the same function type it makes sense. As certain "types" have mostly similar kind of design challenges and therefore specific products. Thirdly grid, floors and size of the building. Or an estimation of the number of beams and columns.

Later, disassembly strategies should be decided, but that should be at the location itself. Some information about demount-ability is practical and supports the estimation of the costs. Connection types could be of interest unless sawing is used as a disassembly strategy. Lastly: photos do say a lot!

(Engineer 3) We have less experience with the re-use of buildings. But first, I would like to search for the type of buildings. Such as: Station, House, Utility, Storage/Logistic, Stadion, Concert, Hotel or Schools.

(Engineer 2) Firstly on square meters. Furthermore, if possible, for applied loads (or function of the building). Span sizes are not that interesting as they could always be smaller. Floortensions vs. column tension and the materials of the building are useful parameters. Some photos, preferably of the structure will support in decision making. Floor heights and other functional requirements would influence search parameters. Nevertheless, if engineers want to be more creative, reusing school elements from a hospital is possible. Therefore, searching on the applied load is crucial. Engineers will always get tension between accommodating, re-use, and construction. Thereafter, traditionally, the municipality archive is visited. To jump to the element/product level and see what is possible. We prefer to call an owner instead of online communicating. The archive-quality differs a lot and always take a lot of time and energy. To have such information already digital is valuable (in the future this could be a IFC).

(Re-use expert) Crucial is promising/potential products and materials. This depends on the knowledge of the re-use expert. Otherwise, search on sizes of the building and its grid. After that photos of the building are essential to judge on re-use potential.

Validation Smart search

(General) Do not take over the work of the structural engineer

Engineer 1: no this will be way to hard. Loading types and deformations depend on the connection type as well. So, you have to take many factors into account which lower the usability of a search tool / marketplace.

(Engineer 2) I think it is hard. Our job is difficult as well. There are many exceptions.
Smart search with entering a force combination is difficult because when we decrease the beams' size, we can have higher forces. Buckling factors etc make it even more difficult. Maybe layman could use it to make some initial concepts. But in the end the structural engineer is responsible and has to sign for the safety. You could take a look to the VBI tool for easy design of different floor types. But to start with a marketplace it could better be a “dumb” tool.

(Eningeer 3): you do not want to build analysing software. If it is not working properly engineers will be dissatisfied and will not use it. E.g. difference between point loads and distributed loads.

What about recommending other products with the same structural functionalities?
(Engineer 3) Recommending like “others also checked” is okey. Recommendations outside the original material search will still be hard, as many design decisions are related to this “main” material selection. Therefore, only suggesting different profiles is good enough. For example, recommend a HEA320 profile instead of an IPE400.

4.3 conclusion; Does it solve the problem?

This research aims to solve problems to stimulate re-use in the AEC sector. Therefore, it makes suggestions for change in the design culture and a suggestion for the core interaction of a marketplace.

The literate study identified the following obstacles for reuse in relation to digital marketpaces:

- Additional time in search for materials and products
- The need for information (about reusable products) and the current lack of it
- The ecosystem of the existing supply chain, the lack of a re-use ecosystem
- The need for change in the design culture
- The lack of filters and knowledge about champions for design with reusable products

Functional filters over economic filters will solve a part of the problems. It will reduce the time to find products and give information about the possibilities. If insufficient information exists, 'building search' solves the lack of accurate data. The change in procurement (see figure 35) and earlier product decisions will stimulate an ecosystem for re-use. All interviewees mention that such a marketplace will stimulate creativity in the validation phase of the expert's and the design team.

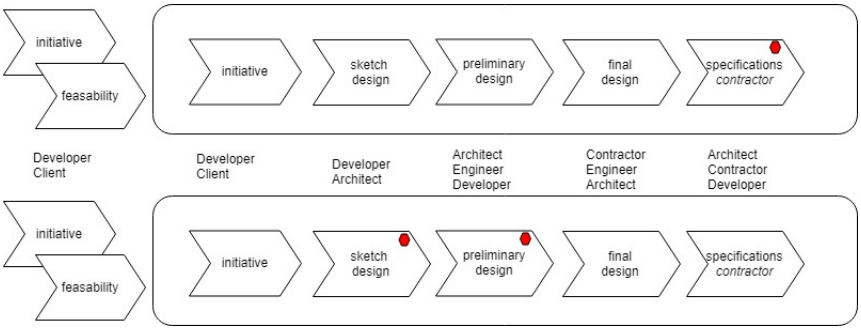

Figure 35: proposed change in product procurement during the design process. If done earlier more products could be reused.

The functional filters work for the structural engineers; this is not validated for other design/engineering roles and the other brand layers (skin, services & space).

Economical

Related to business value, costs and pricing of reusable products are essential, this is not taken into account within this research. The core interaction of this marketplace does contribute to the economic benefits of re-use. If done properly, it could save storage and logistics costs (due to virtual storage). Other benefits include; saving time in search, no costs for in-between parties, stimulating local reuse, and encourage innovation and possibilities with the current supply.

Other measures could be taken to stimulate the demand further. Such as lower taxes on manual labor (to stimulate dis- and reassembly), introduce a C02 tax so new products will be more expensive than re-use., abolish VAT (BTW) on reuse. The VAT is already paid on the first purchase. Or tax raw materials (reused products will become cheaper in comparison with new products)

Chapter 5: Discussion

This chapter will discuss the findings and meaning of the results in relation to the research question and the literature research. The existing literature suggests that reuse is possible, but we encounter a problem with stimulating the demand as it currently requires significant time (of releasing reuse). This research primarily focus on facilitating the process of finding products (in a digital manner), which is a component of time reduction (although a substantial portion of additional costs lies in disassembly, increased testing time, etc.).

Currently, the literature does not address search criteria and filters for niche marketplaces as the reuse of construction materials. Where removing barriers/friction is a key component of this effort.
However, this research can be segmented into the core interaction (see literature) parts namely: participants, value unit, and filter. Each component can be examined individually.

Participants

The literature study states that this marketplace will focus on b2b practices. Therefore, there is mostly no single user, buyer and decision maker within one role. Furthermore, reusing a product is even more complicated as multiple companies have something to say over a specific product.

This research claims that the specialists/engineers should be the marketplace user to select and propose a product that could be reused. Whereafter the project manager and/or client can make the decision.

Gorgolweski (2006): “Successful steel reuse projects are generally the result of **a willing client and a tightly integrated team** responsible both for the design and rebuilding.”

A report from Finland confirms the champion role of designers. “Designers have an important role in the re-use of structural elements. Their documentation, drawings, and instructions significantly affect the effort needed in the building deconstruction. Not only selected components and technologies are important, but also how the availability of final design documentation will be secured for the building's whole life span. The maximization of environmental, cultural, and financial value at the end of the building’s life should be considered already in the design stage. Designers have to gain access to the information about the actual and potential supply of reclaimed components, sizes and material grades, and they need to be flexible to adapt to the current situation.” (Hradil et al., 2014)

Another persona (not interviewed within this thesis) is the government, she came to the discussion in several interviews with marketplace initiatives. It is mostly related to the need for regulation and obligation. The government could also play a massive role in the demand size as it is responsible for many building projects. Bukvić also states finger-pointing to the government in his study to the circular economy within the concrete supply chain. 73% of the actors assign responsibility outside the supply chain (mostly government) for a circular supply chain change. (Bukvić, 2018)

After making designs for every brand layer, this research validates the designs for the structural layer. The proposed filters and marketplace seem valuable during the validation phase with structural engineers.

Filter

The significance of well-developed facet filters for functional search queries is crucial, and their importance cannot be overstated. While price and other product attributes are relevant, they are considered secondary in this regard. It may even be feasible to establish a marketplace that is entirely demand-driven. However, the current literature shows that facet filters have not been adequately developed within the current marketplaces. Nonetheless, research indicates that these filters are further developed in larger e-commerce players, such as bol.com, over the years of their existence/growth.

The use of classification systems as a starting point for the navigation system is questionable. Madaster, for instance, uses a combination of NL-FsB and Stabu. Although this approach has some advantages, such as architects' recognition of specific categories of Stabu, it also has some disadvantages. For instance, multiple user types, such as engineers, clients, and project managers, may not be familiar with these classifications. Therefore, a main split in the brand layers is chosen, within which different users have been interviewed to create a more detailed facet filter.

This research aims to determine which parameters are significant for product search and selection. While economic considerations are important, they are not central to this process. Pricing information is critical in e-marketplaces, but not for filtering purposes. Although environmental impacts are compelling, they are not directly linked to marketplace use or product procurement insights. This may be due to the lack of appropriate environmental decision-making methods, and most reuse projects begin with the client's willingness. However, engineers interviewed view reuse as an excellent environmental practice, so additional filters may not be necessary in the initial stages. Nonetheless, this could be an exciting future development beyond the core interaction.

Other research also supports this perspective on reuse properties, as the cost of reuse was not seen as a significant barrier, contrary to what other studies suggest (Satu Huuhka & Hakanen, 2015). In-depth survey research by Hradil et al. (2014) indicates that environmental benefits are the primary perceived benefit of reuse, as shown in figure 36. While functional reusability should be the core interaction, the high perceived value of environmental benefits is already established, and high profitability has a lower benefit. As Satu Huuhka and Hakanen (2015) noted, "Remarkably, the cost of reuse was not seen to be among the most significant barriers," a finding confirmed during interviews with structural engineers.

Figure 36 illustrates the survey results of benefits for reuse (Hradil, 2014). This research explored many different parameter options but concludes that the filters should be simple and effective. Starting with functional properties, such as physical properties for structures, filtering the product should contain in-depth information, including old drawings and calculations, to enable the full potential of its reuse capacity.

Figure 36: benefits for re-use, survey results (Hradil, 2014)

Culture change

One of the steps within the research question relates a change in the design culture. Which is mentioned within the research of BAMB. Culture change contains a lot, from mindset for reusability to willingness of clients and so on. This research focus more on the design process and suggests to change when products should be procured. This is still a major discussion point and it is not a main part of this research. Starting earlier with 'reusable' product selection has the benefit that design choices still could be made, and therefor a potential increase in a match between supply and demand. A few studies have described this change as well; In their means-oriented approach to design, the available materials provide a starting point (Pereira et al., 2016). A harvest mapping tool is used to discover what is available (Jongert., 2011; van Hinte, 2007). In the initial design, the area around the site(25km) is scouted for available waste streams. Providing a material catalog to assist the design team and a means of communicating material choices to the client (Jongert, 2011). (Stegemann, 2018)

Discussion this research

The research field of UI is young, and very rare in the construction industry. Also, circularity is a young research field, combining these is hard. As barriers come up when discussing the future of circular construction in a digital tool while doing it analogue (without a marketplace) is already tricky. The IS framework is a highly iterative process and does fit in such a new research field. The application field and literature study gave proper input for the relevance cycle. The rigour cycle could involve more design and evaluation theories to specify the design. Techniques to determine the filters and information structure could be used. Such as tree testing or closed card sorting. These techniques where not known before and would support the research to have a more explicit guideline and framework. The information system framework offered lots of flexibility in iterating and doing rigorous research by continuously consulting the existing literature. This benefits in understanding the problem field rather than in taking more evident steps in a specific topic as filter design.

