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PROPOSAL OF INTERACTIVE WORKFLOW FOR CIRCULAR TIMBER STRUCTURE DESIGN

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ABSTRACT: The methodology and design methods are often neglected and not discussed as indicators for the popularization of circular design. In this paper, which is part of ongoing research, we propose a design strategy and method for designing a building from reclaimed wooden elements, based on the actual building project case study in Oslo. The design method is a plugin for the Algorithms-Aided Design environment integrated with the database of available reclaimed elements. The plugin is based on algorithms suggesting suitable elements from the database in real-time. This helps the designer in tedious selection processes. Used in the concept and engineering phase of the building process, it can save time and rationalize design choices. The optimization objective is the structural performance and environmental impact of the final structure.

KEYWORDS: knowledge-based design, circular economy, timber structures, parametric modelling, algorithm aided design

1 INTRODUCTION

Timber products are light, relatively sustainable and have a good strength to density ratio. Increasing the usage of timber in construction is one of the priorities to decrease the environmental impact of the building sector[1]. The annual production of timber products is growing yearly worldwide, at the same time, timber production is limited by the sustainable forestry area in every country[2]. Some countries are already at the limit of their wood production capacity. Moreover, the use of timber is limited by the material price, which increased significantly in recent years [3].

Timber elements usually end their life being downgraded or burnt after the demolition of the building [4]. Downgraded timber elements sometimes come back to the building industry as plywood or other derivative products. Those products often require chemicals, such as glues, which make them structurally weaker, less sustainable, and sometimes more toxic. Every operation made to downgrade or even upgrade the timber product will lead to an increase in CO2 emission.

Today, the designed life span of the building is only 50 years [5]. The growing population of cities and changes in lifestyles require us to build higher and bigger buildings. In most of those buildings, the trouble with the structural system was not the leading cause of demolition[6]. Often the structural (load-bearing) elements are wasted, although they are in good technical condition and could be in use for the next decades. Timber elements are even great loss because the timber absorbs stresses with time, and it is rational to use it with a long lifetime.

To encourage engineers to involve circular economy aspects in the design, international standards have been created [7]. In those standards, it is highly recommended to pay attention to sustainability aspects of the structure already at the conceptual stage when it is still cost-effective. Our research group focuses mostly on conceptual timber design [8]. In this article, we want to show the study case in which the key concepts of the circular economy have been applied in digital design.

We observe a need for developing methods and methodologies to increase the usage of reclaimed timber elements in the building sector. The number of scientific articles, start-ups, and projects involving reclaimed timber is growing yearly. From a circular economy perspective, the ideal situation would be to extend the lifetime of buildings and not demolish but just renovate or repair them. Unfortunately, in many cases, the topology of the building must change. In this scenario, the reuse of deconstructed elements should be the priority.

The reusing of timber elements can be split in several steps. One of the most important is the timber classification. Many timber elements have been in use for decades. Timber properties can change due to rheology

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and defects. Those information have to be set and preferably digitalized to be useful in common design process. After assessing all of the information, the database can be generated. The database should be usable in the design environment to provide an immediate feedback. It means that the access to the database should be provide directly from design software.

1.1 OBJECTIVES

The aim of this project is to show a possible change in the methodology of design by implementing a computational design method focused on using the available stock of reclaimed materials , also called Material Bank [9]). This project uses as a study case the design process for a small timber building in Oslo. The building called "Sletteløkka" is a timber extension of the existing building. It has its own supporting system built on the axial grid with a spacing of 2.5 meters. The length of the building is 10 meters, and the width is 5 meters. It has two stories with a floor height of 2.6 meters. The rooftop is placed 7.1 meters above the ground.

This project illustrates one possible computational method and methodology of conceptual design to reuse timber elements. Gathering the material stock (used elements), creating a digital material bank (a database with the digital representation of timber elements) and finally using a material bank in the conceptual and engineering design deliver several unknowns and important issues. How can we design from used elements? What is the best design strategy for the circular economy? How can the new technologies improve designing from material stock? How can we involve timber-specific mechanical properties and imperfections already in the concept design? How will reclaimed elements influence the structural and architectural performance of the building? Those are questions addressed in this work.

