REFLECTION:

ZERO-WASTE MASS-TIMBER RESIDENTIAL HIGH-RISE

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This reflection is a part of the graduation project '*Zero-waste mass-timber residential highrise*' and the research paper associated with it '*Designing a zero-waste mass-timber high-rise load-bearing structure*' . It reflects on the research and the design performed in this graduation project. This reflection consists out of five parts.

The first part will reflect on the relevance of this project and the relationship to the graduation studio and the wider framework. The second part discusses the design product as a background for the other sections. Thirdly, a reflection on the applied method and approach is elaborated. The fourth section discussed the relationship between the research and design, as well as the feedback from the different tutors during the process. It also compares the process to academic literature about research and design. The last section concludes the reflection and answers the research questions as posed in the graduation plan, as well as reflecting on the finished design product.

I. TOPIC AND RELEVANCE

The graduation topic '*Zero-Waste Mass-Timber Residential High-Rise'* was chosen based on the topic '*A Million Homes'*. The gradation project is related to the *Architectural Engineering* studio within the direction of '*Make*'. The context for the topic was related of *Amstel III* in Amsterdam. The chosen topic reacts to the urbanization problems in the Netherlands, which has the ambition to create a million new homes by the year 2030. But the subject is also related to the global urbanization trends.

This theme determined the program of the building (residential) and also inspired the scale of the project. The proposed solution to the problem is to densify the existing building stock by replacing concrete and masonry buildings with lightweight high-rise timber structures which can extent higher and therefore house more residents compared to the original buildings. At the same time, the new made buildings should be designed in such a way to prevent the waste of resources at the end of life, which is an increasing problem as stated in the research paper. Hence it was chosen to design according to zero-waste design rules. The project extends and applies the research earlier performed in *A Zero-Waste approach in the design of buildings* (de Lange & van Houten, 2016).

Mass-timber high-rise buildings are at the moment of this graduation study at the cutting edge of architectural technology. The material '*mass-timber'* provides a set of challenges in creating high-rise buildings, such as fire safety and dealing with high wind loads. This graduation project explores these problems. It incorporates lessons learned from other existing high-rise mass-timber structures and also explores the different mass-timber materials available. The findings in this graduation project can be used for other architectural designs.

The zero-waste aspect adds another dimension and additional challenges to the mass-timber material and to architecture in general, as end of life situations are often overlooked (Crowther, 2002, p. 6). This method is related to preserve materials and their embodied energy. Zero-waste design is a different way of designing and requires a different mindset to conventional architecture. Common assumptions in architectural design become irrelevant. Each component, its connection and material has to be carefully considered. Especially the connecting elements become important.

II. DESIGN PRODUCT

This section shortly discusses the design as a background for the following sections. The finished design is a high-rise residential building with a mass-timber structure. It is a large closed building block, extending 96m in height with an enclosed open atrium. The mass-timber has been used as an architectural expression in the form of a diagrid exoskeleton, defining the look of the building, placed on the concrete foundation of the existing office buildings. It also forms the primary solution in flexible use of the building, making it future proof for reuse, a primary requirement for zero-waste design. The exoskeleton allows for completely flexible floor plans. The floor system has been designed as cassettes which house the installations, piping, wiring and other climate applications.

Strategically placed gaps in the building block form public space for the residents to enjoy, while at the same time reducing wind loads on the structure. Daylight is introduced into the central atrium of the building by a large cut-out in the south side of the building. This provides the apartments with an interesting double oriented lay-out and effects the quality of the internal atrium space of the building. The cut-out also reduces the total weight of the building on the existing concrete foundation. The ground floor levels provide service areas such as parking, storage, installations and waste facilities, as well as commercial space in the plinth. The public space created on the first floor becomes the new surface level, where the timber structure interacts with the existing concrete basement, spreading its loads across the entire surface.

