CIRCULAR DESIGN: DIFFERENT PROCESS FOR OPTIMAL REUSE IN ARCHITECTURE

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Abstract

Despite efforts to reuse and recycle materials in the building industry, the vast majority of materials used is new, which does not contribute to a circular built environment. Additionally, the way we design influences the amount of waste produced by the building industry. This research aims to develop circular design principles for optimal reuse of building components during the design process. Main factors of availability, dimensions, aesthetics, technical performance, environmental impact and the costs influence the reuse potential. Through qualitative data analysis, including in-depth interviews with pioneering architects who apply reuse as building method, this study identifies design principles and strategies for implementation in the design phase. By starting the design with identifying the reused materials, early collaboration, designing for disassembly and adaptability, and allowing flexibility during the whole process, optimal reuse can contribute to circular building practices.

Keywords: *Reuse, Design for reuse, Design process, Used building products*

I. INTRODUCTION

The demolition of buildings comes with waste. According to the European Commission (2020) more than a third of all waste generated in the European Union (EU) comes from construction and demolition waste (CDW). A diverse range of materials is getting lost, including concrete, wood, glass, bricks, metals and plastics (European Commission, 2020). In this traditional linear economy where materials are extracted, utilized and disposed the industry contributes to environmental concerns. According to research 40% of all materials are used in the construction industry, where at the same time the industry is responsible for 40% of all waste. Besides, the emissions for the construction of buildings are largely influenced by how we build and design (Malabi Eberhardt et al, 2020).

Despite efforts to reuse and recycle materials, the vast majority of construction materials is new and comes from all over the world according to research by Gorgolewski (2018). Even though materials and building components are available, the habit of reusing and designing with those elements is not visible enough in the building industry (Malabi Eberhardt et al, 2020). Architect Van Assche (Bureau Sla, Circularity conference, 2024) states*: ''Currently architects drag a material for a structure or façade-element from the top left corner of the computer screen into the designed element and lost their understanding of the material''*. This common practice allows us to design for future waste. In contrast to this traditional linear economy, a circular economy strives to close the loop by minimizing waste and promoting the reuse of materials.

The principles of a circular economy have been introduced in the construction industry, through projects that reuse constructions or facilitate the future reuse of building elements or integrate renewable materials. While such circular solutions gain in popularity, the reuse of building materials remains a specialized practice in architecture (Kozminska, 2019). Researcher Addis writes (Addis, 2006): *''...one respect, designing buildings to incorporate reclaimed products and materials is fundamentally different from conventional design methods.''* Currently, we face a time with pioneering architects that strive for

circular architecture using mainly reused materials. Multiple strategies arise facing different difficulties: uncertainties about the materials, different design process and lack of experience (Heesbeen et al, 2021).

One thing becomes clear, for both materials and space, it is essential to start with what already exists as a basis for further development. The design phase is hereby crucial to shape circular objectives, as described by the Ellen MacArthur Foundation (2020). The task for the new generation architects is to rethink the design process to lower the CO_2 emissions and waste in the building industry and focus on reusing existing building components and materials in architecture.

1.1. Objective

This project aims to explore the feasibility and implications of reuse in architecture and how this affects the design process. According to professor Gorgolewski (2019), the starting point for architects and designers is to identify the potential for reused materials and building components in new projects involving reuse. Afterwards, they develop their concept and ideas depending on these materials.

The conventional design approach starts with designing the main elements of a building, which will be followed by selecting the right materials, tools and installations to meet the required specifications. To design new buildings with existing materials, it is important to understand how these materials are suitable for reuse in a new building. A distinction can be made between already existing research into reuse potential and the pioneering architectural approaches in the field.

This theoretical research aims to generate multiple design principles that illustrate the requirements and important strategies of how to design with reused materials. The focus on reused materials will not mean that other solutions like building with biobased materials or the transformation of existing stock of structures are of less importance. The thematic research will be put in context for a design, based on the transformation of an existing theatre building (currently Amazing Oriental Supermarket) in the inner city centre of Rotterdam, dated from 1930, on West-Kruiskade 26.

1.2. Research questions

This graduation project investigates the role of the architect incorporating reuse of materials. The research tries to answer the following design question:

- *How can architectural reuse principles guide the transformation of an existing building (Amazing Oriental Supermarket) in Rotterdam into a collaborative centra for learning, testing and showcasing innovative applications of reused materials?*

The research will be centred around the following research question:

- *What design principles can be developed to enable architects to effectively integrate reuse on different scale levels during the design phase?*

1.2.1 Sub questions

- *How can reused materials be defined in the building industry?*
- *What are main factors that influence the potential for reuse?*
- *What are challenges for architects to select reused building components and materials for a design project?*
- *How can architects design with reused materials that have irregularities and imperfections due to a previous use?*

II. REUSED MATERIALS

2.1 History of reused materials

As historian and architect Moravánszky states in the book *Reuse in Construction* by Stricker et al (2022), the majority of human creations undergo modifications and transformations at some stage. Reusing materials or building components is therefore nothing new in architecture and the building industry. The removal of building components from their original setting and reuse in a different structure is referred to as *spolia* (Stricker et al, 2022). The terminology comes from the Latin *spolium*, which refers to loot or plunder that was taken from the enemy. Stricker et al illustrates that in Italian cities it became common to reuse building components during the Middle Ages, for example the highly valued stone from Colosseums in order to build new structures.

Moravánszky adds that on the one hand, reuse of building components comes from a pragmatic approach. Namely, to use available building components from nearby to reuse it in a new structure. On the other hand it also incorporates the idea of a symbolic and cultural value that is contained in the material. This pragmatic and symbolic use of materials resulted in a high level of reuse of building materials and components, with old structures often serving as the foundation for new ones, and materials being repurposed until they were no longer viable.

In contrast, this practice of traditional reuse has declined in the last decades (Hobbes and Adams, 2017). Moreover, according to Stricker et al (2022) reuse becomes more challenging in the current modernized building industry with tight plannings and standardized production processes. The term *reuse* currently implies on a shift in use, ownership or location (Baker-Brown, 2017). In the building industry it means using a product or construction element again, in a new context, that has been extracted from an existing building or structure. Reusing or *reclaiming* materials means without any modifications such as: refurbishing, repurposing, reworking or repairing. Some cleaning or minor adjustments to ensure the quality can still be made. In this way the intended purpose of the product stays the say.

2.2 General circular strategies

The build environment generates residual flows of building products on a daily basis. These residual flows consist of building components and raw materials, as research shows by Malabi Eberhart et al (2022). The difference between calling these elements waste or not is dependent on the value that these elements have after the end of use. According to Stricker et al (2022) if there is a purpose for it, it is no longer waste. However, currently waste is a common end product in the building industry (Malabi Eberhart et al, 2022).

In the building industry and in this paper we describe materials and building components that are no longer in use and have been considered as waste as *used building products*. A distinction will be made between *end-of-life* and *end-of-use* in the product lifetime. A product is considered to reach its end-of-life stage when there are no further opportunities for reuse, leaving only recycling or disposal as suitable options. End-of-use occurs when a product is no longer in use, yet various reuse strategies remain feasible. So, in order to contribute to a circular world, it is important to extend the lifecycle of resources and to prevent that building products become waste.

2.2.1. R-Ladder

The principles of extending the lifecycle of a material in order to become circular are described by the Ellen MacArthur Foundation. The principles are illustrated in the circular R-ladder as part of the butterfly diagram (see Appendix A) visualising the circular economy. The R-ladder shows ten strategies that refer to the waste loop for used products. The higher the strategy is on the ladder, the tighter the waste loop, thereby more circular.

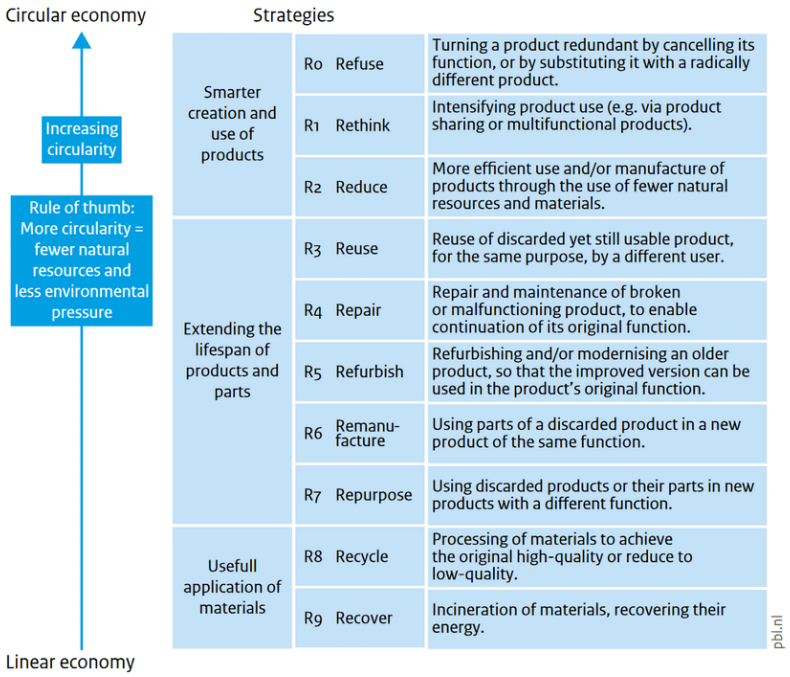

Figure 1. The principles of the circular R-ladder (PBL).

Key elements in the building industry for extending the lifecycle of resources are according to Sticker et al (2022) *reduce, reuse* and *recycle*, by (re)designing building components that use materials more efficiently. These R-strategies mentioned are visible in the R-ladder scheme, whereby reduce and reuse are on the top of the list and recycle is seen as less impactful. The other R-principles of repair, refurbish, remanufacture and repurpose are seen as ways to enable the reuse of the used building product, however, this paper aims to explore the feasibility of (direct) reuse, since this is more efficient and circular. A literature review on the R-strategies by Reike et al (2018) describes the definitions based on multiple research papers and their usage in the field, these definitions (see Appendix A) are used in this research paper.