1.2 METHODOLOGY

This is a proof-of-concept paper describing an innovative strategy of supporting the design. In common design strategy, the decisions are in the linear form. Design steps must follow the decision made in the previous phase. Very often, choosing the cross-section of the elements is the last decision made by the architect or structural engineer. In design based on the circular economy, the geometry of the available reclaimed elements strongly impacts the design space. The designer has access to limited elements with limited shapes and sizes. Moreover, from an environmental perspective, the more reclaimed elements are used from material bank the more sustainable structure is. These facts demand implementing methodology with automated design methods. This design method should automatically map elements from the database with the building concept.

In a project like this, the methodology should use available design methods in the best way. This way, one of the challenges of designing with reused elements, namely the assignment of old elements to appropriate positions can be solved. The tool for matching old and new elements is a necessity in this project. Moreover, the whole concept design should be made in a more generative way. In this project, we used the Rhino/Grasshopper environment to apply a parametric workflow and to open the project for possible quick modification or optimization.

2 DESIGN AND WORKFLOW CREATION PROCESS

2.1 IDEA - BUILDING

The function of the building is a social, open-for-public space. With the help from the municipality of Oslo, volunteers and resident from Sletteløkka and Bydel Bjerke, together with the architects, initiated this project in 2019. Thereby providing a social space for all residents in the area. The architectural assumptions are to create an open and easy-access two-storey building. It should be accessible from both floors, and it should be easy to build. Since the neighbourhood society could be involved in erecting the building. One of the design limitations is that building from one side is touching the existing shop (see figure 1), but structurally it should be an independent structure. It means that the stiffness and structural performance of the structure does not depend on the surrounding structure.

Figure 1: *Front façade of the structure, on the right side of the structure, it is visible the existing shop building.*

However, the building is not as important as the materials which will be used to build it. The design team assumed to use as many reclaimed elements as possible. The reclaimed elements are used to create a primal structural system and also to use in not load-bearing elements. The façade system for the glass panels is produced from Japanese timber[7]. The elements used to create the structural system come from deconstructing an old barn in south Norway. In figures 2 and 3 the elements are marked with different colours and annotations, depending on their source. Norwegian timber has been reclassified as at least C30, and it can be used for structural elements. Timber from Japan is Japanese cedar (Cryptomeria japonica). It is a little bit weaker and elements from it has been dedicated only to transferring external forces to the main system.

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Most of the elements have been 3D scanned from outside and physically tested on the macroscopic level.

2.2 IDEA - FRAMEWORK

The objective of this research is to find an appropriate design strategy to enable building it with reused elements. The design strategy, which follows and methods are algorithms, software, and tools which can lead to making this strategy as efficient as possible. Before it is explained how the framework has been applied, the assumptions are highlighted:

- In this project, the structural elements' database is known, but the design object can be adjusted. It is then needed to maximize the usage of those elements and, by this, increase the sustainability of the building
- The project is led by architects who would like not to change their habits to work in computational design. It is, therefore, necessary to implement a framework inside the design software, preferably with optimization working in the background.
- All the design decisions should be based on structural analysis. The algorithms should be using Finite Element Method (FEM) as the basic investigation tool.

Complying with these statements, the conceptual design is based on the parametric model made in Rhino and Grasshopper. Using this environment allows the inputs that define the geometry can be changed and adjusted. The axis spacing, floor height, roof angle or bracing position can be easily changed. The structural analysis of the structure is made in Karamba3D, which is merged with the parametric model. The outcome of Finite Element Analysis (FEA) is utilization and deformation. After creating an interesting topology of the structure and assigning sections, the matching algorithm is connected. After assigning the elements from the material bank one more time, the FEA proceeded. The last structural analysis is finally checking all the ULS and SLS criteria of the building (see the scheme of the framework in the figure 5).

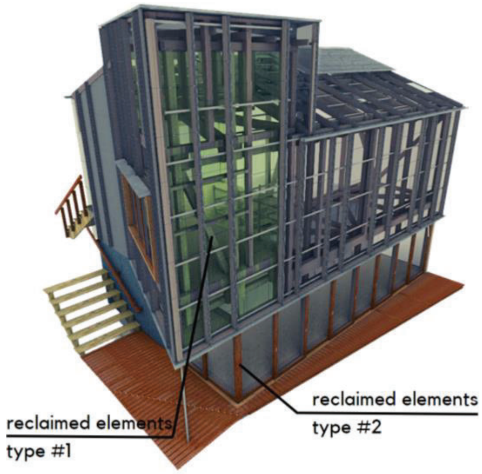

Figure 2: *General view of the structure with the facade, type #1 elements come from Norway, type #2 come from Japan.*