Literature provides a lot of answers and knowledge about re-use. The proof is in the use of a marketplace and thereby its realisation. That requires entrepreneurship, supporting re-use on the demand side and developing digital tools to facilitate this process. This paper could contain too much literature and touch on a wide range of topics. Whereby the focus of designing a filter is a bit neglected. Before start designing the problem field should be clearer. However, continuing research on the functional filters will lead to more in-depth research. Though when deciding the core-interaction, a broad aspect of the problem field should be mapped. This research succeeds in that.

Recent research (Eindrapportage Circulaire Handelsplatformen, PzH 2021) about construction marketplaces state that many construction-related platforms are rising, but that for users, it stays difficult to oversee the supply. Therefor it is relevant to cooperate, bundle or communicate with each other. Developing more advances ‘search’ filters based on the ‘functional’ needs of the specific needs of the users will be helpful.

Chapter 6: Conclusion

This thesis identifies the challenges for implementing a reused-product marketplace, recommending the earlier involvement of reused product procurement. The procurement process of both new and reused products is complicated, non-transparent and consists of many process flows and business models.

The following research question is introduced: "How can a digital market platform address the construction market for secondary materials?".

With three sub-steps, participants, filter and value that together define the core interaction of a platform. This thesis aims to design facet and search filters, a crucial part of the core interaction, for a reused product marketplace and aims to identify the users of such a marketplace. The research combines human-interaction design, semi-structured interviews, and literature related to the reuse of construction elements. It concludes that engineers, architects and deconstruction experts *(collegium subrutorum)* are champions in the design with reusable products and champions for the core interaction to search reusable products. Producers and suppliers will play an important future role by taking responsibility for their "circular" products and offering clients and contractors alternatives by for example leasing facades. In this case, designers still could use a marketplace, especially for reusing the existing built environment. The current environment lacks the (digital) information that designers need for their design decisions.

To answer step 1, who would be the users and how will they search. In the case of a reuse marketplace for the structure/construction layer (S. Brand), the users would be structural engineers. Their information need focus on the **elements' functional and physical properties** (moment-of-inertia, material type, strength and dimensions). Thereby the core interaction disregards environmental or economic properties. These are of secondary interest for the core interaction. The need for information about connections is also up for discussion, as most connections are cut-off or not reusable in the new design project. It could benefit deconstruction times if a building is designed for disassembly, but that is not the case for many buildings. The three main materials, wood, steel and concrete, require all different ways of working for reuse but share common properties which makes the design of filters less complex. Capacity and dimension, grid size and floor height, and filters could influence the structural material design decision, which could increase the demand for reusable structural products. However, more traditional engineers prefer to filter within one type of material. The specific material and product knowledge for reuse could be a next step for the core interaction, thereby evolving into a knowledge marketplace. For the Dutch market concrete, the most difficult material to reuse has the largest stock. Concrete reuse requires information about the reinforcement. This could not be seen from the outside, which is not digitally modelled and modelled not like the as-built situation.

Within step 2 also the other Brand layers (skin, services and space) are designed. Those should focus on their functional and physical reusability properties as well, which is covered in this thesis but not validated with real users. The skin and the space layer are more visually oriented, images support decision making for both architect and engineer. Aesthetic filters to filter on certain styles, colours, types and tags will support the architect where functional filters relating to dimension are of first need for the façade engineer. Secondary the physical filters do benefit the search tremendously such as; U-value, fire resistance, Rc-value, sound resistance, waterproofness and more. Within these physical properties there is no research done to the layering and ranking of interest. The user for the service layer would be the engineer and would filter on three categories. Namely the machine, the distribution point (ventilation grille, water tap, heating element) and the transport(cable tray, pipe and wires). The machine (e.g. heating, cooling and air filters) has a more dynamical environment with a high change in regulation, expecting a low reuse pattern. The other two categories; distribution and transport are more suitable for

reuse, these filters contain service type, (energy, water, air, data and heating), minimum length, capacity of distribution and transportation.

After this first phase of the core interaction, a marketplace could potentially be a digital ecosystem where more parties (such as demolition company and project developers) could find and upload there specific information need. Already reused material marketplaces do exists, founded by the opportunity for an extra sales and marketing channel. Within those marketplaces oral tuning is needed due to lack of information and this hinders the search time, usability and with that the demand for reusable products.

To overcome the lack of digital information of the existing built environment a donor building marketplace is proposed (step 2). This is validated with two user types (step 3); the structural engineers and an expert in reuse. Here, the filters contain part of the design requirements such as; floor surface, façade dimensions, grid size, and the building's function to be deconstructed. Other search filters could support search filters depending on the engineer's expertise such as; building year, floor types, stability system and material type. If this information is not available photos are mentioned to support decision making for possible investment in further mapping of the building. Opportunities for donor building marketplaces lie in the integration with the old technical drawings and calculations that provide the structural engineer with more certainty for reuse. A claim, bid and buy system is mentioned to increase incentives for more careful deconstruction of buildings.

The trend of service marketplaces and incorporating new technologies to automate processes could support the procurement process. The implementation of cost-estimation, delivery, deconstruction, guarantees and re-assembly is of secondary interest for the core-interaction. IFC seems the most proper solution to overcome different kinds of languages between the different stakeholders in the reuse process. So far IFC covers the most properties needed for reuse (e.g. IfcOwnerHistory, IfcStructuralProfileProperties) and could be used in product trade but for the existing built environment R&D needs to be done to overcome deconstruction challenges and missing information about product properties. Literature already exists about BIM for the existing built environment, together with facility management reasons and reuse purposes this could be integrated in a platform ecosystem.

A reuse product or donor building marketplace is not the holy grail for an increase of reuse demand. More measures should stimulate project developers and clients to reuse products among which; obligation, improvements on existing metrics (e.g. MPG and BREAAM) and C02 tax on products.

Concluding the value of a marketplace will; increase the search range and thereby stimulate the creative reuse of products, lead to faster search time and aims to connect reuse champions in the future. With the suggested system changes; lease products, earlier reuse product procurement, start with niche products for fast changing commercial buildings and the use of a marketplace and her filters the demand should increase and thereby be an accelerator for a circular construction community.

For the prototype see the following links

- https://bit.ly/thesis-general
- https://bit.ly/thesis-structural
- https://bit.ly/thesis-donor-building

Limitations

The findings of this master thesis have to be seen in the light of some limitations. In sequence of relevance these are related to, the interviewees, chosen champion, literate relevance and the outcome of the facet filters.

Related to the interviewees

The interviewees had an interest in circular design. Still, they saw many obstacles in re-use and even more in realizing and using a marketplace. The group could be seen as early adopters but crossing the chasm to the majority will be even more challenging. A limitation of this research is that critics of reuse are not interviewed to validate the possibility of such a digital marketplace.

Method used and the chosen champion (key user)

The method used in this thesis is a user-centred design, which puts (one) user type in the centre of the design. During literature and interview analysis the use of reuse material marketplaces is complex, and it is hard to appoint one persona as champion. During this research, the structural engineer (due to time limitation) is picked as the structural (Brand) layer champion. Another ‘champion’ could be the project developers or contractor. During the interviews the role of project developers, clients and contractors are mentioned several times. As they are key in creating demand, the one interviewed project developer pointed to the supplier for support in these demand questions. This limitation goes hand in hand with the previous one.

Another method, instead of user-centered design is activity-centred design, which focuses on software development for certain activities instead of a specific type of user. Another suggestion would be to develop project-centred design methods, as projects drive the construction industry. However, this term is not used before and needs more development. Interviewees have mentioned the crucial role of a whole project team in re-use success, as there are many interfaces/interdependencies for reusing products.

Related to the type of interviews

The semi-structured interviews are qualitative and exploring. To decide on the data structure and the filter functions a more quantitative approach could help. Before doing this, re-use should be more common. For most engineering companies, reusable products are never used before. To develop something for users for a process, that they never have experienced before and probably will not experience soon, could be hard to imagine and therefore results are influenced be the current obstacles (such as not economically, difficult and risky).

Qualitative research is done as this research (and reusing construction materials) is more in the pioneering field. Therefore, the dataset is limited, and more quantitative research methods should be used to rigour the outcomes.

Related to literate research

Literature about IT adoption around the dot come era is outdated. Recent literature about user experience and platforms within the construction is scare.

Limited business models

Business models of products play an important role on the functioning of the marketplace. The research into this field is limited to one business model (second hand market). Other business models, more related to the producer's responsibility, could be beneficial. The producer takes back his product after demolition and put it back in the market after testing, repair, and new warranty conditions. This could be

done with buyback guarantee or lease constructions. Still this raises some new challenges relating to the existing built environment and the lack of product ownership. In both existing and new situations (supplier responsibility), a reused product marketplace brings together supply and demand. Search and filter function could change depending on the ownership of the products.

Recommendations

To better understand the implications of these results, future research could address the following topics: ‘core interaction and chosen champion’, ‘marketplace functionality and filters’, ‘design culture and other barriers for re-use’,

Recommendations on the chosen champion and the core interaction

Support demand side on the process of re-using material. This is the most important recommendation. As all the interviews mention the extra time needed to search / find and integrate products in the design is time consuming. Experts are needed, such as the Collegium Subrutorum (reuse experts) in the roman period. A marketplace in its first stage should be more than only a digital place where supply information is collected. It should support teams in the use of a marketplace and help them in their re-use challenge.

Thereby take a very close look at the buy-in proces of materials. How could you change or support this? This research only interviewed 2 ‘buyers’ to get a more holestic view of the opportunities and barriers of reuse.

For further steps explore and validate the other Brand layers instead of the structural layer. A similar research process could be applied, but other functional filters will appear. After a next design iteration usability test could be done to validate the practicality of such a marketplace further.

Recommendations on marketplace functionalities and facet filters

Get better terms for the quality for reused products. Come up with better check list and analysis instead of good and bad quality. This goes hand in hand with the education of engineers to calculate with re-used materials. Therefore, better sources and literature should be available about the reuse potential. Currently the sources about reusing different materials are very diffuse.