The strategies of reduce, reuse and recycling are besides the other R-strategies important elements in the circular economy. A thorough (re)design on used building products is needed per situation to understand what strategy to apply to have the least environmental impact. The process of recycling for instance, often still requires energy and in some cases also produces CO_2 emissions (Gorgolewski, 2018). Recycling after the end-of-use stage means breaking down the used-building-product into a uniform material used for less valuable applications. However, reuse has usually less reprocessing since the building component or material will be used as a whole element and requires minimal processing (Hobbs & Adams, 2017).

2.2.1. Building layers

As discussed earlier, for a circular approach the lifecycle of buildings should be extended. This idea is visible in the vernacular architecture in different cultures, where for instance earth buildings have an extended life, since people renew and repair the existing buildings in order to extend the lifecycle (Stricker et al, 2022). In these situations buildings can endure in their original architecture. It is difficult to speak of extending the lifecycle of a building, since all the parts of a building have a different lifetime. This concept was recognized and firstly introduced by Stewart Brand and Frank Duffy, who developed the scheme and idea of a building existing out of multiple layers with their expected lifetime in 1998, see fig. 2.

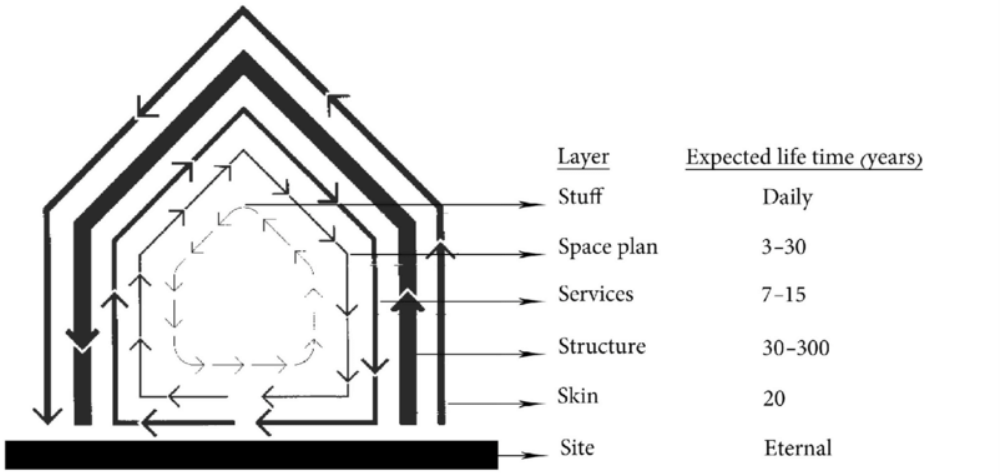

Figure 2. Visualization of building layers by Brand & Duffy (1998).

As visible in the scheme the site is eternal and the structure has the longest expected lifecycle. After these the skin, space plan and services are separated and all have an expected lifecycle of less than 30 years. This is dependent on different factors and on the materials used for these layers.

According to Brand and Duffy buildings should be understand as a dynamic system, which is: 1) easy adaptable; 2) have layers of time; 3) low tech and flexible solutions; 4) inform feedback for future design decisions; 5) design for longevity and durability. Together with the subdivision of building layers it aims to show that buildings should be adaptable in time. Reuse can play an important role in this, when the end-of-life of a building layer is reached it can be replaced with reused materials.

2.3 Reuse strategies

Literature describes multiple forms of reuse strategies (Gorgolewski, 2018; Kozminska, 2019; Addis, 2006). However in architecture and the building industry this paper divides roughly two distinctions. The first one is the adaptive reuse of existing buildings, with a focus on the existing structure, building components and materials that can be reused in the same building. The second one is the reuse of used building products – building components and materials – into a new or transformed project.

By looking at the reuse of building products it is important to divide the different levels of scale present in a building: the whole building, building parts, building product, building component and material. To look at the reuse potential it is most circular to start with bigger components for reuse and end with the individual materials, as illustrated in fig 3. This is due to the amount of time and energy that is involved in the deconstruction of a building into smaller elements. Moreover, according to Ed Forwood (Circularity Conference Future Envelope, 2024) from the engineering company Arup, in general it saves energy and CO_2 when bigger elements are suitable for direct reuse.

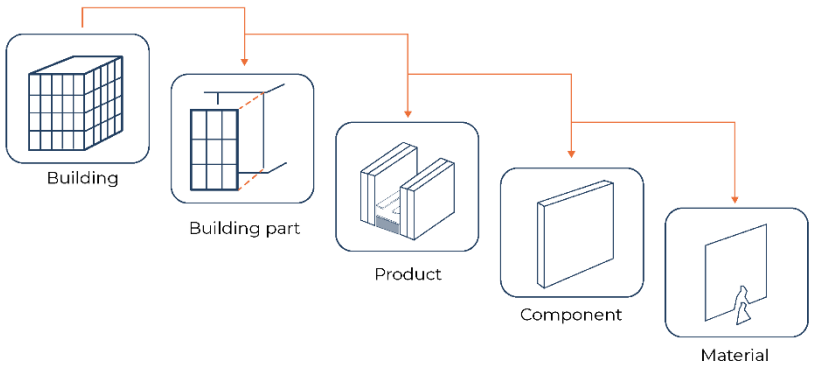

Figure 3. Different levels of scale for reuse present in a building (by author)

For (direct) reuse this process start with the inventory of components that can be reclaimed or with finding a *donor building*. A donor building is a building that served its use and becomes available for deconstruction. This process of using components from the existing stock of buildings, infrastructure or industries is referred to as *Urban Mining*. Multiple tools currently exists to find secondary materials and to 'mine' the existing stock.

The search for a donor building and used building products needs an own investigation and therefore multiple strategies are possible. In general two principles can be applied. First, to find materials by looking at what materials are available on the market, via material hubs and online platforms, such as: New Horizon, Insert, Harvestmap. Or a donor building will be selected and serve as a building component bank. The other principle is based on using material passports to identify what materials become available in the upcoming period.

Both principles are largely influenced by the factor time. According to a rapport by SGS Search (2021) an element to incorporate in circular building is this factor time. There is a need to specify the quantity of time of the process and the estimations to overcome uncertainties.

2.4 Factors influencing the reuse potential

The reuse potential is dependent on each individual available material. Gorgolewksi (2018) states the main factors influencing reuse: availability, technical performance, aesthetics, dimensions, lifecycle assessments and costs. These elements may all impact the design process. It is only possible to reuse an used building product when it had been assessed with a positive outcome. The first assessment of suitable components should ideally be done by experts or demolition companies on-site in order to identify the components with most potential (Addis, 2006).

A distinction can be made between the more generic used building products and more specific products. More generic used building products are for instance: plumbing installations, roof tiles and ceiling tiles. The more specific products are window frames for instance, since these have often different dimensions. For component reuse it is crucial to look at the feasibility per used building product. The reuse potential of each individual element will be analysed and afterwards the choice can be made by an architect whether to use the element in the design or whether it needs further processing or will not be selected for the design.

Table 1. Main influencing factors for component reuse potential explained

Availability	The availability refers to timing, location and quantity in the which used building product becomes ready for reuse. The availability lays the base for the component bank the designer can choose from. The more generic used building products, such as: plumbing installations, roof tiles and ceiling tiles, create a larger quantity and therefore often a higher availability and higher change for reuse.
Technical performance	The condition of the components in terms of technical state. A component suitable for second use should still meet the requirements and safety regulations for safe application in the build environment. Guarantees of safety are difficult for secondary products.
Environmental impact	Reuse lowers the amount of raw materials, saves energy for manufacture and prevents waste. The environmental impact has to be analysed per product, which can be done with a Life Cycle Analysis (LCA) or looking at the embodied energy (Addis, 2006). Transportation of reused components is influenced by the distance travelled, the quantity and the weight of the materials and the mode of transportation used.
Dimensions	The dimensions can be crucial when standard sizes have changed in regulations, for example doors. Also the uniformity of the dimensions becomes important when dealing with multiple products of the same type.

Aesthetics	The aesthetics are subjective to assess, but depending on former use of the product, reused products often vary in appearances and can contain imperfections. The appearance can also be positive effected through the history and uniqueness of the product.
Costs	According to the *Leidraad Circulair Ontwerpen 2.0* (2023), the supply and demand of used building products have to be aligned during the design phase, since the market value is determined by supply and demand, just like other products. The economics of material reuse are difficult and have uncertainties (Gorgolewski, 2019). The costs for the materials are normally lower than new materials, but the labour costs for deconstruction are a new factor. Moreover, storage costs can play a role in the costs analysis.

To conclude, a distinction between measurable and non-measurable factors are visible. The difficulty is that different stakeholders and factors have a risk and uncertainty in it.

III. REUSE IMPLICATIONS FOR DESIGN PROCESS

As set out by multiple researchers the regular design process, or traditional design process, is different from the circular design process aiming for maximal material reuse (Gorgolewski, 2019; Kozminska, 2019; Addis, 2006). First of all, a distinction can be made between the approach that is used. Addis (2006) describes two different approaches to design, based on the book *Superuse* (by Van Hinte et al, 2007):

- *Means oriented design:* The design progresses based on the resources at hand and available, including the materials. This process requires more complexity, experimentation, flexibility and adaptation.
- *Goal oriented design:* A goal or vision is set and defined, the process decisions are directed towards that goal.

The traditional or conventional process can be recognized as 'goal oriented design,' where architects design the main features of the building and present a desired vision or render of the goal they envision. In this way the design develops from large to small, from structure, facades, floors to bathrooms and finally to door handles. In contrast to the traditional design process asks reuse for an approach of means oriented design, where availability is leading. It can be seen as a process of diverge and converge. The traditional process is a process of converging to a desired goal and making choices on that goal. Where reuse asks for creating choices and making different solutions possible, while not all information and or materials are available.

3.1. Conventional design process

Research by Van Dooren et al (2014) into the generic elements in the design process, to make design decisions explicit, sets out a conceptual framework (see Appendix A) with different elements a designer uses. The main elements are set out in the table below. The generic elements, explained in table 2, do not follow a chronological order, however a certain funnel effect can be recognized in the framework. Hereby, the guiding theme and domains are leading the design process towards the desired goal. One could say that the factor of coincidence is not present in a regular design process, since this is part of a converging process including making decisions. This in in relation with the building process which is also more linear and corresponds to a certain time management.