All the materials used in the design are fully recyclable, with the exception of standard double glazing systems and the final finishing which can be applied by the end user. Mass-timber forms the majority of the structure, consisting of dowel laminated timber columns and beams and laminated veneer lumber floor cassettes. Timber boards are used for cladding, ceilings and flooring. Dowel laminated timber panels with rockwool insulation form easy to change separation walls. The facades are filled with timber window frames. Water proofing of the roofs, balconies and galleries is created using an aluminum cladding system. Gaps and joints are sealed using cork.

III. METHOD AND APPROACH

This section discusses the methods used in the research and the design. The Architectural Engineering studio focuses on new technologies as inspiration; contribution to the architectural design and improving social issues. Functional, material and technical aspects are central.

In this graduation project the overall approach followed a heuristic methodology. In short, this means that rules of thumb are applied or extrapolated to reach a solution for a problem. These rules are in general derived from experience or from references (Calle-Escobar, Meija-Gutierrez, Nadeau, & Pailhes, 2014). The design and research of this study are focused on the properties of mass-timber, zero-waste and high-rise design. The research is used to establish precedents and knowledge, which can then be used to build upon during the design. A method as also described by Gray, Seifert, Yilmaz, Daly, and Gonzalez (2016).

The research section consisted of a research paper towards *'Designing a zero-waste mass-timber high-rise load-bearing structure'*. In this paper four subjects were explored: zero-waste design and its requirements, mass-timber high-rise structures, extending existing structures vertically and the material properties of mass-timber. For the zero-waste design and the material properties, literature study was used as a method. For the other two aspects, case studies were used to examine the state of the art in building tall with mass-timber and the possibilities to extend existing structures. Also, for the material properties the information as provided by several suppliers was studied.

The design process follows a heuristic methodology based primarily. In this particular study, the specifications of mass-timber and the requirements for zero-waste design are the ‘rules of thumb’ of the design process. Each consideration and each design step were tested to the findings of the research. Additional questions that rose during the design were researched during the process. This was mainly research into the zero-waste qualities of materials, such as for example plaster and mineral wool, into requirements of the target groups or the design aspects of micro apartments.

The described method and approach was a foundation for a (scientific) relevance of the design. The case studies and the research into material properties created a knowledge base containing design solutions which could be applied during the process (the ‘rules of thumb’ as described earlier). Each design step could be argued from the standpoint of the goals of the study.

Planning was an integrated part during the research and design. In order to limit time spending on certain tasks, or in order to encourage to spend more time on other subjects, a planning was made for each period in the graduation process. The tasks were broken down in main aspects and given time frames. A more detailed planning was made each week using a logbook. This logbook contained the planning and was also used to note down what was done on each day. This approach gave a structured time designation to each subject and provided a backbone to the process.

IV. RESEARCH AND DESIGN

This section discusses the research and design process. First a description is given of the process of this graduation. Then other processes are discussed from literature. The last section compares the applied approach and process of this study with the literature.

During the graduation timespan my personal perception of the relation between research and design has changed. At first, during the period towards the P2 where the research paper stood central in the process, the design was created as a direct result of the research. The philosophy behind this approach was that each design step could be substantiated. The structural use of mass-timber and the zero-waste design methods dictated the design choices. The architectural and social aspects, which were to create a residential building of a high density with high quality public spaces, became a secondary objective. This resulted in a unsatisfactory, one-sided and overly complex design. The process has been illustrated in figure 1.

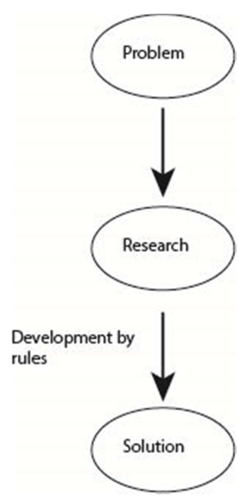

Figure 1. Used method during the P2 period

The P2 presentation and the following feedback were a tipping point, resulting in a different approach in the research and design of this graduation project. The findings in the book *Lateral Thinking* by Edward de Bono, as recommended by my tutor, opened up new approaches on how to design. Instead of only thinking vertically, as a progression of choices, the process could also be horizontally, creating new approaches to the problem. The architectural, social and functional requirements became equally important compared to the research. The lateral approach also allowed for design options where a single requirement was explored which was then integrated into the whole. A representation has been made in the diagram shown in figure 2.