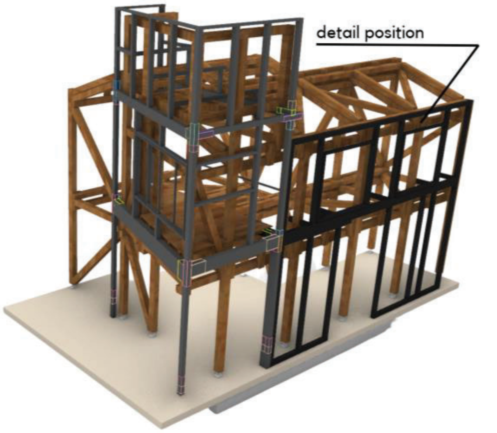

Figure 3: *General view of the structure without the facade, brown elements come from Norway, gray and black elements come from Japan.*

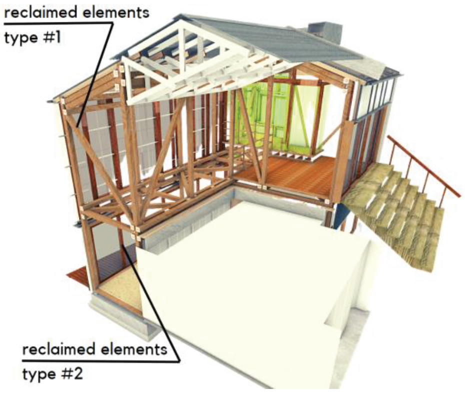

Figure 4: *General view of the structure from inside, type #1 elements come from Norway, type #2 come from Japan.*

The framework is oriented to maximize the usage of reclaimed timber elements in the structure from the available elements in the material bank. The algorithm to map the elements from the material bank has been created as a Python tool [Insert Artur et. al] with a wrapper for using it in Grasshopper. To create a material bank, we scanned (see figure 6) or measured available elements. The information about them are stored in a database which is available during the design and can be changed at any time. Since timber is an orthotropic material which has the best performance in the direction longitudinal to the grain, the decision was made to adjust optimization algorithms towards beam elements. It means that the axial direction of the elements is leading the matching algorithms. After scanning of reclaimed elements, the mesh is imported into Grasshopper where the length, and cross-sectional data needed for the material bank is extracted.

Figure 7 illustrates how different design options obtains different placement and amount of reclaimed elements in the database. This way, multiple options can quickly be evaluated and compared with regards to sustainability in addition to all other aspects. The idea of the framework is to deliver the designer a tool which, in real-time, will be reacting to topological changes in the building system. It means that if the designer changes the topology, the algorithm should automatically propose the best location of the available materials from the stock. The matching algorithm tries to assign the elements from the material bank to the design structure based on the specific features. The cross-section of the element from the material bank cannot be smaller than those from the structural analysis made before matching, and the length of the element cannot be shorter than the ones in the design model. Also, the algorithm to avoid locations of pockets (fabrication elements for detail generation) and imperfections cannot be in the sensitive places of beams and columns.

Figure 8 is a final presentation of the matching algorithm; each colour link is connecting elements from the databank to design model.