Clarifications in this area are required to promote a mutual understanding and a common consensus on the way EC is accounted for. This would provide the means for the development of a framework that would contribute in the assessment of the real value of a component after recovery and create a taxonomy of materials based on their EC reuse efficiency potential.

Recommendations on the design culture and other barriers

Instead of single (champion) user , See if material “brokers” / re-use adviser could make use of such marketplace. Continue on pricing information! And offer alternatives (products).

Support decision making: (no core interaction) This method should advance a more sophisticated and informed decision-making process, so that the reuse of existing, relocated components may be weighed against the procurement of **new** components, using parameters such as cost, transport, embodied energy and carbon footprint.

The brand layers provide a rough filter, but we should be able to reuse elements in other layers. But re-using it in its existing layer is practical. The structural layer requires at least filters on minimum length, Wyy and material strength. Connections are not needed because these will always be different.

The hard thing is in the wide arrange of products, materials and difficulties related to re-use. Therefore suggestion to use the same method but explore these parts in more depth. Such as wood re-use, HAVC re-use (all separately). In this field also more complex area’s such as taxology and ontology come in play.

Recommendations on further research of realizing a digital marketplace

Use the digital platform canvas mentioned in part 1.4 to research the other components that are necessary to realize such a platform.

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Attachments

Content of attachments:

Chapter 1 (Introduction) appendix

Pre-research overview

Table 1: Economical trends

When	Who	What Economics
1930	John Keynes	Practical men, who believe themselves to be quite exempt from any intellectual influences, are usually the slaves of some defunct economist
1968	Sweden central bank lobbie	First Nobel-Memorial prize in Economic science.
1974	Fredrich Hayek	'the influence of the economist that mainly matters is an influence over laymen: politicians, journalists, civil servants and the public generally
1989	Franco Archibigu	Economy and ecology need to be merged from a local to a global perspective.
2002	Braungart & McDonough	a biomimetic approach to the design of products and systems that models human industry on nature's processes viewing materials as nutrients circulating in healthy, safe metabolisms
2010	Leonard A Story of Stuff	rue recycling achieves a **circular closed loop production** process, while downcycling just makes Stuff into a lower-grade material and a secondary product
2017	Kate Raworth	GDP is as a cuckoo in a bird's nest.

Table 2: Reuse and circular design trends within the construction industry

When	Who	What Construction
1990	Duffy: Measuring Building performance	Start with building layers
1994	Brand: How buildings learn (What happens after they are built)	Difference in building layers their technical life and functional life
1999	Crowther: Design for Disassembly	We must design to later disassemble a building
2001	Macozoma	This means that building deconstruction (Reused) helps to close the loop on material flows
2001	E.S. Slaughter	Design strategies to increase building flexibility
2006	Addis: Building with Reclaimed Components and Materials	The acceptance of materials reuse in mainstream professional construction is in its infancy, and needs exposure and the reassurance of its peers. Shows many methods
2013	Glias: The donor skelet	Reusing elements is cheaper than new elements (concrete)
2017	BAMB	Change **design culture** & link between marketplace - passport
2018	Broekhuizen: A Study of the Challenges and Strategic Opportunities Facing the Dutch Construction Industry	1. **The industry is innovating, but the current focus is on cost-cutting process innovations**. 2. **Sustainability is seen as a requirement, and not a differentiator.**

Table 3: Development of Material passports

When	Passpoort	What Material Passports
1968	"The book"	John Abrams: "open-wall photos plus the keyed plans. The times of greatest value of the book are during finishing, later during remodeling, and any time the house is sold."
2008	"Database" Steel re-use	Fuiji: "proposed that in the design phase, structural engineers can access the DB in order to choose the suitable components"
2012	Resource Replitition / Nutrient Certificate	Braungart: The concept of Nutrient Certificates is introduced as a counterpart to emissions certificates to account for the value of defined highquality material flows.
2013	Glias	As soon as these elements and their properties become known, they can be used to design new buildings.
2015	Circularity Passport	EPEA/BAMB: Buildings as a material bank
2015	Oogstkaart	platform voor de uitwisseling van restproducten van bedrijven
2016	Material Matters	Thomas Rau: "Afval is materiaal zonder indentiteit"
2017	Product Passport	Circular building platform (BAM)

Table 4: Development of re-use projects

When	Which Projects	What Projects
1996	Udden	Materials and products from about **50 larger apartments** in the two buildings that were **deconstructed were used** to construct a building containing **22 smaller apartments** (totaling 1070 m2).
1996	PROgroup	agreement with supplier on buy-back option of the steel beams at deconstruction
1999	Nya Udden	reused concrete elements cost roughly 10% to 15% more than building with conventional building practice.
2013	Brummen	Gebouw ontworpen als grondstoffen depot, 90% is demontabel
2015	Venlo City Hall	Inspired by cradle-to-cradle principle
2016	Alliander	is 80% van al het materiaal (zoals gebouwen, plafondplaten en toiletpotten) hergebruikt en is oude werkkleding verwerkt tot isolatiemateriaal.
2017	BAMB Different feasibility projects	The feasibility studies have also shown that, although challenging, **the technical aspects of Reversible Building Design are not the biggest issue** in regard to the transition towards a circular and dynamic built environment. **A shift in mentality and design culture seems to be an important barrier to circular economy in the built environment**.

Chapter 2 (Literature) appendix

Core interaction and Literature

Table 5: an overview of platform and core interaction theory

Book	Theory	Examples
Platform revolution (Parker et al., 2016)	Why > Core Interaction: Participants + Value unit + Filter How > Pull, Facilitate & Match	Facebook, LinkedIn, Amazon, Microsoft Visa, Quora, AirBnB. Cohealo (B2B) = Airbnb of expensive hospital equipment. Mercateo (B2B) = marketplace & procurement
Modern monopolies (Moazed & Johnson, n.d.)	Core Interaction: 4 actions Create, Connect, Consumer, Compensate	Tinder, YouTube, Instagram, WhatsApp, Spotify (B2C) Salesforce (B2B),
Platform Scale (Choudary, Parker, & Van Alystne, n.d.)	Core Interaction incl: Creation, Curation, Customization, Consumption	Medium, Uber, 99designs, crowdfunding platforms, Etsy, PayPal, Reddit (B2C) Salesforce (B2B)
(Täuscher & Laudien, 2017).	Connect, direct interactions, commercial transaction. Institutional and regulatory frame for transactions.	

User research techniques appendix

For specific user interface design, different techniques are used. Much more information could be found on the internet or relevant books. This part briefly touch upon these.

Thematic analysis

Here, we will focus on one a standard method for analyzing semi-structured interviews: a thematic analysis. The thematic analysis enables to identify patterns of themes in the data and is useful in explorative studies. Virginia Braun & Victoria Clark “Using thematic analysis in psychology”. (Braun & Clarke, 2006). A common pitfall is confirmation biases. Also, it is hard to know how to start and when to stop.

Semi-structured interview

Interviews are a great way to empathize with users because interviews can give an in-depth understanding of the users’ perceptions, values, and experiences**.** When conducting semi-structured interviews, an interview guide with the questions or themes to talk to the user about, but the flexibility to explore different topics that may arise during the interview or to change the order of items. The advantage of semi-structured interviews is that it can define a predetermined set of relevant issues *before* conducting the interview but exploring topics that had not previously thought relevant. This makes the method suitable for creating insights into design project.

User archetypes & detailed persona's

The Client

A client is rarely a single person. There are likely to be several groups and individuals with an interest in, or control over, the project. What makes a client organisation different is that there are many specifiers all with different functions. Within the client organisation, there are also a few influencers. These specifiers and influencers will have varying construction-related interests and expertise. A difference should be made between the private and public sector

Private Sector

- Main Board of Directors –responsible for the success of the project
- Project Board -the project board sits below the mainboard but usually is chaired by the main board director. It is responsible for monitoring project progress and decision making within any financial parameters set by the mainboard.
- Project Manager -responsible for the day-to-day management of a project. Sometimes known as Project Director, Client Manager, Promoter's Manager

Public Sector

- Investment Decision Maker –An individual within the client organisation that decides about the investment in the project and then oversees senior management
- Senior owner -Has ownership of the project at a senior level (equivalent to the board director responsible for private projects). They are responsible for the success of the project that it meets objectives and delivers the projected benefits.
- Project Sponsor -The project sponsor might be equivalent to a board director in the private sector. They are the interface between the Client Team and the Supply Chain, via the project manager, acting as the day-to-day client representative.

The public sector differs from the private sector with greater layers of decision making.

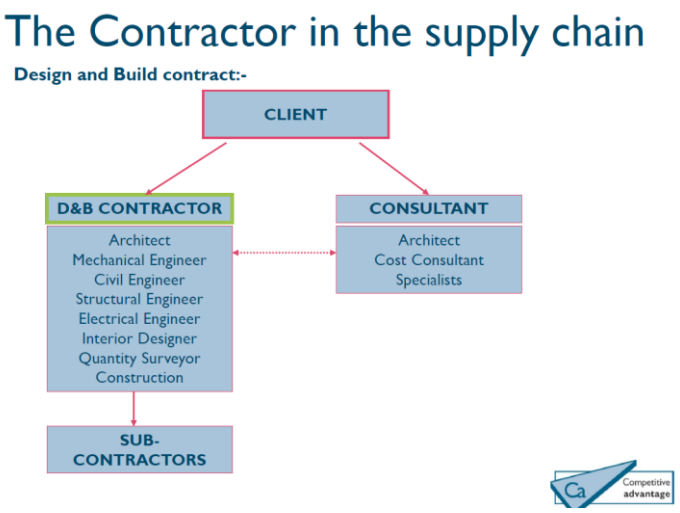


Figure 1: The client and her relation with contractors & consultants

Did not look further into project developers and their regulations. However, part of the key could be there. As they could be key in demand, while the one project developer that is interviewed pointed towards the supplier for support in these demand questions. He did not mention when or how the demand for reuse will/could be increased. His main reason is marketing purposes.

According to BAMB the role of the client to enable the circular economy in the building sector (Elma Durmisevic & Beurskens, 2017). “The client has a key role in overcoming a number of the challenges for adoption at a project level including providing enabling conditions for collaboration and innovation across the supply chain and the sharing of data. One of the most important CSFs identified by others in the supply chain is the need for greater clarity of the client’s vision and strategy with long-term thinking; however, there is a disconnect here, with the client not recognizing this as a major factor. To enable the client to have a pivotal role, support is needed from the rest of the supply chain such as the provision of new business models, evidence of the benefits of circular economy applications, technological innovation and provision of performance information and assurance.”
Related to government both as client and regulator. Construction for long life is what invites the long-term tampering it takes for a building to reach an adapted state.” The lack of economic incentive suggests a role for government, using building codes, tax credits, and even direct sponsorship to get buildings that will serve the community for generations. To encourage reuse, policymakers should first ensure that existing legislation does not present disincentives.(Cooper & Gutowski, 2017) For example, Power (2008) notes that the UK charges a value-added tax on refurbishments, but not new-build construction projects. The government could stimulate demand and effective supply of reused products by mandating some reuse in their purchasing and construction decisions. In academia, further research is needed to understand how reuse could maximize the displacement of new products.