This approach worked better towards the P4. Multiple aspects could be stacked into the design without fully compromising the total architectural concept. Massing, daylight, functional program, social design, climate and structure form a delicate balance in the design choices. In the end, the finished design is not fully zero-waste as first intended (Chapter V), but it did succeed in combining the different aspects into a coherent design.

Feedback given by the different tutors were directly written down in short punctual notes after the feedback session. This feedback was combined with the now more circular or lateral approach. Notable feedback came at the P2 presentation regarding the design approach as previously explained. It was also commented that the design should not be too complex. Other important feedback was on the technical design of the water proofing of the roofs; to respect the load bearing capacity of the existing structure, and incorporating social and functional requirements in the design.

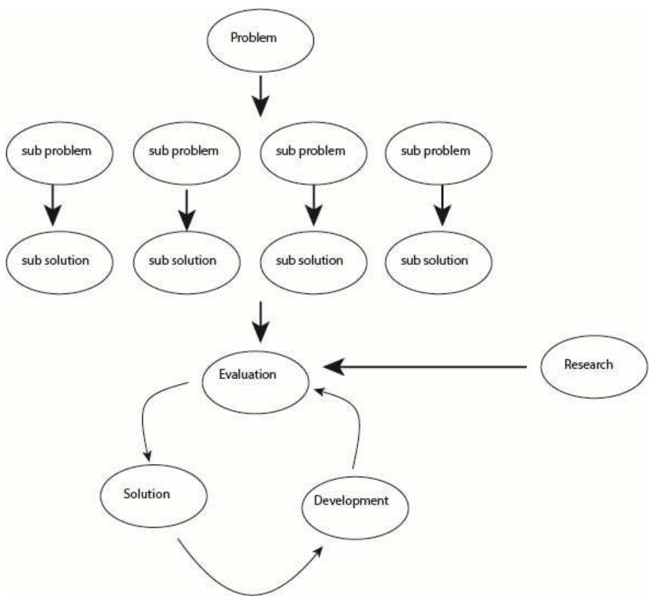

Figure 2. Used method during the P3 and P4 period

The design process has also been studied by N. Cross in Research in design Thinking (Cross, 1991). He states that design problems are poorly stated assignments. The problems are often explored using drawings and models. The solution is not a logical consequence of the problem, but by simultaneously working on a design and the understanding of the problem, the understanding of the problem in increased, which then also enhances the design. This is shown in figure 3. Alternative design solutions are often used to understand different perspectives. This has also been found and recommended by de Bono as described earlier (de Bono, 1970).

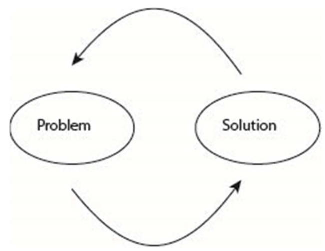

Figure 3. Representation of the method of designing by Cross (1991)

In other literature the design process is defined using a cyclical model. Evaluation and feedback are central in the design process (Crawford, 2004). Because evaluation is central during the process, the design is tested multiple times against the requirements. This can be repeated endlessly or stopped when a satisfied solution has been achieved. This model is illustrated in figure 4.