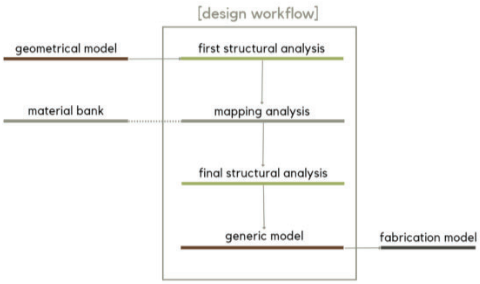

Figure 5: *Scheme of the framework.*

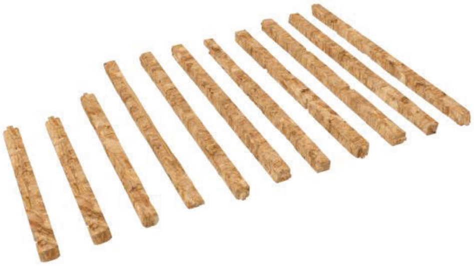

Figure 6: *Scans of reclaimed timber elements.*

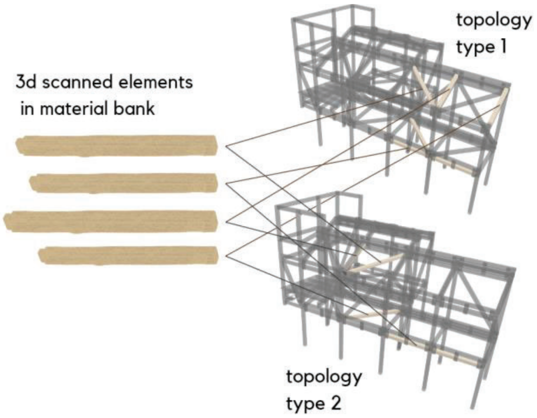

Figure 7: *The concept of the framework.*

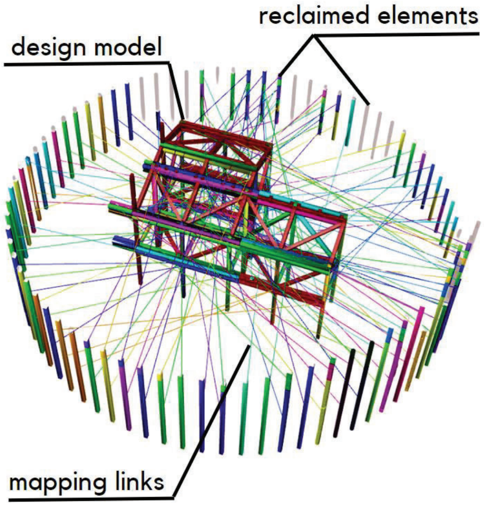

Figure 8: *The visualization of the matching produced by the algorithm.*

2.3 THE FINAL DESIGN

The timber building is designed to resist dead and live loads. The building is a public space category and has to resist 5kN/m2 on every floor. The snow load on the roof is estimated to be 3.8 kN/m2. The wind load of magnitude 0.3 kN/m2 is considered from three sides.

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As mentioned before, the stock of timber elements origins from an old barn deconstruction. Figure 6 presents 3D-scans of some elements after deconstruction. The specialist categorized the timber quality as C30. A lot of elements have small imperfections, and the endings of the elements have the remains of the old joint systems. To see all those defects and judge if they comply with the architectural vision, we decided to include a 3Dscan of the material bank. Each element was scanned and represented with a 3D mesh with texture. What is also important, precise digital representation of the elements allow to involve the imperfections in the matching algorithm. matching

In this particular design, it occurred that the material bank was not covering all needed elements. The workflow allows for a combination of new and old elements. Importantly, the LCA calculations were made in real-time, giving the designer feedback about the current design's performance. Figure 4 presents the architect's desired structure together with the elements from the material bank (displayed in a circle around the model). The illustration depicts the final design which, at the moment the paper is written, waits for building acceptance by Oslo authorities.

3 CONCLUSION

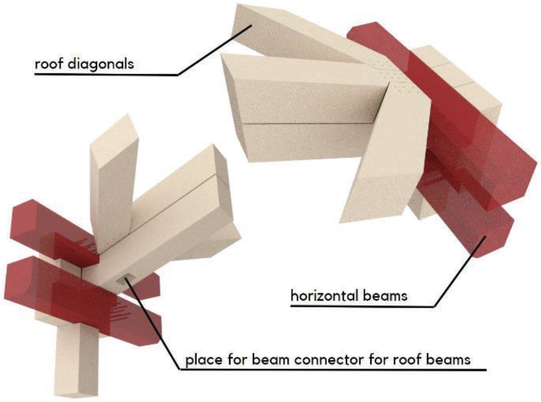

Figure 9: *Detail of the connection.*

The construction project is to be started before the summer of 2023. In this project, we do not only focus on the conceptual design and algorithms. The extra goal is also to measure the values of environmental and structural (displacement) performance.

The work made till now can be summarized in the following points:

- Creating an innovative design methodology, which quickly matches reclaimed elements from the material bank with the initial design model.
- Implementing several matching algorithms, in Python, and wrapped in a Grasshopper module to link it with parametric design.
- Visualizing the impact of using reclaimed elements by adding the 3D scanned meshes to the design model based on the results from the matching algorithms.

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