Architect

Architectural firms with fewer than 5 people usually have no formal organisational structure. Medium-sized firms with 4 to 50 employees are often organised in departments such as production, design, business development, and administration. Larger firms of over 50 people may be organised departmentally, regionally, or in studios specialising in project types. Said is that 60% of architectural practices do not have a business plan and only 16% plan beyond 12 months.

Decision-makers:

A Project Architect is the individual who is responsible for overseeing the architectural aspects of the development of the design, production of the construction documents ("plans") and specifications. ... Additionally, the Project Architect may take on the responsibility for managing the project. On larger projects, or in large offices, a separate project manager may be assigned to assist in the non-technical or accounting tasks related to the delivery of the work. Principal Architects are licensed, experienced design professionals who hold senior management positions at architecture firms, such as Practice Partner or Director. Principal Architects lead all design work at an architecture firm and maybe founders of a firm. They may utilise Architect Interns and Drafters to research building codes, make schematic calculations, and draft technical materials. Typically, the Principal delegates day-to-day contact with Clients to a Project Manager, who may be another Architect or a Drafter.

Influencer:

Architectural Technicians are structural designers that work with Engineers and general Architects to create construction blueprints. Architectural Technicians advise in the application of technology in architecture. They are an integral supporting part of the design team specialising in the research of processes, products, legislation and technology as well as detailing, designs and drawings.

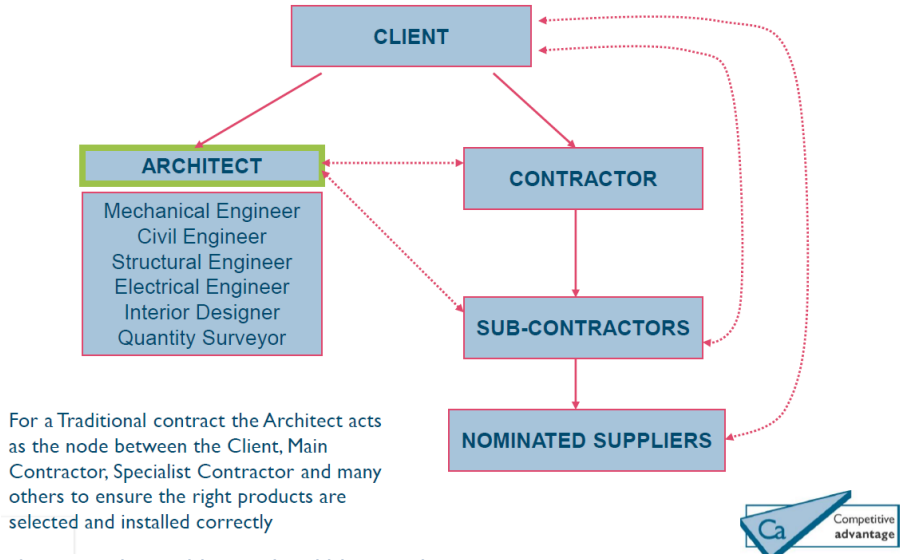


Figure 3: The architect role within a project

To get an idea of the complexity of all the different persona's only within the persona Architect, different roles are included, such as:

Architect	Interior Designer	CDM Coordinator	Practice Manager
Architect Director	Landscape Architect	Design Manager	Project Administrator
Architectural Assistant	Lighting Director	Divisional Director	Project Architect
Architectural Technician	Marketing Manager	Electrical Engineer	Quantity Surveyor
Architectural Technologist	Mechanical Engineer	Facilities Manager	Surveyor
Associate Architect	Office Manager	Group Director	Sustainability Consultant
Associate Director	Planner/Project Manager	Head Architect	Technician
Associate Partner	Planning Director	Urban Designer	Town Planner

Contractor

Within the Main Contractor, there are several roles with influence over product specification. The estimating group want to know about the compatibility and availability of products. The Contract Manager will be interested in Sub-Contractor familiarity and minimising disruption to the building programme. The Design Manager will be involved in the most efficient solution to provide a first-class outcome. The Buyer's task is driving down the cost of purchase by as much as possible.
The project manager manages all the processes on a building or construction site. This can be a highly satisfying but challenging role as a crucial part in the success of a building project. They are highly motivated, professional individuals and are asked to use organisational and problem-solving skills daily." Specialist Sub-Contractors are close to the main contractor and are influencers. Tender proposals may include specialist components that are designed in detail by their manufacturers or installers. Such items could include; escalators, lifts, cladding systems, switchgear, refrigeration units, heating ventilation and air conditioning systems(HVAC). In such cases, it is desirable to secure this specialist design before the supply contract has been tendered so that they can be integrated into the overall design without occurring delays.

Interviewees mention that a contractor does not want to take unnecessary risks and is not responsible for delivering supplies. Recent interviews have done similar kind of research and do confirm this. "In reuse context, the contractor lacks knowledge of needs beyond their current project and is not motivated or equipped to make a robust assessment of component usefulness. The use of reused material marketplaces to test demand and sell reclaimed components is not an established practice. Those interviewees that were aware of their existence reported finding them inconvenient (time-consuming with low expectation of sales) or untrustworthy (typically selling to unknown individuals rather than to businesses). Interviewees could not imagine their own company using reused material marketplaces to purchase materials, due to non-compliance with client specifications, concerns over quality, and concerns over quantities available.

Given that they do not perceive significant building consumers materials like themselves as potential customers, their scepticism about posting items to reused material marketplaces is logical. To do so is considered a positive, community-minded action, but not a viable alternative to conventional waste management." (Rose & Stegemann, 2018)

Different roles within the persona contractor:

Asset Manager	Contracts Manager	Facilities Manager	Operations Manager
Bid Manager	Cost Manager	Framework Manager	Planning Officer
Building Manager	Site Manager	Head of Estates	Pre-Construction Mngr
Buying Manager	Design & Build Manager	Health and Safety Manager	Procurement Manager
CDM Coordinator	Design Manager	Land and Planning Manager	Project Manager
Civil Engineer	Energy Assessor	Landscape Architect	Quantity Surveyor
Client Liaison Officer	Engineering Manager	Major Projects Manager	Site Manager
Construction Manager	Estimating Manager	Mechanical Engineer	Supply Chain Manager

Engineer

The civil engineer will start to be involved in the concept design and continue that involvement till construction. For infrastructure projects, the civil engineer is the principal design role. Leading consultancies in this sector include Mott MacDonald, Aecom, Arup, WSP and Arcadis. In general, the Engineer will write a performance specification. But where there are challenging problems, they may well nominate a product, and when this happens, it is likely to stay firm. Very often they will sign-off the sub-contractors installation, carrying the responsibility for any failure and thus making them vigilant about product selections. To get your product nominated, you need to demonstrate the importance and significance of your product by providing lots of facts
Influences on the engineer are;

A Project Architect is the individual who is responsible for overseeing the architectural aspects of the development of the design, production of the construction documents ("plans") and specifications. ... Additionally, the Project Architect may take on the responsibility for managing the project.
M&E Engineer as they install, design and maintain the services in new and existing buildings. These services cover areas such as heating, heating, air-conditioning, energy supply, security systems etc. In summary, they are responsible for the engineering of the internal environment of the building, with an ever-increasing emphasis on carbon reduction. To get an idea the complexity of all the different persona's only within the persona Engineer different roles are included, such as:

Access Consultant
Acoustic Engineer
Electrical Engineer
Assistant Engineer
BIM Manager
Building Services Manager
Building Surveyor
CAD Technician
Chief Engineer
Civil Engineer
Environmental Engineer
Fire Engineer
Flood Risk Manager
Highways Engineer
Infrastructure Engineer
Landscape Architect
Mechanical & Electrical Engineer
Precast Manager
Procurement Officer
Quantity Surveyor
Energy Assessor
Services Engineer
Site Manager
Structural Engineer
Sustainability Engineer
Technical Manager
Transport Engineer
Facilities Manager
Conservation Engineer
Contracts Manager
Design Engineer

Other works of literature discuss the role of the structural engineer and the environment as well. Such as "The role of the structural engineer in green building" (Anderson, 2009) and Sustainability Guidelines for the structural engineer (Kestner, 2010). Anderson & Silman and Webster identify how the structural engineer may work with an integrated design team of architects, engineers, builders and owners to make the structure sustainable.

Interfaces of current marketplaces that offer construction products

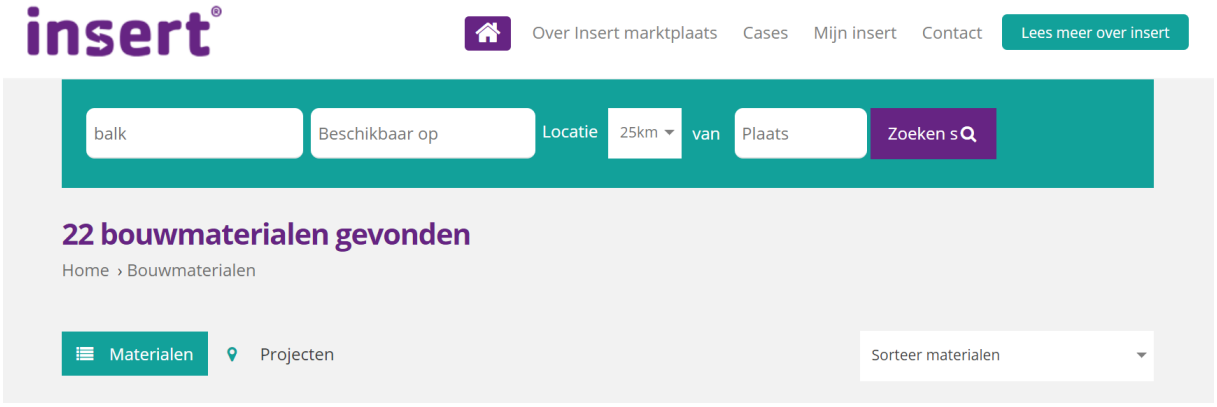


Figure 4: Insert marketplace and a simple search bar with a maximum locations setting