Table 2. Generic elements of design process by Van Dooren et al (2014) explained by author.

Experimenting	This element emphasizes the iterative nature of design. Designers experiment with ideas, explore possibilities, and make decisions throughout the process.

Guiding theme	Designers often work with a guiding theme or specific qualities they want to achieve in their design. This provides focus and direction. It can be formulated as a starting point for the design, also referred to as concept.
Domains	Designers draw from various domains of knowledge, such as space/form, materials, function, site, context. These domains influence design decisions.
Frame of reference	Having a well-defined frame of reference is crucial. Designers rely on existing knowledge, references, and resources.
Laboratory	Designers create visual representations, sketches, and prototypes. The skills and methods they use are part of their laboratory.

In this more conventional design process the domains, such as: materials, form, function and structure are largely influenced by the experiments or design decisions by the architect. As Van Dooren states, this part of the domains are in fact the designer's playground. Here a designer can freely design and iterate back and forth between the elements of for instance light, composition, texture and materialisation.

After a more final design is drawn, the designer will set the limits, which will be followed by specifications and requirements. This is the starting point for the next phase, where the design phase is more coming to an end and where first the needed materials will be bought. Since new materials and structure elements meet the new standards and are available no other implications are met for the designer. This process is visualised in figure 4.

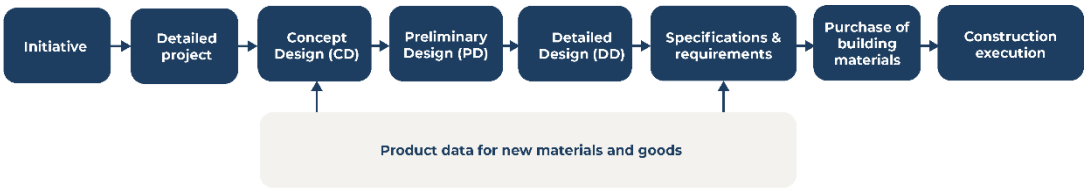

Figure 4. Regular design process in the building industry (simplified)

3.2. Design process incorporating reuse

As set out earlier, literature research describes that the starting point for projects including reuse is the inventory of potential materials that can be used. This results directly in an elongated introduction phase asking for collaboration of multiple stakeholders in this part of the project phase (Kozminska, 2019). Since reuse has a certain uncertainty, the early involvement of the experts and contractors prevents unfeasibility of design decisions (Addis, 2006). Moreover, the choice for a reused building material needs to be analysed on the potential before the material is incorporated into the design, therefore these experts should be part of the conceptual design phase.

According to research by Kozminska and interviewing architects in the field (Popma & Halbmeijer, 2024) incorporating reuse brings variables to the design and building process. To prevent undesired decisions a clear environmental goal, for instance the percentage of reused building materials should be defined in the project specifications at the start of the project. Other variables arise from the material costs, the unpredictable availability and time, looking at the dismantling, transport and storing of the materials available. Moreover, the building methods are not clear from the beginning, but dependent on the material. These variables results into a non-linear design process.

The discovery of new materials constantly challenges design decisions. The skill of being able to adapt, combine, and fit things together relies on flexible design principles. Designing variations, before searching for materials, can help the design team to explore different approaches further and to know what direction to take in the search for components. Once the concept for the design is set the

shape will not change much, however designing the details for the building will keep developing and changing as components are added. According to Stricker et al (2022) it is not possible to ignore the details, since every reused element should be adapted to the placement and characteristics of the other component. Moreover, this involves a 'chains of effects,' since all components are connected, certain flexibility should prevent that all other elements have to be changed. These connections should make a distinction between different building layers, to enable adaptability.

This literally flexibility in space between elements should also be implemented in the whole design process and how stakeholders interact with each other. The need for physical tolerances and for flexibility in the process asks for creativity and being able to adapt quickly

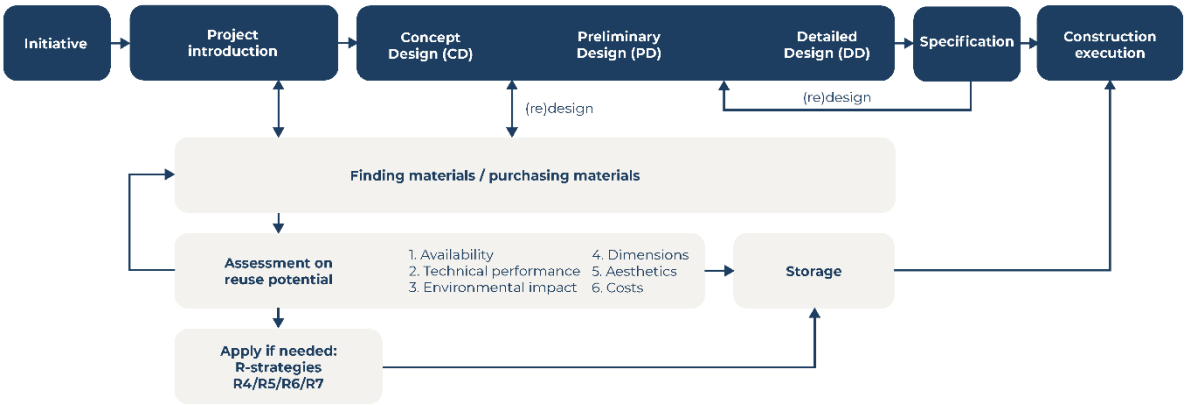

Figure 5. Design and construction process implementing reused materials.

3.3. Stakeholders

Circularity and reuse strategies should become the new normal and therefore all stakeholders in the building sector should be familiar with these strategies. Moreover, as research and architects describe the early collaboration and open shared data information will increase and improve the possibilities of reuse. Research by Galle and Van Vooren (Circularity Conference Future Envelope, 2024) and interviews with architects led to insights into the different stakeholders that are involved in a project that focusses on reuse strategies. A changing role of numerous stakeholders and the introduction of two emerging roles of Reclaimed material scout and Circularity advisor are visible. It becomes clear that the architect stays responsible for the overall management and design of the project and collaborates with multiple (new) stakeholders (see appendix A for elaboration on stakeholder analysis).

3.4. Design projects focused on reuse

Two architecture firms, Apto Architecten and Popma Ter Steege Architecten and their projects are analysed to understand the design principles they applied in the design process and to gather information about the design strategies they applied. The main design principles and design strategies per architecture firm are visualised in appendix C. These results are concluded from the conducted interviews (see appendix B) and case study analysis.

3.4.1. Apto Architecten – Kokomo

The 2.000 m^2 plot exists of two buildings and an outside bar that together create a space for people to eat, work and have social activities. It is located in Amsterdam on Zeeburgereiland and realised in 2024 for the upcoming period of ten years. The high ambitions on circularity allowed to focus on reuse of building components and materials, where the contractor will deconstruct the whole building in ten years time to give the materials a third use.

The design phase started by developing and creating the identity and character of the new place and building. This resulted in the creating of the ambition for the project that was visualised by making

renderings. After this first CD/PD phase the contractor was selected, this was however too late according to the architect. Since the contractor had experience needed for this circular project.

The first vision (see appendix B) existed out of multiple wooden structures and containers that together formed a cohesion. The tender was won and the client and users were convinced with this vision. Certain elements from the architecture from this first design are still recognisable, but the end project has multiple differences, such as one floor down, no balconies, no sliding shutters and no wooden structure for the bar. The architects describe that this vision was needed to convince the users and client, but would be open to use a different technique, such as a collage or moodboard, since the uncertainties with reused components make it difficult to strive for the exact picture. However as Mark described: *'Sometimes you just need to take a step too far, so you can take a step back again.'* Reused wood is already available, so more specific ambitions allow for a more tailored search. '*The availability of materials isn't always guaranteed because there isn't a sufficient scale yet. The availability of materials is primarily the determining factor.'*

3.4.2. Popma Ter Steege Architecten – Kantoor Vol Afval

Kantoor Vol Afval (KaVA), is the Dutch translation for Office Full of Waste, which showcases as a model project form the Rijksvastgoed to demonstrate the possibilities of circular construction processes. KaVA is situated in Katwijk and is an outdated defense office from 1980, approximately 2.100 m² in size. This building was renovated within defined circular principles, trying to push the boundaries of reused materials and develop new products for the reuse building industry.

As a result, nearly everything in the building incorporates reused materials: demountable kitchen units, climate ceilings, balustrades made from cut-out masonry elements, frames constructed from reused wood, air handling units, ceramic floor tiles, light fixtures, wooden ceiling elements, interior glass walls and carpet tiles.

The main aspects are to look at each component of the building. They consistently asked themselves how to minimize the environmental impact of each part. The approach was to systematically review each building element, from facade to interior walls and shell, assessing what is needed, what is available, and what is desired. On one hand, they follow the standard design process: create a program, develop a concept design, study the site, conduct volume studies, and understand the logistics. On the other hand, evaluate the individual reclaimed components. Refine these components over time. Transition from the broad to the specific. Conduct multiple facade studies, adjust materials or forms several times as you explore options. This method allows for extensive development, adaptation, or interchange of the components.

3.5. Design with imperfections

Components that become available after the end-of-use phase, have imperfections such as irregularities, scratches or colour differences. However, the value of the materials can also be an architectural quality, since it shows the authenticity of the material. The main implications can be divided in architectural consequences for the final building and design consequences for the process, as visualised in table 3.

Table 3 Main implications for designing with imperfections according to architects (Popma Ter Steege & Apto Architects, 2024) explained by author.