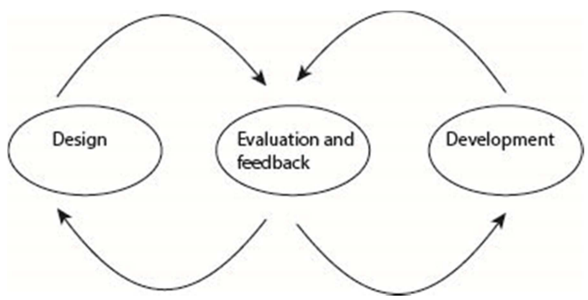

Figure 4. Cyclical model by Crawford (2004, p416)

Roozenburg and Cross (1991) discuss a hybrid model, combining the linear engineering process and the cyclical process of the architectural and (industrial) design sectors. The model consists of a series of activities: clarifying objectives, establishing functions, setting requirements, generating alternatives, evaluating alternatives, improving details. These activities can be addressed from anywhere within the process of defining the problem and the solution. The designer is working between problem/sub-problem and solution/sub-solution. This model is shown in figure 5.

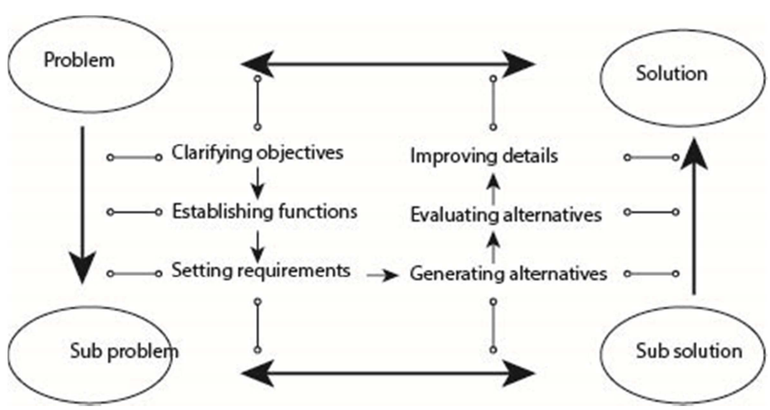

Figure 5. Model of Roozenburg and Cross (1991, p219)

The model by Roozenburg and Cross (1991) is arguably closest to the process in this graduation study. It is also a good representation of the complexity of a research and design process, compared to the more simple model Crawford (2004). The importance of a thoughtful process has been ignored during this graduation study, focusing more on the methodology. This process should however be more integrated into the methodology and methods employed during a research and design.

V. Conclusions and reflection

The goal of this research was to explore the possibilities of sustainable densification in cities using zero-waste timber high-rises. The overall question was how these buildings contribute to sustainable densification in Amsterdam. Mass-timber can be used to extend existing structures, densifying the city. The material is fully recyclable and by designing for zero-waste, these buildings are flexible in use and produce no waste at the end of life.

Densification can be achieved by extending buildings directly, using latent strengths in the load bearing structure, or by stripping structures of heavy traditional materials such as concrete or masonry and replacing it by lightweight mass-timber to achieve greater heights and thus more space. Zero-waste design requires careful thought in the design process to separate the materials and components, as well as the use of fully recyclable or renewable materials.

When designing high-rise structures with mass-timber, the effects of wind loads should be considered. Stability is a major design influence and because of the lightness of the material, tipping over of the building should be prevented. A larger footprint is a solution of solving this problem.

In this design densification has been achieved by replacing three concrete office buildings with a mass timer residential building. The gross floor area of this site has been roughly doubled compared to the original buildings. At the same time, the increased density has been compensated with public and collective space by creating parks at three levels. Architectural solutions have been implemented to create a higher quality of living in the building: high ceiling heights of 3,5m, gallery separated from the façade, two-way-oriented apartments and large collective space.

A fully zero-waste design has not been achieved: the spacers and sealants in insulated glass panels, the concrete basement structure and membranes are not regarded as zero-waste because these materials are not fully recyclable. This is however a small part of the total building. The majority of the building has been designed to be fully demountable and fully recyclable. This has been achieved by using recyclable materials (mass timber, aluminum, glass, cork, mineral wool, plaster-board, steel) and by using demountable connections (bolts, plugs, screws). All of the individual elements (floor elements, columns, nodes, walls, windows, floor and ceiling) can be reused or recycled.

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