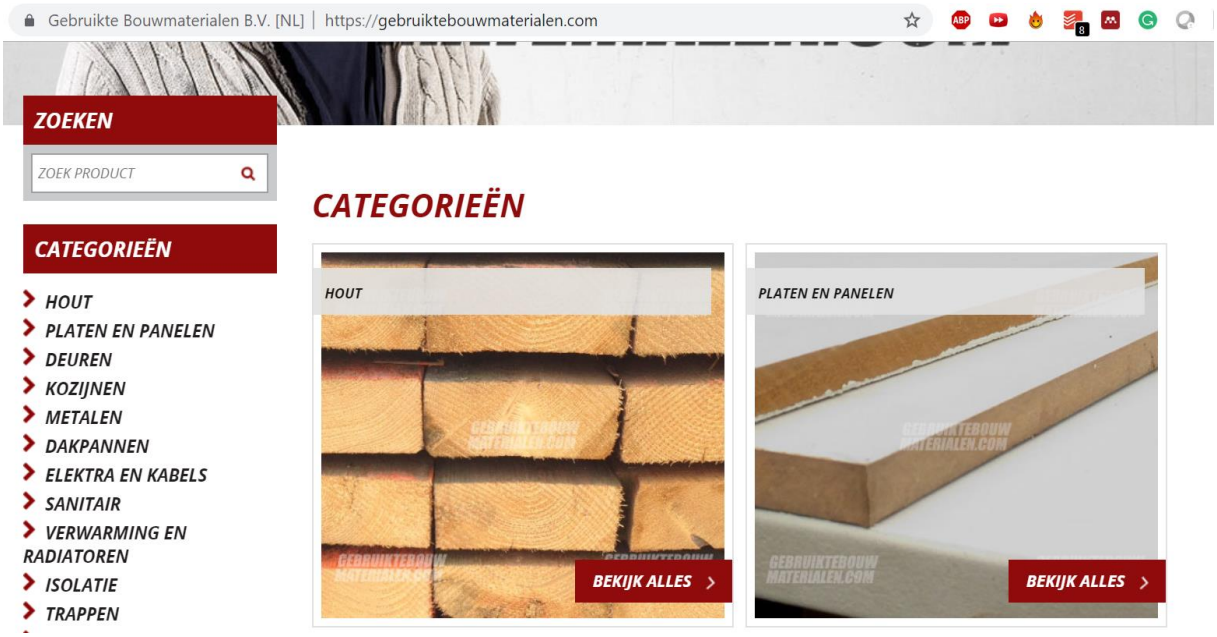


Figure 5: Gebruikte bouwmaterialen.com landingpage including facet groups on the left

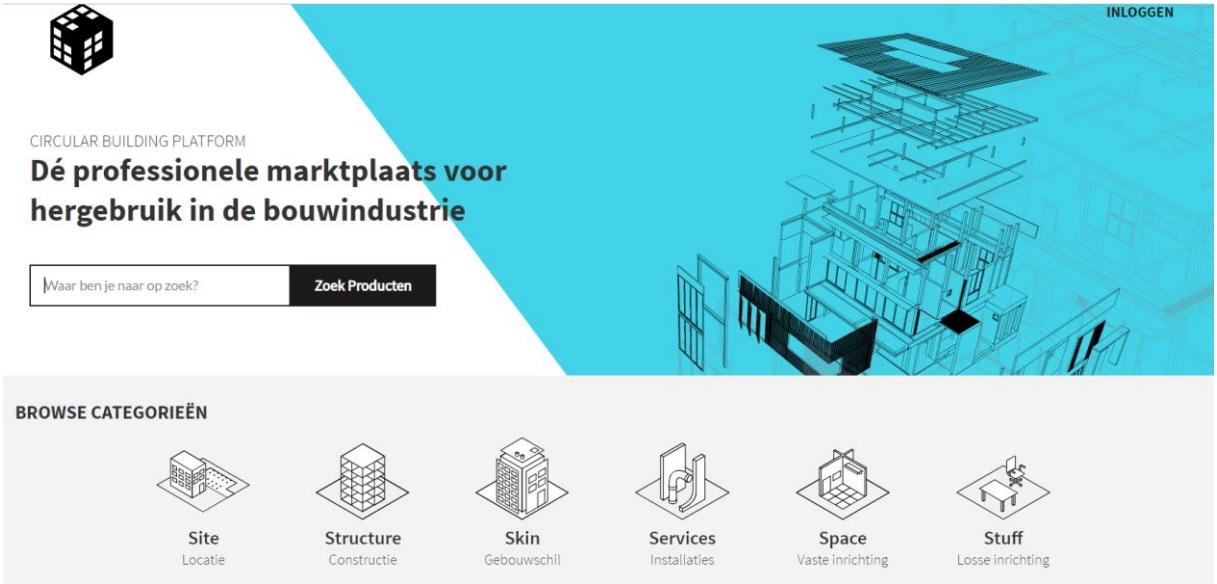


Figure 6: Development of reusable product marketplace (CBP) based on brand layers

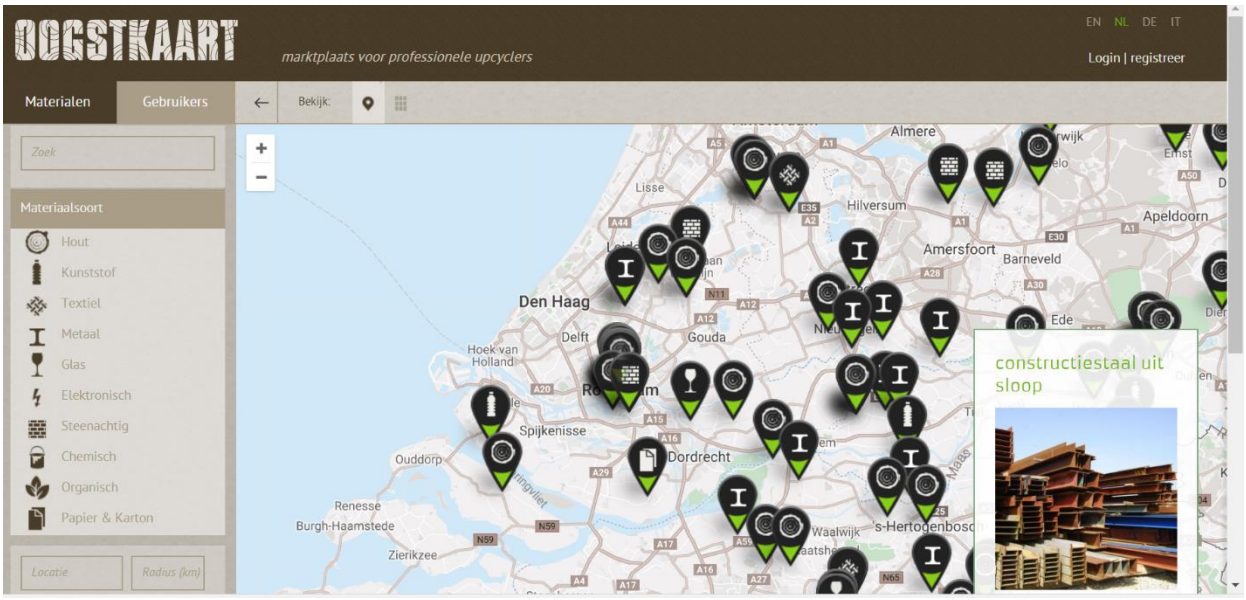


Figure 7: Oogstkaart includes a facetgroup based on material type

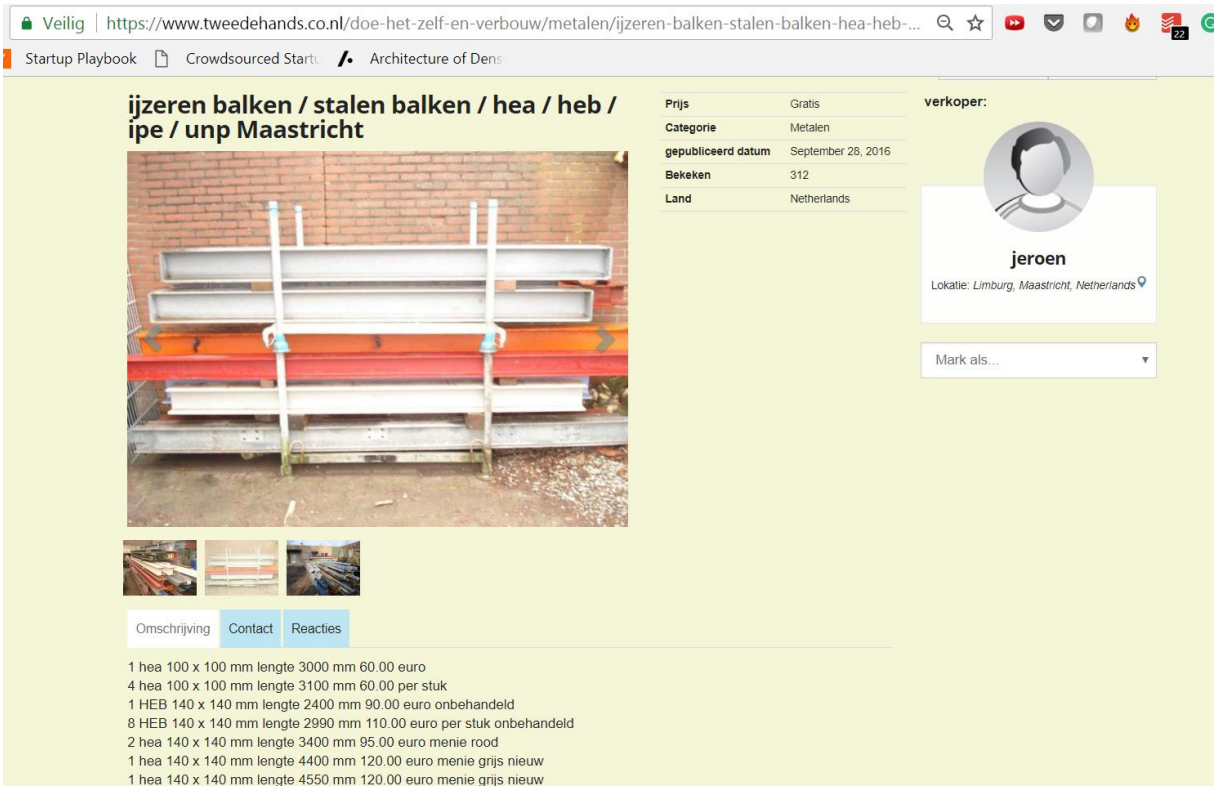


Figure 8: One of the many other marketplaces that offer construction products without any specific category or facet filter

Figure 9: Another marketplaces article that offer construction products without any specific category or facet filter

IFC

The industry foundation class (IFC) is a standard for data exchange between different software used in the AEC industry. To get a better understanding of IFC and her use in reusing materials research is done. This chapter set-out the IFC challenges, opportunities and other (IFC) developments. Thereby is considered how the parameters for reuse could be stored in an IFC kind of data format. For the common things about IFC the websites bimloket.nl, ifcwiki.org and buildingsmart.org[10] provide enough information.
To get a better idea of the value of IFC for reusing products purposes, the social and technical parts are taken into account.