Architectural consequence	**Imperfections adds extra value** It showcases the authenticity of the material and its character and therefore creates a different feeling than with new materials.
Process consequence	**Architect needs to have a deeper understanding of materials** Understand how an element works and what requirements are necessary, as the materials are not new.
Process consequence	**Allow for more tolerances between components** Be specific in the detailing and drawings to prevent unclarities

Process consequence	**Adjusting details on site (during construction phase)** The tolerances and irregularities of components sometimes ask for creative sustainable solutions on site by the architect and constructor. Anticipate and prepare everything thoroughly, as there are indeed more tolerances in the construction and flexibility in the building process. Do not leave the solutions up to the constructor, but keep it to the designer.
Process consequence	**Detailed specification comes later**
Process consequence	**More collaboration with other parties** Understand how an element works and what requirements are necessary, as the materials are not new: technical, aesthetically, transport…

IV. CONCLUSION

- This graduation project investigates the role of the architect incorporating optimal reuse as a circular strategy. The research tries to answer the following research question: *What design principles can be developed to enable architects to effectively integrate reuse on different scale levels during the design phase?*

To support optimal reuse in the design phase, nine key design principles for the design process have been identified (see appendix D). In general reuse, starts with identifying reusable materials. This involves assessing the available materials before applying in the design process, starting on a bigger component level. The factors of availability, technical performance, environmental impact, dimensions, aesthetics and costs are hereby the main elements that impact the reuse potential. The element of finding and purchasing materials is already involved at the start of the process, whereby the availability of data of these materials is not a given constant. This makes the design process that involves reuse non-linear and asks for a means-oriented design approach.

Qualatative data by literature and in-depth interviews has identified that the process (see appendix D.3) where reuse is optimal used should start by early stakeholder involvement in an elongated introduction phase. The uncertainties and variables reuse brings asks for the involvement of new experts, the circularity advisor and a reclaimed material scout, also shifting roles of the familiar stakeholders. This early collaboration prevents unfeasible design decisions. The second design principle is to define a clear environmental goal, for instance the percentage of reused building materials in the project specifications at the start. The discovery of new materials constantly challenges design decisions. The skill of being able to adapt, combine, and fit things together relies on flexible design principles. A flexible concept and description of the performance and disclaimers per elements can provide the boundaries of the design and help the designer to know what materials can be applied. This flexibility should also be implemented in the whole design process and how stakeholders interact with each other. The need for physical tolerances and for flexibility in the process asks for creativity and being able to adapt quickly.

Finally, architects should continually seek ways to minimize waste and promote the reuse of materials. This involves not only integrating reused materials in new projects but also designing buildings that can be easily disassembled and their components reused in future constructions. Moreover, a deeper understanding of materials is needed, where design can also be lead by availability.

In conclusion, developing multiple design principles for architects to integrate reused materials in the design process asks for multiple shifting roles in the building industry. However the new architect should start with identifying the existing materials, embracing flexibility and adaptability, fostering collaboration, ensuring detailed documentation, and increasing the material knowledge to contribute to more circular building practices.

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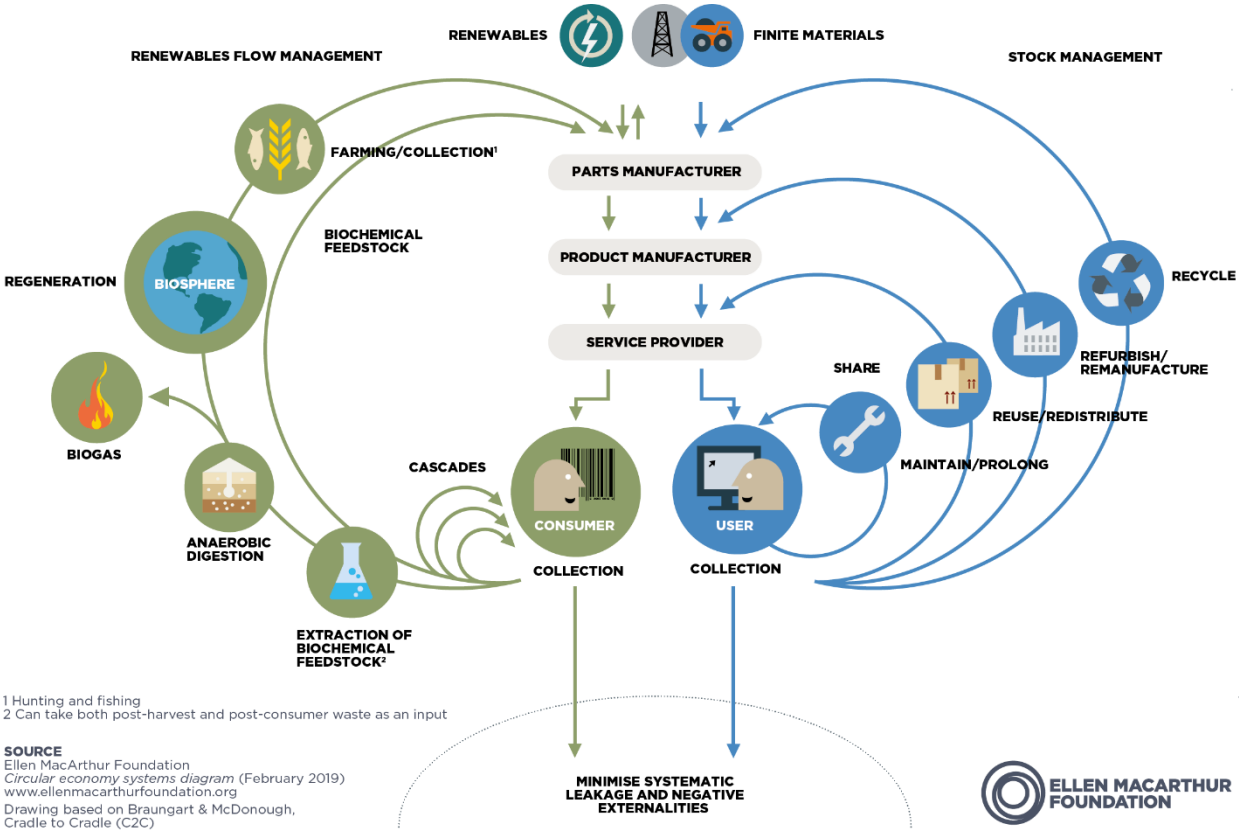
APPENDIX A – VISUALS & EXPLANATIONS

A.1. The butterfly diagram: visualising the circular economy



A.2. The Delft Ladder

This ladder divided ten stages of the lifecycle of materials and used building products. The designer can use it to consider design choices regarding materials.

Table 1. First 5 stages of *The Delft Ladder* explained by author

1 Prevention	The design tries to avoid waste in advance, by minimizing material usage for instance.
2 Object renovation	The extending of the lifetime of building elements/ layers, by renovating the elements or building components. Demolition/dismantling is avoided.
3 Element reuse	The reuse of a building component after removal or dismantling. The bigger elements consisting out of more materials have priority and avoid waste.
4 Material reuse	The reuse of materials after removal. After components are reused, smaller, individual materials can be reused.
5 Useful application	The search for a new application for building components or materials after removal. Reusing, repurposing or recycling.

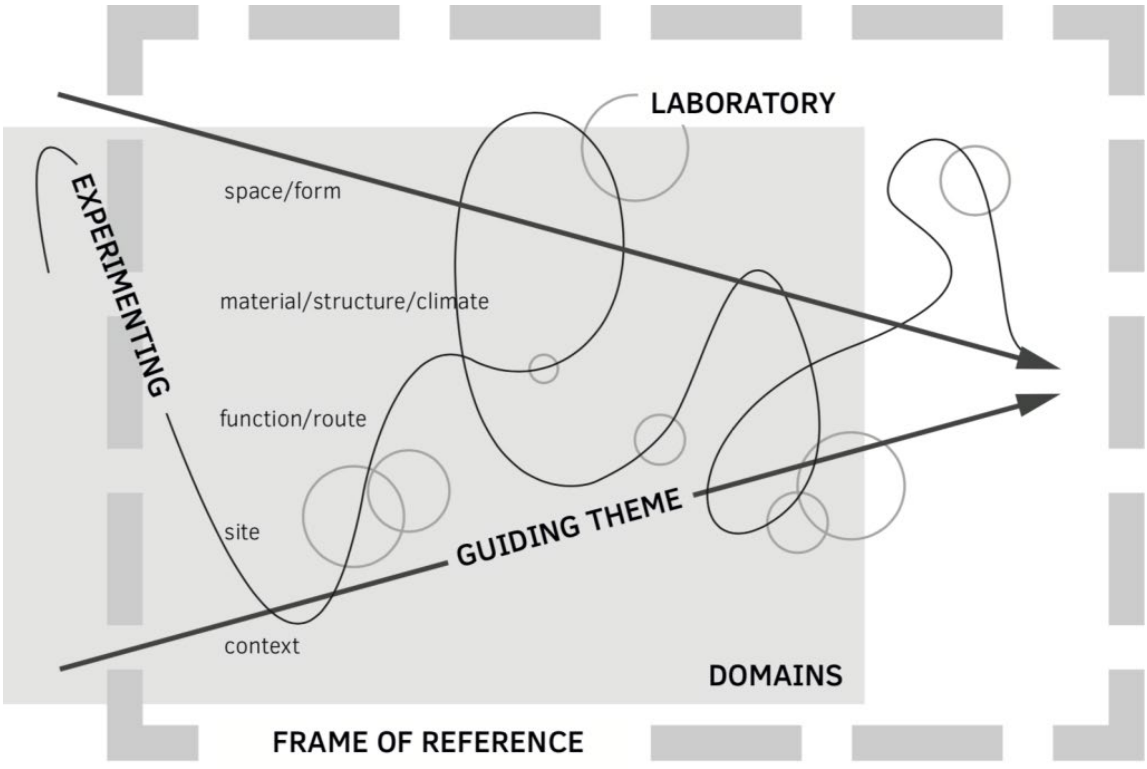
A.3. Definitions for reduce, reuse and recycle based on research by Reike et al (2018)

Reduce
Reduce refers to minimizing and preventing waste production and optimizing resource use. Reike et al (2018) states that this reflects both on the consumer as on the producer, by minimizing the amount of usage and decrease the amount of materials in products or components. Reduce is a top strategy since it aims for prevention and calls user and producer to first act circular while making or using a product.

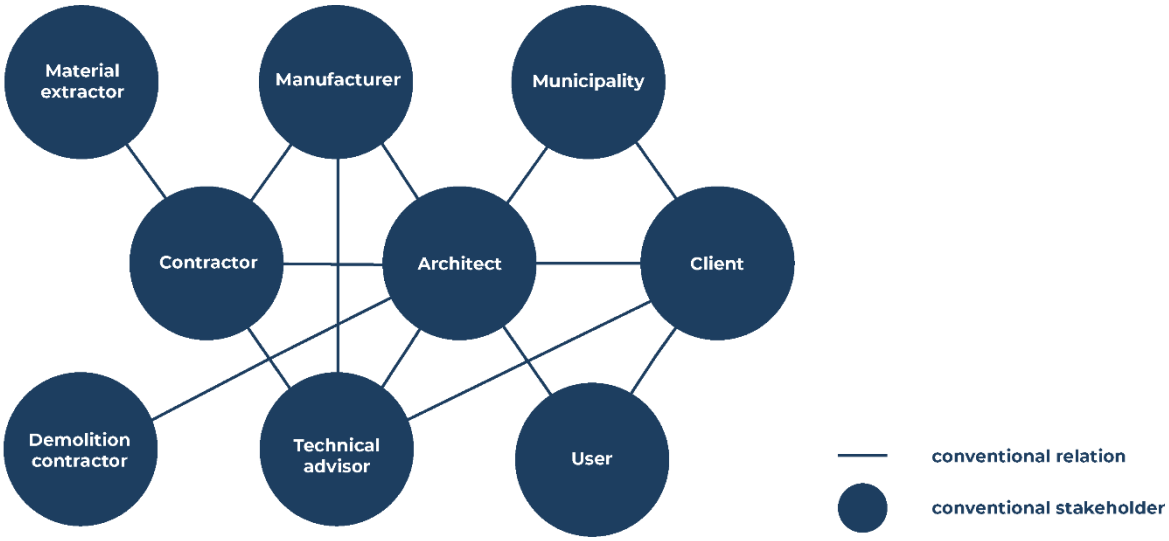
Reuse
The research of Reike et al describes reuse (or resell) as an approach to return products to the market or into usage after the initial use is finished, so after the end of use stage. Reuse means without any modifications such as: refurbishing, repurposing, reworking or repairing. Some cleaning or minor adjustments to ensure the quality can still be made. In this way the intended purpose of the product stays the say. The term *reclaimed materials* is also used besides reused materials, which refers to the same strategy of using building components or materials in a different structure without any processing.

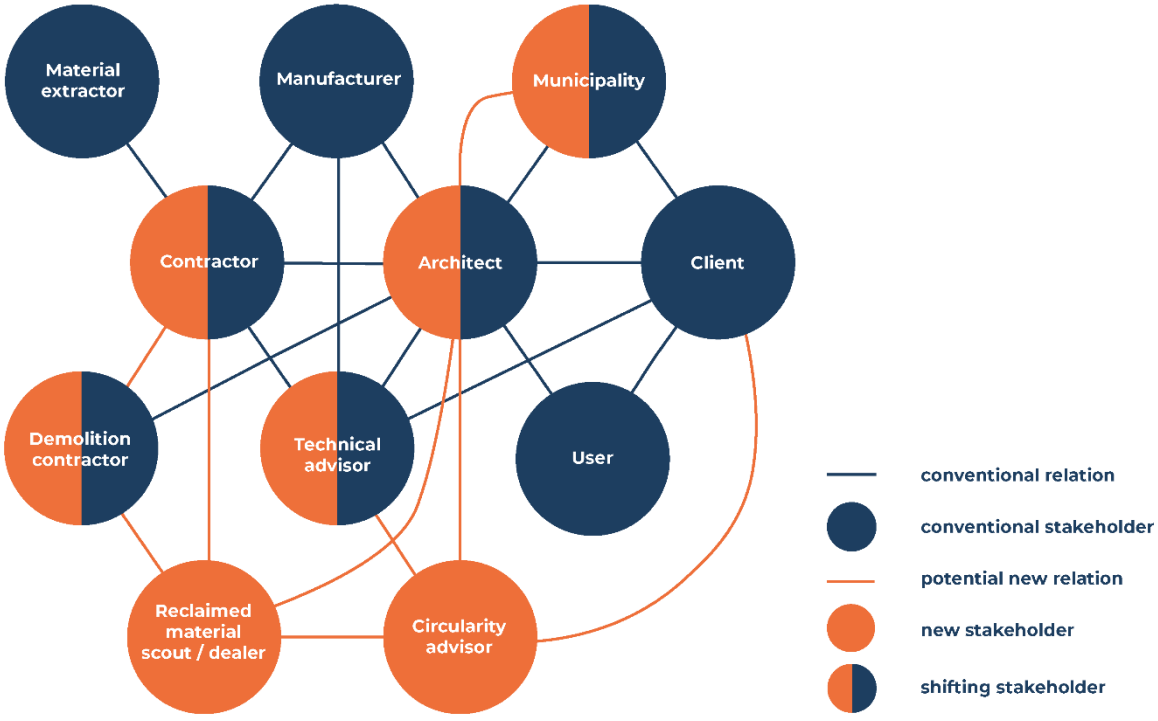
Recycle
This strategy is the most applied strategy in the circular economy (Reike et al, 2018). It involves processing waste streams of used building products, after the end-of-use, into more pure materials or different products. Recycling is a useful way of preventing a product from becoming waste and research by Gorgolewski (2018) describes that more and more demolition waste is recycled, but the value that results is not always optimal. Gorgolewski adds that a big part of recycling currently means 'crushing' materials for use in low-value applications like road base. In the Netherlands this is also visible, where recycling of concrete for instance results in road base or foundations (Rijkswaterstaat & RIVM, 2015). The process where the value after recycling is less than before is called downcycling (Gorgolewski, 2018).

A.4. Five generic elements in design process by Van Dooren, 2020.



A.5. Stakeholders analysis conventional process and process involving reuse (by author).





APPENDIX B – IN-DEPTH INTERVIEWS (DUTCH)

B.1. Mark Halbmeijer - Interview 14-05-24 - Summary

Partner Apto Architecten

Heeft het project Kokomo de benadering van Apto Architecten tot hergebruik van materialen beïnvloed? En voor welke schaal is het nu toepasbaar?

Ik denk dat het van belang is om meerdere niveaus aan te tikken bij hergebruik. Het gaat niet alleen over materialen, maar ook voornamelijk over samenwerkingen. Het type partijen waarmee je samenwerkt is cruciaal. Traditionele denkwijzen moeten plaatsmaken voor circulair denken. De aannemer bij dit project was bijvoorbeeld belangrijk omdat hij leefde voor circulariteit en over opslag beschikte. Wat ik heb gemerkt, is dat je een bouwer vanaf het begin aan tafel moet hebben, vooral op casco niveau. Dit vereist ook flexibiliteit van de gemeente. Bij Kokomo hadden we bijvoorbeeld te maken met kavels die schuin liepen, wat het hergebruik van containers bemoeilijkte.
Dus de maakbaarheid binnen wat de stedenkundige bedenkt is vaak heel erg anders bedacht dan vanuit materiaal te gaan denken, vanuit bestaande dimensies. Dan heb je vanuit de voorkant flexibiliteit van de gemeente om af te wijken van de regels die er gezet zijn.
Uiteindelijk hebben we een hybride oplossing gevonden met zowel hout als containers. Het project heeft ons laten inzien dat vroegtijdige samenwerking met bouwers en flexibiliteit van de gemeente essentieel zijn. Voor grotere schaalprojecten moeten er constructiehubs zijn en moet de gemeente bereid zijn af te wijken van strikte regels om circulariteit mogelijk te maken. Het schaalniveau is nu toepasbaar in projecten waar deze samenwerkingspartners en flexibiliteit aanwezig zijn.
Ja, maar het is een iteratief proces. Soms kom je erachter dat je toch een stapje terug moet. Omdat het dan niet lukt met de beschikbaarheid. En dat is mijn punt. Leuk dat we dat hier gedaan hebben. Maar als je kijkt naar... Een klant betaalt ervoor. En je mag als architect dat gaan doen. Dan ben je heel veel uren aan het besteden. We hebben het materiaal. Het is wel goedkoop. We willen het betaalbaarder gaan doen. En we gaan weer terug naar de tekentafel. En je bent elke keer opnieuw dingen aan het doen.

Ik denk dat er een veel meer een hybride overlap zit tussen aannemer en architect. Of het nou collectieven worden of samenwerkingen, dat weet ik niet. Maar je moet in die voorfase gewoon aan tafel. De kans ligt hem ook in de elementen waarvan we weten dat er veel beschikbaar zijn, zoals bepaalde deuren.

Hein: Eigenlijk zijn jullie dus eerst begonnen met partijen aan boord brengen.

Mark: Ja, wij hebben dat te laat gedaan. We hadden dat eerder moeten doen, wetende wat we nu hebben. We hebben een SO en een VO gedaan. Wat je nodig hebt voor een vergunning. Toen wij bij de vergunning hebben we de offertes uitgevraagd. Naar de aannemer en toen vervolgens, dat we alleen nog maar die containers hadden. We zijn met de aannemer gaan praten. Uitgelegd dat we de schuine maten hadden van de kavel, daarop kwam de aannemer met het idee om alles van hout te gaan maken. Dat doen we met hergebruikte hout, dat is veel beter. Toen hadden we alles in hout. Toen halverwege proces, kwamen we erachter. Dat beneden die containers te koop waren in Utrecht. Toen hadden we al een vergunning, toen hadden we al een DO-fase. Toen hadden we al 12.000 euro aan leges betaald voor de vergunningsfase. Toen zei de gemeente, ja maar het is leuk van die containers, maar dan moet je een nieuwe vergunning aanvragen. Toen we een nieuwe vergunning aangevraagd, kregen we weer 9.000 euro aan leges. Maar we konden die containers plaatsen, dus dat scheelde ons geld. Vervolgens kregen we het feit dat we containers beneden hadden met hout boven. Een soort tussen hybride oplossing. Toen zeiden we, ja maar zichtlijnen. Toen kregen we weer dat gelul over uitstekende randjes. Gedurende het proces is het heel belangrijk dat de gemeente ook welwillend is ten opzichte van wat wij tekenen.