IFC challenges

The most critical obstacles to overcome to come to full use of vendor-independent, interoperable building information models, is the reduction of the complexity and size of the current IFCs. Not only has the extent of its existing versions (2x3(g)/2x4) reached a level of sophistication that requires the devotion of a considerable amount of time before any interfacing of custom of the shelf-solutions can be done, but also the prospective future extension for domains like bridges and roads and the growing number of standardised and non-standardized extensions using the property set mechanism will further increase the demand for partial model handling in future. While importing an IFC instance, data can get lost because of an invalid IFC implementation in the software (Amor, Jiang, & Chen, n.d.). Pure architectural features such as windows, doors, railings and opening caused drastic changes in the IFC object configuration(Nizam & Zhang, 2016).

IFC data loss

The research BIM modelling for structural analysis (Fleming, 2016), shows that most exchange scenarios do perform well related to section and material properties, but not for boundary conditions Which is nowadays for reuse purposes probably enough.

Similar research is done to geometrical interoperability within different software packages in 2012 and 2017. Between 2012 (first test), and 2017 the IFC standard itself had evolved. In 2012, the then-current IFC2x3 specification had support for various kinds of solid geometry, and these definitions have been improved and enhanced in the IFC2x4 standard. (Benghi, …, & 2018, n.d.)

[10] http://www.buildingsmart-tech.org/specifications/ifc-overview

IFC opportunity

Research (Van Berlo, Beetz, Bos, Hendriks, & Van Tongeren, 2015) has come up with some tentative conclusions. It seems valid to conclude that IFC works in daily practice in the Netherlands related to experienced users. Users unanimously agree that there are many myths about general BIM and IFC in specific. While there is no data loss because there is no round-tripping with IFC (not even a wish for that), and IFC can be exported in a proper way when users know what they are doing. Inexperienced users still seem to stick to the myth that there are problems with all the above statements. These negative rumours make it difficult for advanced users to cooperate with inexperienced users. New users first need to be talked out of disbelieving before the actual education can begin.

IFC technical

The following parameters seem to be of value after the application interviews (phase 1); conditions, connection, grid size, price and functional parameters related to the specific Brandy layers. See the solution below wich IFC properties could be used. Note that colour information and pictures are not an option. However, there are ways to export colours as well, but this won't be treated in this thesis.

Table 6: IFCparameters that could be needed for reuse 'data'

Needed parameter	**IFC solution**
Ownership	IfcOwnerHistory
Connections	IfcRelConnects IfcRelDecomposes
Parameters	IfcSIUnit
Grid size	IfcGridAxis
Business	IfcMonetaryUnit
Condition	IfcRelAssociates
Documentation	IfcRelAssociates
Moment-of-inertia / structural info	Library IfcStructuralProfilePropertie
Colour	Not an option
Pictures	Not an option

IFC and physical properties

If it is not possible to connect the IFC file with the software standard libraries, there is a way to save the moment of inertia in the IFC files. The material properties are specified in ifcMechnicalSteelMaterialProperties and associated with a material name in ifcMaterial (figure XX) . The material is linked through ifcRelAssociatesMaterial[11]. In IFC the section profile properties are IfcStructuralProfileProperties[12] (Lipman, 2009)

IFC and reuse

Mcginley connects a marketplace interface (eBay) with IFC (Mcginley, 2015). Ultimately these tools should link to a digital design environment such as REVIT that can arrange the search results into a 'super' component containing individual eBay items that could form a wall, slab or roof item in a CAD program using the IFC schema. This should also be able to identify material clashes and propose the necessary joints and cuts.

[11] http://www.buildingsmart-tech.org/ifc/IFC4/final/html/schema/ifcmaterialresource/lexical/ifcmaterial.htm
[12] http://www.buildingsmart-tech.org/ifc/IFC2x3/TC1/html/ifcprofilepropertyresource/lexical/ifcstructuralprofileproperties.htm

IFC and e-procurement

IFC nowadays is mostly used in the design phase. The next step is using it for procurement as well. The paper “Challenging electronic procurement in the AEC sector: A BIM perspective” (Grilo & Jardim-Goncalves, 2011) describes possibilities for IFC and e-procurement. Still, e-procurement falls short of reaching the tipping point in the AEC sector, and one of the main reasons lies in the inability to deal with the unstructured procurement.Quantities for tendering are easy to obtain, directly from the BIM model, but how to organise the elements to be tendered is ar ather complex issue, and the existing models do not reflect this need.

IFC and connections

Topology and connections are critical aspects of a BIM tool that specify what kinds of relations can be defined in rules. They are also important as design objects and often require specification or detailing. In architectural BIM tools, connections are seldom defined as explicit elements. In fabrication-level BIM tools, they are always defined as explicit elements. (Eastman, Teicholz, Sacks, & Lee, 2018). The need for knowledge about connections for reuse purposes will be discussed the validation phase.

Other IFC(OWL) developments

Other developments are related to dictionaries, libraries, open standards, taxonomy and ontology. Some examples are BCF, mvdXML, Bimsie, BimQL, bsDD, CB-NL, xBIM toolkit and ifcOpenshell. IfcOpenshell is taking a library approach, making it easier for computer programmers to access building model data by providing a higher level of abstraction when creating programs that work with building models. IFCopenshell is researched less, but the potential for data analysis and reuse potential is there.

Data dictionaries

Another topic that should be treated is the upcoming of different data dictionaries such as the buildingsmart Data Dictionary and the Dutch version CBNL. A concept library which tries to overcome the language barriers in the built environment and connects RAW, STABU, NEN, IMGeo, ETIM, Rioned etc. According to a BIM Expert concept libraries are overkill because projects are always local. However, classification is important.

“We have no problem that can be solved with CBNL/BSDD (that cannot be solved with just IFC) “ – Leon van Bérlo

ifcOWL more simplified?

After the rigour interview with a BIM expert, he advised using IFCowl for reuse purposes. As this is much less complicated then IFC itself. Diverse suggestions in academic research to make IFC available as an OWL ontology confirm this statement.(Beetz, van Leeuwen, & de Vries, 2009) (Schevers & Drogemuller, 2005). Within ifcOWL, there is a need for formalisation and standardisation bodies such as W3C and BuildingSMART need to play a role in here. Through an ontological analysis of IFC, the ifcOWL ontology might be greatly simplified, and it might become more natural to use the IFC information.

IfcOWL,reuse

Literature specific related to reuse purposes and ifcOWL is not found. Some disadvantages are discussed in the literature (Rasmussen et al., 2017). However, since IFC is not initially designed for being used on the web, the structure, size and complexity of ifcOWL make it hard to use and extend in practice. For that reason, post-processing of ifcOWL called SimpleBIM is suggested, which omitted all geometry and inter-mediate relation instances between objects (Pauwels & Roxin, 2016). The latest release of SimpleBIM also allows colour information. [13]

[13] https://simplebim.com/whats-new-in-simplebim-8-0/

IFC and model view definition

Model view definition (MVD) defines a subset of the IFC schema. Therefore is satisfies many exchange requirement of the AEC industry. Besides, so far there is no publication defining MVD for audits of existing buildings (e.g. with respect to structural and inventory survey), MVD for deconstruction, recycling or rubble management processes and functionalities in BIM yet (Volk et al., 2014). The MVD approach provides the receiving application and receiving project parties with more control over BIM data exchange (Afsari, Eastman, & Shelden, 2017).

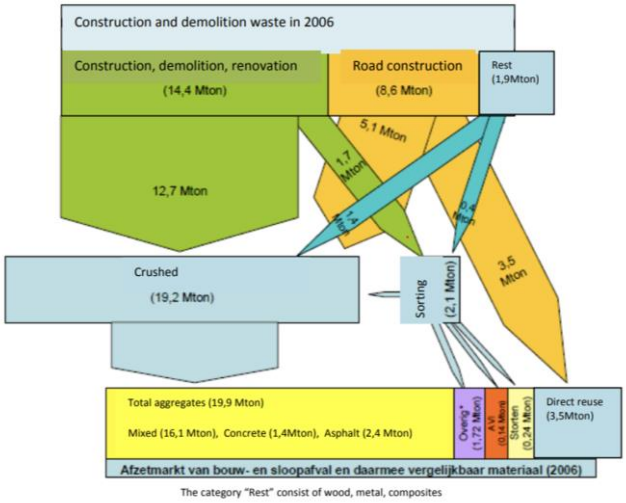
Barriers for deconstruction

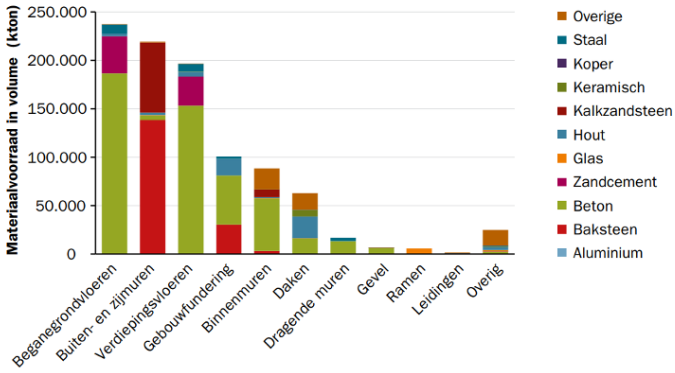
Table 7: barriers for deconstruction (Tingley, 2011)

Barriers to design for deconstruction and material reuse	A&S	D,L,D	G&C	G&S	JH	M&S	S&P	DM
Perceived risk in specifying reused materials	■				■	■	■	
Lack of legislation requiring consideration of DfD or reused materials	■			■				
Perception of second-hand materials, generally people prefer new	■						■	
Additional design costs	■							
Insurance constraints – can be unfavourable to use reclaimed materials	■							
Design codes of practice generally encourage specification of new materials	■							
Financial constraints – DfD likely to more expensive	■		■		■		■	
Composite construction	■		■		■		■	
Designing for robustness – can reduce ease of DfD	■							
Performance guarantees for reused materials	■						■	
Lack of reused materials market		■		■	■		■	
Ensure materials are salvaged in a safe manner		■		■	■			
Time constraints – deconstruction can take longer		■		■	■		■	
For existing structures, the type of jointing used, & inaccessible joints			■	■	■		■	
For concrete structures, reinforcement corrosion will not be visible – tests needed					■			
Visible aesthetic degradation of reused materials					■			
Contamination of materials (eg. From fire protection)					■			■
Site/storage for recovered materials				■			■	
For existing structures, lack of information about materials & techniques used							■	■
Loss of craft skills to create exposed connections that are aesthetically pleasing too			■					
Perception that DfD systems will compromise value, aesthetics, & safety			■					
For steel, coatings could contain banned chemicals								■
Coatings on steel can contaminate the shot used to remove the coating								■
Additional fabrication may be required on steel sections								■