Hein: Een andere element met hergebruik is ook dat het vrij moeilijk is om een render te maken of een visiebeeld. Jullie zijn nu begonnen met een SO en een VO. Maar ik loop er ook tegen aan dat sommige architecten zeggen. Eigenlijk moet je dit niet meer willen, in plaats van dat je een SO en een VO-fase in gaat met echt een plaatje dit willen we, zeggen andere architecten, nee we kijken eerst naar de materialen die we kunnen vinden.

Jullie zijn dus wel eerst begonnen met een ontwerp en een visiebeeld?

Mark: Ja, wij moesten een plaatje maken om de gemeente en iedereen te overtuigen dat wat wij gingen neerzetten de beste optie was. Iedereen is verliefd geraakt op dat plaatje. Het is eigenlijk een stukje marketing in zo'n aanbestedingsfase. Als je dat plaatje niet maakt, je maakt een leuke handschets. Dan moet je verhaal erg concreet zijn. Dat hebben we hier ook gedaan met de ondernemers die erin gingen zitten. Het betrekken van Dynamo bij het project. Dat hadden niet andere partijen.

Hoe ontwerp je met imperfecties:
Tonen van imperfecties biedt extra waarde: Je wilt de echtheid van de materialen en het karakter ook tonen. Wat ik misschien soms een beetje de laatste tijd heb geroepen is. Circulair bouwen zijn een soort van de monumenten van de toekomst. Dus hoe je het moet zien is dat een monument wordt opgeleverd. En eigenlijk het mooie wat je daarbij hebt is dat je bestaande plek hebt. Je hebt het verhaal, je voelt het als je binnenkomt. Er zit ook karakter in de plek. En wat je hier omdraait is dat de karakter niet per se in de plek zit, maar in het materiaal. Dus of jij nou weet dat dit circulair is of niet. Ik denk dat je er een ander gevoel bij krijgt dan nieuwbouw.
Meer moeilijkheden in het werk
Denk aan aansluiting details, diktes, stramienlijnen, die moete nu meer ruimte bieden voor toleranties en spelingen. Ook wordt er meer opgelost in het werk en dient de architect creatiever te denken.
Bouwproces verandert, andere bouwvolgorde.

Wanneer stap je over op een nieuw materiaal?
Afhankelijk van tijd, geld en eisen.

Waar liggen dan nu de grootste uitdagingen op het gebied van hergebruik voor architecten?
Met bouwhubs. En opslag. Want dan ligt er wel een hoop materiaal niks te doen. Dan vraag ik me af of het niet beter is om materialen zo te ontwerpen, dat je ze door de grinder kan gooien en dat er op-maat-gemaakte kozijnen van te maken zijn. Of ga je materialen upcyclen?
Terugkijkend, nu met de oude materialen, dit ontwerp maken, Ja. Maar kijkend naar de toekomst, dan zou ik zeggen. Ik bouw het, het kan uit elkaar, of delen. Kan ik het ook smelten of door de grinder heen. Ik maak gewoon een nieuw kozijn. Maar het is dan wel helemaal biobased. Een gedeelte van de oplossing moet daar gaan liggen. Want anders blijven we met hergebruik proberen.

1. Vrijheid van gemeente om af te mogen wijken van wat er wordt neergezet
2. Versnelling van processen via gemeentes > veranderingen in materialen vanwege beschikbaarheid moeten ook makkelijker bij gemeentes moeten worden aangepast
3. Schaalbaarheid > meer projecten en ook grotere projecten die meer materialen uit één donorgebouw kunnen halen bieden oplossingen.
4. Demontabelheid > Straks zou je met de nieuwe materialen van de toekomst datzelfde kozijn gewoon door de mangel moeten gooien, kunnen grinden. En een nieuw kozijn moeten kunnen maken. Gewoon dat wel past in het huidige ontwerp. Het gaat om de demontabiliteit. 'Gebouw moet een grondstoffenplek worden om in de toekomst na gerbuik weer herbruikbaar te zijn.'
5. Ik denk de komende 20 jaar zijn we nog aan het spelen en daarna hopelijk zijn we zover dat we wat we nu doen, daar dan van kunnen profiteren. Dat we van een productenmarkt naar een grondstoffenmarkt gaan. Dat is eigenlijk wat je wilt. Want van heel veel dingen, is het ook heel logisch dat we het gaan hergebruiken.
6. Wanneer ga je bouwen > bepaalt zoektocht naar materialen > opslag en kosten.

B.1. Josse Popma - Interview 17-05-24 - Summary

Partner Popma Ter Steege Architecten

Hoe heeft het project van KaVA, wat ook een soort van voorbeeldproject volgens mij moet zijn, jullie hele benadering tot hergebruik beïnvloed?
…Dus daarbij zijn we eigenlijk gewoon gaan kijken per onderdeel van het gebouw. Dus zeg maar, we hebben het over een gevel, we hebben het over een raam, we hebben het over een dak.
Alle elementen, componenten van zo'n gebouw. We hebben ons daar gewoon steeds vragen gesteld van, hoe kan je de milieuimpact van dit onderdeel beperken? Nog niet eens van, hoe kan je een hergebruikt component hierin brengen? Maar dat zou een hele goede vorm van die milieu impact naar beneden krijgen zijn.

Open houding hebben per project: gaan kijken naar de kansen die hier voor dit project liggen.. We hebben doelen, hoe we die doelen bereiken weten we nog niet precies.

- Stap 1: kijken wat kunnen we behouden en hoe het programma eventueel aangepast moet worden op wat echt nodig is.
- Stap 2: Kijken van de aanpassingen die je doet aan het gebouw. Hoe kun je het materiaal dat daar vrij komt opnieuw inzetten.
- Stap 3: Heb je aanvullende materialen nodig? Als je toch iets nieuws nodig hebt, haal wat van een andere locatie gebruikt. Vandaar en breng het hier naar het gebouwproject toe.
- Stap 4: Nieuwe elementen met gerecycled content.
- Stap 5: stap biobased materialen
- Stap 6: overstappen op nieuw materiaal.

Proberen laagje voor laagje alle gebouwelementen afgaan > van gevel, binnenwanden en casco kijken wat is er nodig en wat is beschikbaar en wat is gewenst.

- Niet begonnen met constructie!

Aan de ene kant doe je het standaard ontwerpproces: je hebt een programma; je gaat een vlekplan maken, de kavel onderzoeken, volumestudies doen, kijken hoe de logistiek in elkaar zit. Parallel, aan de andere kant ga je op dat elementenniveau kijken. Hoe ga je die elementen invullen? Die kan je natuurlijk heel lang uitwisselen. Zo doe je dat normaal gesproken natuurlijk ook. Je gaat van dat hele grote naar het kleine. Je doet nog 20 gevelstudies. Je past nog drie keer materialen of vormen aan omdat je nog aan het zoeken bent. Op zo'n soort manier kan je die onderdeeltjes heel lang blijven doorontwikkelen of aanpassen of uitwisselen.

De berustheid op toeval is op dit moment aanwezig, aangezien er een transitiefase bezig is naar een circulaire bouwwereld: Ik denk dat die flexibiliteit van er doet zich een kans voor, laten we hem pakken. Dat is niet hoe je uiteindelijk hoopt dat de bouwindustrie zich gaat ontwikkelen naar een circulaire industrie.

1. Donorgebouw zoeken dat past bij het ontwerp van het nieuwe gebouw en aansluit op de mogelijke functies. Een onderzoek en onderdeel van het ontwerp wordt ook een schouw doen door het donorgebouw of inventarisatie van de mogelijke bouwmaterialen en componenten, hierdoor al een beter beeld van mogelijkheden en hoe je bepaalde materialen zou kunnen gebruiken en waar je iets mee moet doen, ik termen van brandvoorschriften en het bestaande materiaal herontwerpen of refurbishen om te voldoen aan huidige eisen.
2. Geleerd dat de staaltransplantatie niet meer halverwege het proces moeten regelen, maar dit nu aan de voorkant georganiseerd moet worden. Aannemer en sloper in het begin geïnformeerd over de ideeën en betrokken in het bouwteam.

3. Als architect lopen door de donorgebouwen en letterlijk kijken wat kunnen we gebruiken in een nieuw ontwerp en wat kunnen we inpassen.

    a. Hoe gaan je om met maatvoering
    b. Past dat in ritme/stramienmaat
    c. Wat voor effecten heeft het
    d. Moet moet je daar nog tegenover stellen om het beeld te krijgen wat je wilt hebben
4. In de initiatieffase
    a. Plan van aanpak presenteren. Dus met wie ga je het doen, het bouwteam? Hoe ga je het doen? Hoe ga je met risico's om? Hoe ga je met planning om? Wat doe je als je het niet kan vinden?
    b. Binnen een plafondbedrag haalbaar maken
5. Beginfase wel andere partijen betrekken, maar bij innovatieve projecten moet je dat altijd doen, het is echt niet de enige oplossing.
    a. Het is ook fijn bij deze nieuwe en ingewikkelde projecten om ervaring te hebben en partijen moeten het echt ook willen.

Dat inventariseren van materialen en bouwcomponenten moet je parallel met je ontwerpproces ook een beetje van grof naar fijn doen.
En dan moet je dus een manier vinden dat je eerst grof inventariseert, keuzes maakt en dan zegt oké, dat en dat en dat is voor ons project belangrijk. Dus daar gaan we nu verder mee en iets mee doen. En dan hebben we een ontwerpidee. Terwijl wij op dit moment eigenlijk nog juist wel vaak inspiratie ook halen. Door juist keuzes te maken. Ondertussen weten we best wel een beetje wat er veel voorhanden is. Je kunt om je heen kijken en je weet in Nederland waar gebouwen mee gemaakt worden. En daar komen gigantische hoeveelheden materialen weer van vrij. Dus het is soms juist ook wel zinnig om te zeggen. Nou ja, waarschijnlijk is dit en dit en dit voorhanden.

Wat je misschien tijdens je zoektocht tegenkomt. Probeer het aan de andere kant ook specifiek te maken. Zodat je het kan gaan verzamelen en dan kun je gaan testen. Die muur waar ik net over had. Die is eerst begonnen met stapelen van stenen. Die muur is vijf meter hoog. We willen nog allerlei ramen en dingen in. Met betontegels doen? Dat wordt alleen maar grijs. Dus wat voor straatstenen, hoe ga je dat dan metselen? Misschien met je één lagenmaat vastleggen. Dus als je dan op een gegeven moment stenen gaat verzamelen. Dan zeg ik. Als we nou allemaal klinkers maken. Die kunnen we makkelijker krijgen.
Die zijn los. Hoeveel variatie is daarin? Hoe kunnen we dat terugbrengen naar een aantal maten. Die veel voorkomen. Zodat we die kunnen verzamelen. Met koppen maten werken. Dan weet je hoe groot je ramen openingen worden.
En dan hebben we die stenen nog niet. Maar nu weten we wel. We hebben vier type stenen. Een waal formaat. Een dik formaat. En dat kunnen we nu... We weten ook. We hebben er 30.000 van die nodig. En 20000 van die nodig. Dan kan je dat gaan bedenken. Hoe stapelen we ze. Zodat al die patronen door elkaar bij die metselaar komen. Maar dat gaat zo langzaam. Net als met een normaal ontwerp. Specifieker maken. Dus eigenlijk blijven we iteratief bezig.

Hoe ontwerp je met imperfecties:

- Aannemers zijn geen ontwerpers, dus niet de oplossingen in het werk aan hen overlaten. Je moet veel anticiperen en alles hebben voorbereid en hebben doordacht, aangezien het inderdaad klopt dat er meer speling is en meer flexibiliteit in het bouwen.
- Het is fijn als bouwers meedenken, en de wisselwerking is belangrijk, maar de architect blijft ontwerper.
- Alles voorbereiden en dan een bestek maken.
- Specifieker detailleren
- Architect moet zich echt meer verdiepen in het bouwen en in de materialen. Hoe werkt een element, wat voor eisen zijn er nodig, aangezien het geen nieuwe materialen zijn.
- Met partijen kijken naar de materialen die er zijn en kijken hoe het aangepast kan worden: technisch, esthetisch en transport, etc.

Wanneer stap je over op een nieuw materiaal?

- …Ik denk dat één van de afwegingen kan zijn: 1.) Wat is de impact van het nieuwe materiaal? Milieu-impact. Terugkomend, eerst de circulaire ambities opschrijven en vormen > dan weet je in ieder geval waar je absoluut geen interventies gaat doen met nieuwe materialen en waar je juist meer speling hebt zonder dat de architectuur in het beding komt.
- 'pick your battle' > Als architect streef je het ontwerp na > waar mogen wel en waar geen aanpassingen komen.

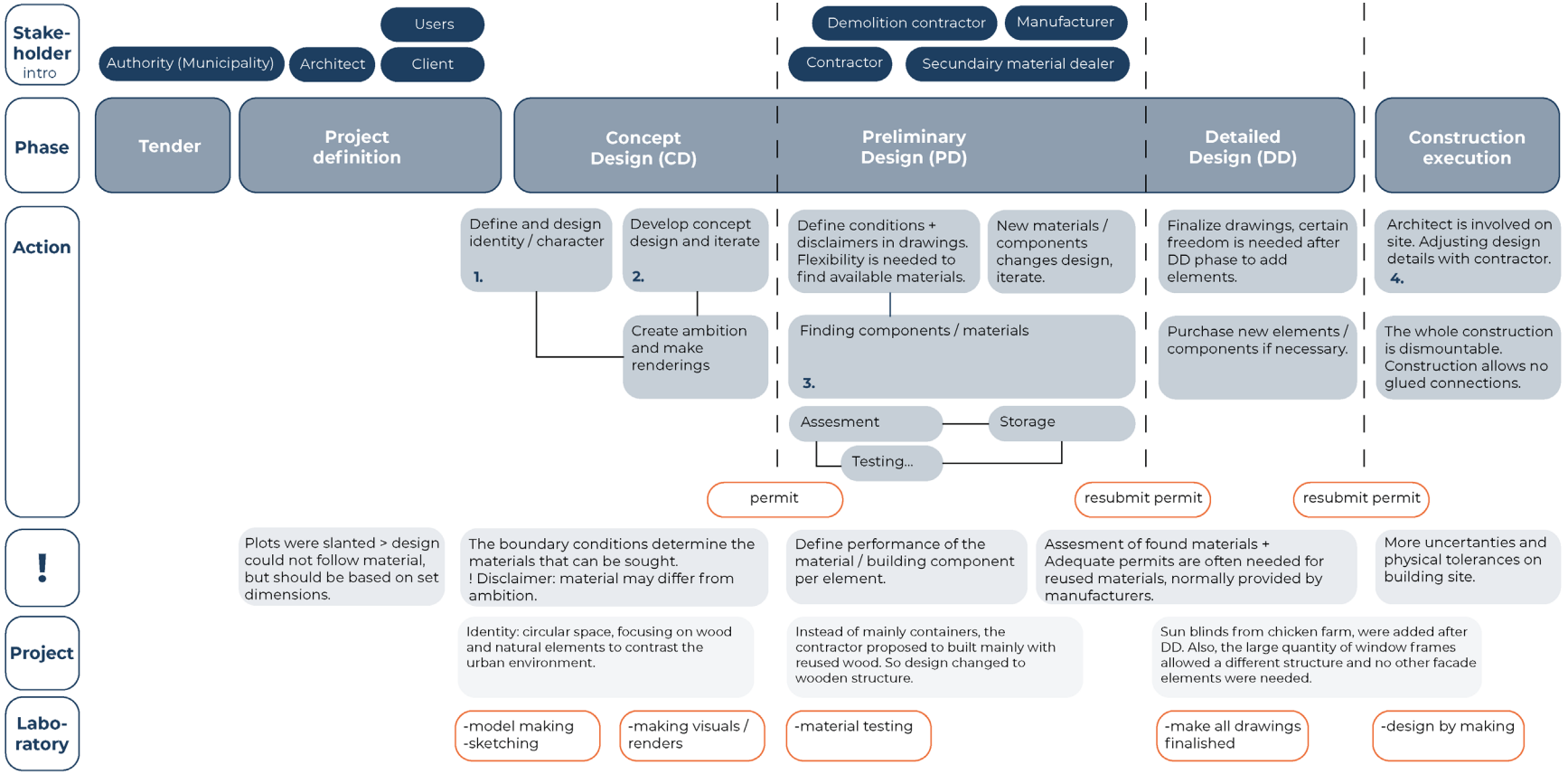
Maar waar liggen dan nu de grootste uitdagingen op het gebied van hergebruik voor architecten?

- De transitie naar hergebruik moet in stappen. Het kan niet 100%, maar juist door deze ambitie meteen op papier te zetten worden er al wel concretere plannen gemaakt en vanaf het begin moet de ontwerper en architect dan ook nadenken over hoe en waar we hergebruikte bouwmaterialen kunnen inzetten.
- De schaalbaarheid van de projecten > het lukt nu op een schaal van 2000m2, maar naar grotere schalen moet in etappes. Het ontwikkelen van meer projecten die inzetten op hergebruik toont ook meer mogelijkheden en daardoor doet de praktijk kennis en methodes op.
- Begin met onderdelen die echt impact maken op het milieu.
- Het enthousiasmeren van andere stakeholders en opdrachtgevers

APPENDIX C – CONCLUSIONS CASE STUDIES

C.1. Kokomo – Renderings + photo of project by Apto Architecten

C.2. Kokomo – design principles applied by Apto Architecten



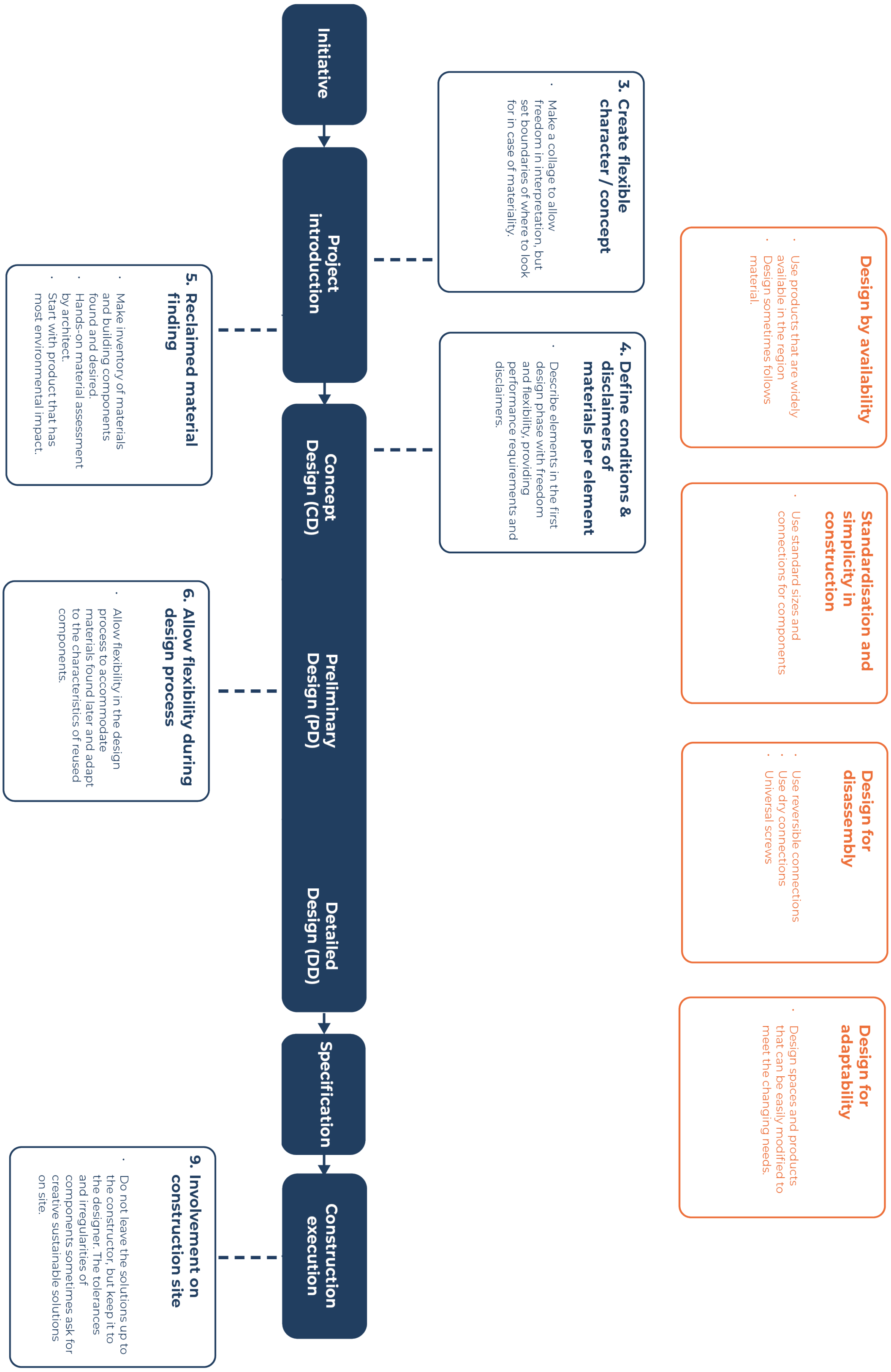
1. Defines the direction of the design, within these boundaries the project will be realised. Design from the identity and character as an ecosystem. Do not design, as usual, from the space.