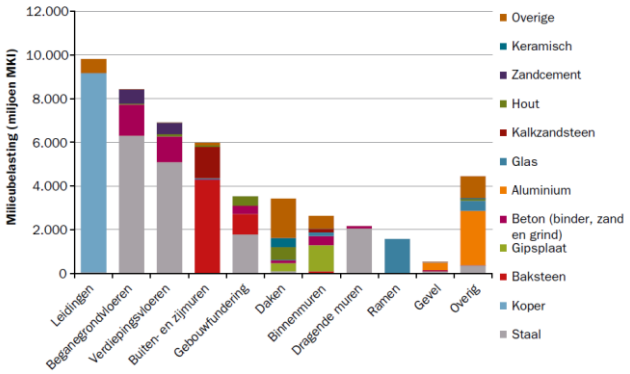
Figure 1. Summary of strategies for design for deconstruction (DfD) (A&S = Addis and Schouten, 2004; C&B = Chini and Balachandram, 2002; G&C = Guy and Ciarimboli, unknown date; M&S = Morgan and Stevenson (SEDA guide), 2005; PC = Crowther, 2001; W&C = Webster and Costello, 2005)

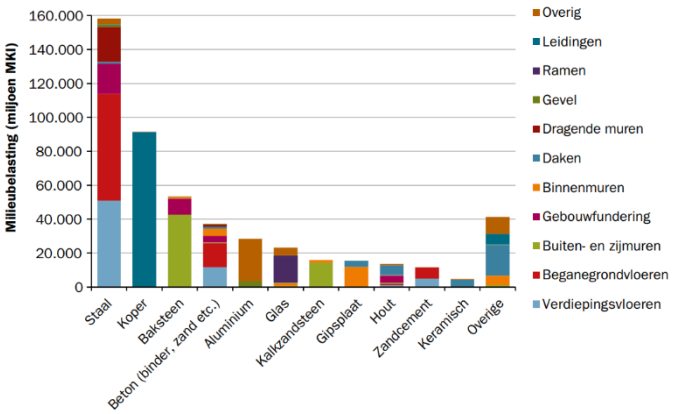
Material volumes in the Netherlands





Products in the Netherlands





Figures from 'Rapport vervolgonderzoek Materialen in de Nederlandse economie' (TNO, 2015)

Chapter 3 (Methodology) appendix

Interview form – Objective 1, Application domain –

Introduction: “The research is about discovering opportunities in the circular design process and developing an innovative digital solution. We won’t go to deep in the end goal of this research as in this part is important to get a clear and clean understanding of the current processes in designing and constructing circular buildings.”

Name	
Function	
Company	
Age	
Knowledge about CE	1-10
Projects or Research conducted in CE	

Part 1 – Problems and Opportunities

Wat is uw ervaring binnen de circulaire economie? En duurzaamheid	
Wat voor projecten heeft u gedaan? *Wanneer voorkennis vraag dan door.*	
Wat was u rol? En hoe ging het in zijn werk?	
Wat vond u het meest lastig aan dergelijke projecten	
Hoe ging u opzoek naar materialen? Wat voor informatie is relevant? **En in welke project fase hebben jullie dit gedaan?**	
Waar ging het meeste tijd in zitten?	
Wat zorgde eventueel voor vertraging	
Doorvragen	
Nut van een marktplaats?	

Part 1 – Persona Specific

Wat maakt een product interessant voor architectuur of constructie op circulair? Technisch Estetisch Marketing?	
Verschil Lease, of aanbieden in de markt Technische en economische levensduur? Grootste bottlenecks?	
Verschil met constructie of andere bouwlagen? Skin, Service, Space & Stuff	
Hoe reageert de markt? En andere rollen?	
Wat zijn andere rollen die meewerken en tegenwerken? Wie is verantwoordelijk voor de product keuze? (champion)	
Met wat voor ideeën komt de gebruiker zelf?	

Part 2 – Virtual Storage & Marketplace
Explanation Virtual Storage and graduation Topic

Hoe kijkt u aan tegen een dergelijke marktplaats	
Wat voor kansen ziet u? Hoeveel tijd bespaart u?	
Wat voor hindernissen ziet u?	
Wat is voor u de meest essentiële data / informatie die beschikbaar moet zijn? Gerelateerd aan de persona.	
Waar gebruikt u deze informatie voor? Waarom? Waarom?	
Ruimte voor extra vragen.	

Part 2.1 – Prototype and evaluating

Reactie prototype	
Wat is goed?	
Wat werkt niet?	
Wat zijn verbeteringen?	
Minimale functie?	
Extra opmerkingen.	

Part 2.3 – Zoek gedrag / stel dat overheid dit verplicht. Hoe ga je zoeken?

Hoe zou je beginnen?	
Volume of meters?	
Staal of beton termen?	
Plaatjes?	
Wat doe je met de informatie?	

Part 3 – Extra Questions & contacts

Welke contacten zou ik nog moeten spreken?	
Welke literatuur is relevant (foundation)?	
Welke boeken zijn interessant?	

Part 4 – Observing (self)

Eerste reactie	
In hoeverre is het onderzoek neutraal	
Wat kon er beter in het interview?	
Wat ging goed?	
Vervolg interview?	
Vervolg acties.	

Interview form – Objective 1 Foundation domain

Interview form – Objective 1, Foundation –
Introduction: “The research is about discovering opportunities in the circular design process and coming up with an innovative digital solution. We won’t go to deep in the end goal of this research as in this part is important to get a clear and clean understanding of the current processes in designing and constructing circular buildings.”
Experience & Expertise interview

Name	
Function	
Age	
Knowledge about CE	1-10
Projects or Research conducted in CE	

Part 1 –

Wat is uw ervaring binnen de circulaire economie?	
Wat voor projecten heeft u gedaan?	
Wat was u rol? En hoe ging het in zijn werk?	
Wat vond u het meest lastig aan dergelijke projecten	
Hoe ging u opzoek naar materialen? Wat voor informatie is relevant?	
Waar ging het meeste tijd in zitten?	
Wat zorgde eventueel voor vertraging	
Doorvragen	
Nut van een marktplaats?	

Part 2 – Virtual Storage & Marketplace
Explanation Virtual Storage and graduation Topic

Hoe kijkt u aan tegen een dergelijke marktplaats	
Wat voor kansen ziet u? Hoeveel tijd bespaart u?	
Wat voor hindernissen ziet u?	
Wat is voor u de meest essentiële data / informatie die beschikbaar moet zijn?	
Waar gebruikt u deze informatie voor? Waarom, Waarom	
Doorvragen	

Part 2.1 – Prototype and evaluating

Reactie prototype	
Goed?	
Slecht	
Verbeteringen	
Minimale functie?	

Part 2.3 – Zoek gedrag / stel dat overheid dit verplicht. Hoe ga je zoeken?

Hoe zou je beginnen?	
Volume of meters?	
Staal of beton termen?	
Plaatjes?	
Hoe verwerk je de informatie daarna?	

Part 3 – Extra Questions & contacts

Welke contacten zou ik nog moeten spreken?	
Welke boeken zijn interessant?	

Part 4 – Observing (self)

Eerste reactie	
In hoeverre is het onderzoek neutraal	
Wat kon er beter in het interview?	
Wat ging goed?	
Vervolg interview?	
Vervolg acties.	

Validation phase – Interview form

In fase 1 van het onderzoek hebben we obstakels geïdentificeerd voor een circulaire marktplaats. Alle aanbod gerelateerde obstakels zijn buiten scope. De focus ligt op het valideren van de zoekfunctie voor de vraag van structural engineers om zo hun ontwerp te laten afstemmen met het potentiele aanbod van herbruikbare materialen in de markt. Omdat dit nog toekomst muziek (weinig data beschikbaar van herbruikbare materialen) is zijn er 2 scenario's die gevalideerd worden. Ten eerste het zoeken naar donor gebouwen en de tweede het daadwerkelijk zoeken van constructieve elementen. Voor het zoeken naar gebouwen is het belangrijk om input parameters te valideren en vervolgens de gelaagdheid van de output.

De constructieve elementen zoek functie gaan de input parameters over belastingen en overspanningen. Om een "slimme" zoekfunctie te ontwikkelen moet er worden gevalideerd op welke veiligheidsberekeningen producten kunnen worden gefilterd in het voor ontwerp. Daarnaast wordt er gekeken welke additionele informatie van belang is. De gelaagdheid wordt gezocht in verbindingen en de drie type materiaal (hout, beton en staal).

Intro onderzoek (richting gebruiker/te interviewen person):

- Core interactie marktplaats
    - Champions (focus: structural engineer)
- Overzicht supply & demand
    - Buiten scope: focus op zoekfunctie en aansluiten aanbod bij vraag
- Validatie zoekfunctie (gebouwen & producten)
    - Gelaagdheid van informatie
    - Gebouwen zoekfunctie ivm project matigheid en dient als tussen oplossing
    - Focus ligt op "constructieve" elementen

(Donor) Gebouwen functie:

Intro:

- Niet genoeg "herbruikbare" producten en data niet aanwezig
- Potentie van gebouwen in kaart brengen met zo min mogelijk data
    - Foto's, meters, bouwjaar etc.
- Vanuit minimale informatie mogelijkheden bekijken voor het verrijken van data
    - D.m.v. scannen, materiaal testen,

Question 1:
Ligt de rol van een donor gebouw zoeken bij de structural engineer? Waarom wel of niet?
Zou dit al in het VO kunnen worden meegenomen? Waarop heb je als constructeur invloed? Hoe zit dat voor de verschillende brand layers (Constructie, gevel & afbouw)?

Question 2:
Wat als dit wel zo is. Hoe zou je op gebouwen gaan zoeken?
Schets situatie waarin er noodzaak is om gebouwen her te gebruiken, en dat er tools beschikbaar zijn.

Question 3:
Wat wil je vervolgens zien en/of weten? Op welke manier en met welke belasting etc.

Question 3: (laat ontwerp marktplaats interface zien)
Is dit een mogelijk ontwerp? Voldoet dit aan de eerste eisen die we zojuist besproken hebben.
Bespreek grid size, materiaal draagconstructie, verdiepingen, vierkante meters (opp. en gevel).
is het noodzakelijk?

Question 4: Gelaagdheid
Zijn de volgende vragen dekkend voor jou als structural engineer voor het bepalen van de herbruikbaarheid van constructies? Zie lijstje met deconstructie vragen gebouw. Gerelateerd aan connecties(type, toegankelijkheid, demontage techniek, herbruikbaarheid), modules, manier van deconstructie, parallel deconstrueren, methode identificeren materiaal)

Question 5: Relatie gebouwen en IFC – IFCowl

Zoekfunctie (constructieve) elementen

Intro

- Randzaken, betrouwbaarheid producten, technische mogelijkheid en kosten zijn buiten de scope.
- Focus ligt op het zoeken naar potentieel aanbod om zo in VO al ontwerp keuzes te maken

Question 1: (*laat afbeelding zien)*
Hoe kijk je aan tegen een marktplaats die draagsystemen en of draag elementen voorstelt voor jou “probleem”?

Question 2:
Is de structural engineer de gene die de marktplaats gebruikt? Waarom wel of niet?

Question 3:
Werken de Brand layers en is het logisch dat dit al in het VO gebeurt?
Of liever op NL-FsB of Stabu codering? Denk aan de toekomst om direct IFC files te koppelen.
Question 3b:
Hoe ben je gerelateerd aan andere product keuzes. Zoals gevel & afbouw.

Question 4:
Wil je Tablelen (waardes) en of foto’s zien? Waarom werkt het 1 beter dan het andere? \

Intro: Slim zoeken. (laat afbeelding zien)
I.p.v. specifieke producten te zoeken is het mogelijk om een product te zoeken dat voldoet aan je ontwerp criteria (bijv. belasting i.c.m. overspanning). Zodat het “slim-zoeken” algoritme een oplossing geeft van een profiel i.c.m. een materiaal.

Question 5:
Door het slim zoeken algoritme zal je eerder producten betrekken bij de ontwerp-fase. Binnen wat voor range kan het systeem elementen aandragen?

Laat een architect zoeken. Zoek functie voor constructeur
Question 6: Wat als het wel werkt?
Wat zijn je input parameters? (belasting en overspanning). Kan je dit reduceren tot 1 of 2? *zie slide voor meer informatie. Verdiepingshoogte, wind area, max belasting, type gebouw, zie VBI vloer ontwerptool.*

Question 7
Op welke waardes controleer of een element voldoet binnen het VO.
Kan dat voorlopig op sterkte en stijfheid of dient stabiliteit ook meegenomen te worden? *Voorbeeld alleen knik*

Question 8:
Voldoen normaal kracht, moment en doorbuiging?
zie slide wat buiten scope is. Let op, bekijk eerst alleen nog generiek, dus niet materiaal specifiek.
Welke informatie over de producten is nodig?
Wyy, E-modules, sigma trek en druk, eigen gewicht, lengte en aantal

Question 9:
Wat kunnen we buiten beschouwing laten?
zie slide: kip, knik, wringing/ torsie, taaiheid etc.

Question 10:
Welke additionele informatie is nodig? Wat is echt noodzakelijk?
Zie slide: denk aan fabrikant, bouwjaar, beschikbaarheid, ken getallen vervoer en demonteren C02 besparing? Schaduwkosten

Question 10.b: kwaliteit
Zou je een idee hebben hoe we de kwaliteit moeten uitdrukken? (schaal 1 tot 5, of goed – herbruikbaar etc.) Of is dit niet nodig? “bijv. tussen-persoon biedt een garantie”

Question 11: Relatie met IFC – IFCowl en building data dictionary

Question 12:
Communicatie noodzakelijk? Of zou je direct een claim, koop kunnen vastleggen?

Question 13: Bouwmaterialen en gelaagdheid.
Bespreek hout, staal en beton. (denk aan connecties, wapening, zagen, vervoeren, kwaliteit en capiciteiten, degradatie, moisture, roest, chloride).
Per materiaal wat is als eerst het belangrijkst?

Question 14:
Hoe classificeer je connecties? Bijvoorbeeld aan de 8 klasses van durmisevic? Of kan je wat anders gebruiken, als het uberhaupt nodig is?

Chapter 4 (Results) appendix

Summary step 1

This overview is based on a thematic analysis of both phase 1 and 2. The three general themes defined are supply, demand, and the core-interaction. All have related challenges; only the core-interaction challenges will be treated in design phase 3 (step 2).
Rigour = literature

Table 8: all issues and concerns related to supply, demand and core interaction of matching reusable products.

		Phase 1 - application	**Phase 2 - rigor**	
Theme's	**By whom**	**Application Interviews - Challenges**		**Rigour Literature - Challenges**
Demand	Rigour	The link between passports and the marketplaces is missing. Supply exceeds demand in today's second-hand building material market.		All materials shared one obstacle; demand. (Hradil et al., 2014) & BAMB
Supply	Rigour person 1	There is a consensus in the academic literature that the scarcity of information about the existing building stock acts as a barrier to effective management of end-of-life components		(Ali, 2016, 2012; Debacker and Manshoven, 2016; Densley Tingley et al., 2017; Horvath, 2004; Hurley, 2003; Poelman, 2009).
Supply	Multiple	Timing and availability of products (guarantee).		No literature found for a solution
Supply	Architect	Till what level does a city has to be circular?		Stewart Brand on different kind of buildings
Demand	Project Developer Marketplaces	Critical mass for e-commerce (Albrecht et al., 2005) Will there be enough (qualitative) supply for specific reuse?		Quick scan circulaire bouwopgave (TNO, 2018) Metabolic research of different cities
Supply	Marketplace	(Virtual) Storage and disappointment		Alexandros Glias
Supply	Rigor person 1	(Rigid) Connections		Design for disassembly (E Durmisevic, 2006)
Supply – costs	Marketplace	Labour of uploading. Too much information related to products. (BAMB, product passport).		BIM for existing built environment BIM for facility management
Demand	Contractor Engineer	Unclear information of extra costs (Disassembly, transport & costs). No rules of thumb. Costs of deconstruction are too high		Superlocal project Kerkrade and BAMB research.
Demand -	Engineer Rigour 1	Regulation in the reuse of products Lack of decision making		BAMB research (Elma Durmisevic et al., 2017)
Supply	Architect, Engineer Contractor	Quality, safety and guarantee of re-used products		Lack of instruments for certification of reusable elements – BAMB research (Elma Durmisevic et al., 2017)
Core interaction	**Engineer Architect**	Time to find re-used products on websites. Unclear info (on current marketplaces)		B2B usability (in construction)
Core Interaction	**Champion**	A different need for information and search methods per persona Architect: aesthetic | Engineer: Functional | Contractor: Practical		No literature found related to champions for reuse products in construction.
Core interaction	**Rigour interview Architect / Contract**	A different need for (procurement) information is needed in different phases of the project, especially for reuse.		No literature found
Demand	Initiator / (client)	Which building, or which nice to start. Lack of market strategy		Stewart Brand building types & TNO quick scan (TNO, 2018)
Demand	Purchaser (*support group)*	Big projects focus on costs and time. Another dimension won't work. Project triangle (Quality vs costs. Time)		Triple constraint , Project triangle and People Planet Profit.
Supply & Demand	Initiator Client	Which product (layer)? Continuously change of products in the service layer. Cross-market fit for a certain layer		The long-life span of products ((Pries ∗ & Janszen, 1995) meaning low trialability (Rogers, 2010)

Core interaction	**Engineer Architect**	Different materials have different reusability challenges and environmental performance. How should a marketplace show this?		Webster, Tingley, Bill Addis
Core interaction	**Marketplace**	One language (e.g. IFC, STABU & products)		Interoperability of Data. (van Berlo, 2015)
Demand	Client	Tendering for the lowest price does not work for circular design. (price vs quality vs reuse/environment)		The business case for lowest price is tendering.[14] Cost-saving in short time (Issa et al., n.d.)
Core interaction - champion	Architect Engineer	Responsibility: an architect is no product trader Contractor right to choose own product with same requirements "Circular design is a quite new" Who takes responsibility?		User research: Who is the champion? Difficult to make journey map and have one clear "end-user."
Supply	Supplier	Role of a supplier in product ownership		*Out of scope*
Supply	Rigour	Cooperation of marketplaces is needed		Different systems by different organisations (e-marketplaces)
Core interaction	**Engineer Architect**	Different websites, different in usages. Therefore it takes more time to find products online.		Variety and heterogeneity of different e-commerce websites (Kong, 2003) & Research bouwmarktplaats (Slager, 2018)
Demand	Contractor Project Manager	different procurement mechanism		Lack of standardization of procurement processes Long & Customized relationships per client
Demand	Contractors	Different stakeholders and interest and therefore hard to design one marketplace.		Fragmented market (Sanders et al., 2001) & (Luening 2000)
Supply	Demolition Suppliers	Different stakeholders and interest in the system for reuse. Demolition is focused on time and costs		Fragmented market (Sanders et al., 2001) & (Luening 2000)
Supply & Demand	Rigour literature	Slow adoption of IT Different marketplaces with low usability		Slow adoption of IT and bad usability with B2B marketplaces.
Both	Marketplace	The physical location of reuse marketplaces		Environmental benefit for transport costs.
Demand	Engineers	Time constraints (for searching products)		In all phases of the project, there is not enough time to look for new ideas and implement them. (Girmscheid, 2001)
Demand	Support group	Non-transparency of industry, difficult contracts, long-relationships		Non-transparency of industry and different revenue models
Supply	Steel seller	Current business of reuse do not see the relevance of such a marketplace		Mindset is producing cost savings in a short time ((Issa et al., n.d.)
Supply -	Madaster	Practical, till what level do you model your BIM? Connect databases		No literature found related to BIM for reuse.
Aesthetics	Architect	No design freedom and reuse of products are not possible when design guidelines and norms change.		Designing new buildings with old spans may be challenging; old wall panels do not fulfil the current minimum room height (Hradil et al., 2014)
Core interaction	**Marketplace**	General constraints of reuse marketplaces in the Dutch construction sector. (Timing, aural coordination is needed, different interfaces)		Bouwmarktplaats onderzoek (Slager & Jansen, 2018)
Supply	**Rigour interview**	IFC models are not as-built. Hard to get relevant information in. IFC OWL or new method for as-built models (interview Rigour expert IFC)		BIM expert interview, 2018

[14] http://constructingexcellence.org.uk/wp-content/uploads/2015/01/CE-business-case-against-lowest-price-tendering-May-2011.pdf

Swift product categories

Figure 10: Overview of 4 main groups and related parameters that impact reusability choice (Swift, 2015)