2. 'The ambition is visualised in renderings and puts sets the boundaries. Now the team nows what materials the look for within the identity of the new building.

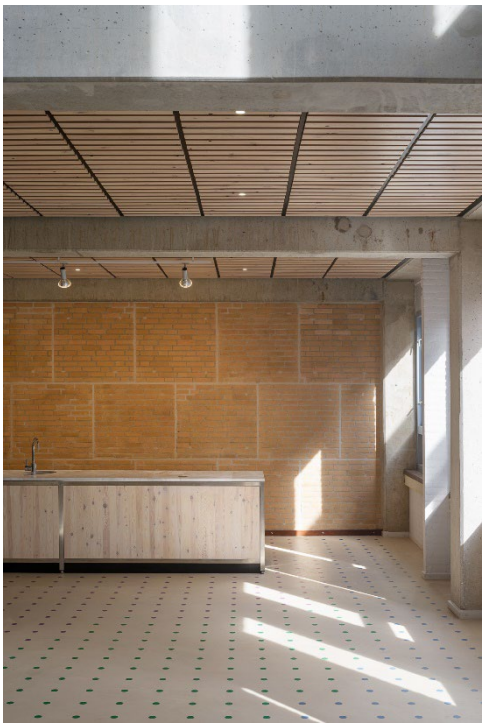
3. Materials were looked for by all collaboration partners: contractor and architect via: materialhubs, LinkedIn, contacts and a donor building. See > harvest map.

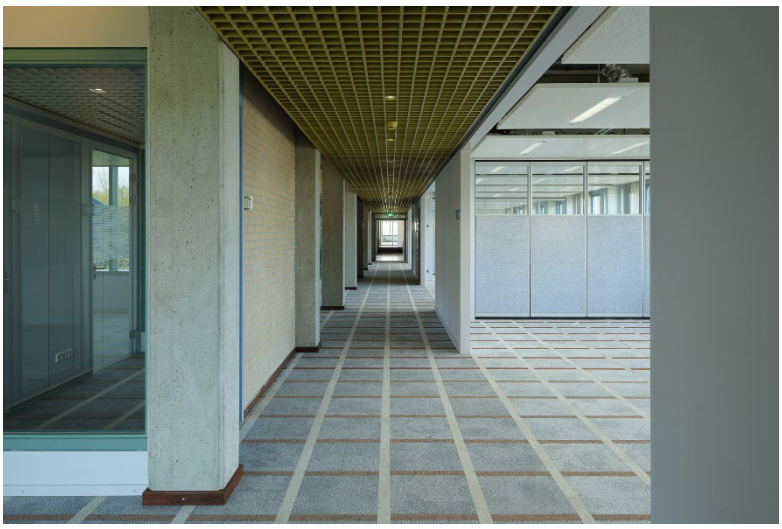
4. Sometimes, gaps and openings need to be creatively resolved, avoiding unsustainable solutions like using polyurethane foam.

C.3. Kokomo – design principles in conclusion

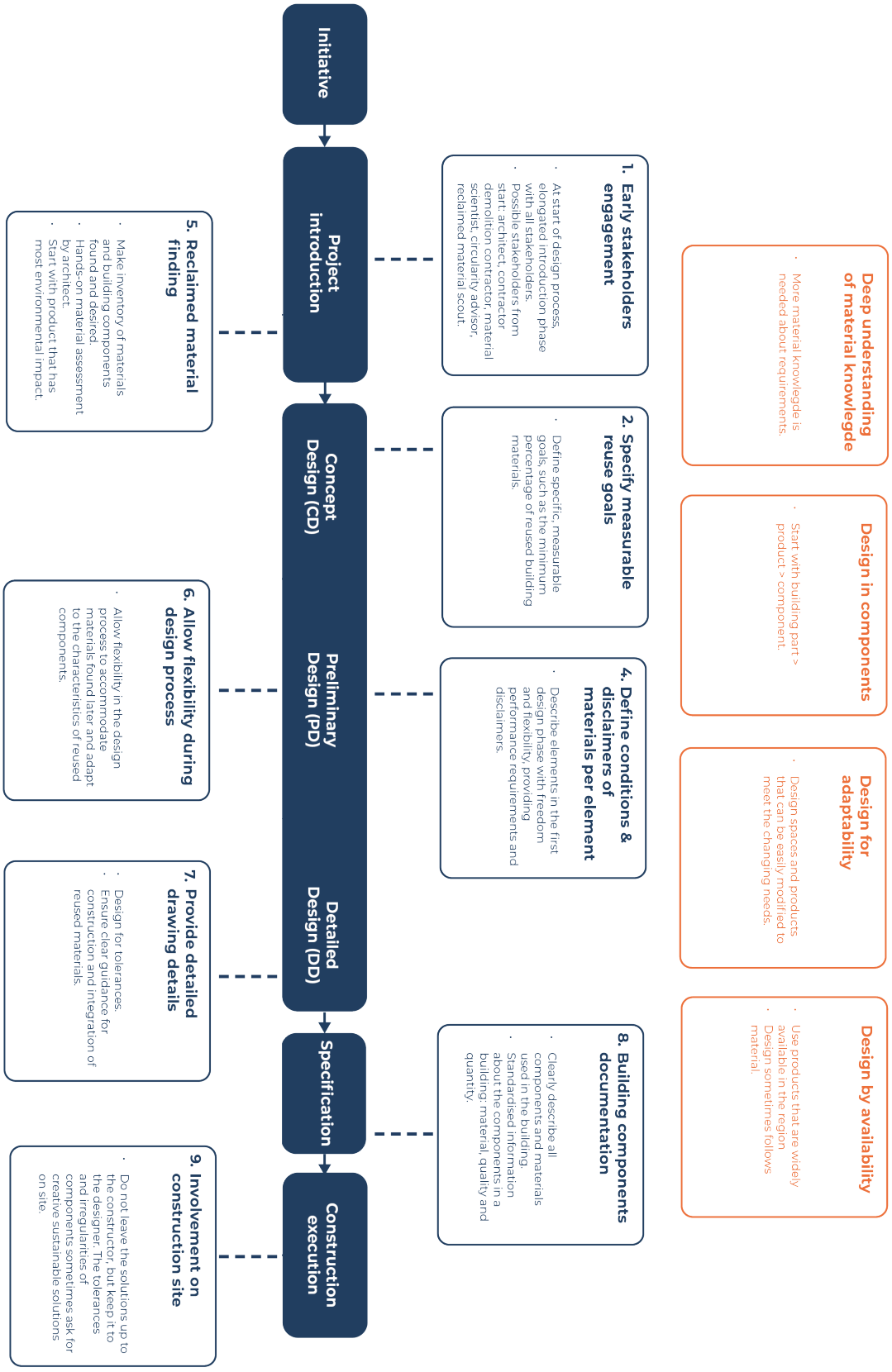


C.4. KaVa - Renderings + photo of project by Popma Ter Steege Architecten





C.5. KaVA - design principles in conclusion



APPENDIX D – DESIGN PROCESS PRINCIPLES & STRATEGIES

D.1. Nine identified design principles

1. Early stakeholders engagement

- At start of design process, elongated introduction phase with all stakeholders.
- Possible stakeholders from start: architect, contractor demolition contractor, material scientist, circularity advisor, reclaimed material scout.

2. Specify measurable reuse goals

- Define specific, measurable goals, such as the minimum percentage of reused building materials.

3. Create flexible character / concept

- Make a collage to allow freedom in interpretation, but set boundaries of where to look for in case of materiality.

4. Define conditions & disclaimers of materials per element

- Describe elements in the first design phase with freedom and flexibility, providing performance requirements and disclaimers.

5. Reclaimed material finding

- Make inventory of materials and building components found and desired.
- Hands-on material assessment by architect.
- Start with product that has most environmental impact.

6. Allow flexibility during design process

- Allow flexibility in the design process to accommodate materials found later and adapt to the characteristics of reused components.

7. Provide detailed drawing details

- Design for tolerances.
- Ensure clear guidance for construction and integration of reused materials.

8. Building components documentation

- Clearly describe all components and materials used in the building.
- Standardised information about the components in a building: material, quality and quantity.

9. Involvement on construction site

- Do not leave the solutions up to the constructor, but keep it to the designer. The tolerances and irregularities of components sometimes ask for creative sustainable solutions on site.

D.2. Six design strategies

Standardisation and simplicity in construction

- Use standard sizes and connections for components

Deep understanding of material knowlegde

- More material knowlegde is needed about requirements.

Design for disassembly

- Use reversible connections
- Use dry connections
- Universal screws

Design by availability

- Use products that are widely available in the region
- Design sometimes follows material.

Design in components

- Start with building part > product > component.

Design for adaptability

- Design spaces and products that can be easily modified to meet the changing needs.

D.3. Design process with principles for optimal reuse of materials.