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CircularWOOD – Towards Circularity in Timber Construction in the German Context

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Abstract. The circular economy can pave the way to achieve ambitious sustainability goals. A major perpetrator of resource and material waste is the building sector. A lot of research results already provide innovative technologies and solutions for circular construction. However, what many of the circular economy initiatives in the construction sector have in common, is a certain malaise in moving from pilot projects with high individual engagement to actions on a larger scale. Prefabricated timber construction is one of the most promising key technologies towards a more resource efficient Europe. Despite this potential, downcycling or an early thermic utilization is common practice. Valuable resources are wasted and already captured CO₂ is released. The research project circularWOOD aims to provide a better understanding for potentials and barriers in a first step. This paper outlines first findings. Prefabrication and element design facilitate circular construction approaches. The context in which stakeholder implement circular construction approaches is widened. A wide range of economic and ecological aspects is supplemented with cultural, political, and regulatory conditions. Under the premise of reuse with a minimum of necessary adaptation structural aspects are evaluated. The results show a current concentration on new construction with easy-to-implement design approaches. Further efforts towards strategies for the reuse of existing construction and experiences to facilitate the diffusion within the timber construction sector are required.

Keywords: Timber construction; Analysis; Circular economy; Prefabrication; Cascade utilisation

1. Introduction

In hardly any other industry is the consumption of energy and raw materials as high as in the construction industry. This has an enormous impact on the environment. According to UN estimates, in 2020, around 40% of energy-related CO₂-emissions worldwide and more than half of the consumption of resources can be attributed to the construction industry [1]. In Germany, the construction and operation of buildings cause almost 41% of greenhouse gas emissions [2]. At the same time, the construction industry generates 55.4% of waste [3]. However, reducing greenhouse gases in the construction sector does not only mean producing and running buildings in an energy-efficient way. It also demands changing linear



models of thought and economics and strategically planning material cycles. In addition, the use of renewable resources to reduce the use of non-renewable resources plays a central role. The ability to recycle in the building sector has been addressed in many extant literatures and is, in part, used in building practice, mostly in the context of pilot projects. The current political debate has identified the circular economy as one of the central challenges for the future of the building sector. However, besides the need for conceptual classification and delimitation, there is a lack of consistent rules and methods for evaluating the circularity of a building [4]. The regenerative resource wood plays a role in terms of CO₂-reduction in the atmosphere. The longer wood can be kept in the material cycle, the longer it serves as a carbon store and thus as a climate-stabilising buffer for CO₂-emissions. In addition, wood as a building material contributes to the substitution of fossil and mineral building materials [5]. This paper analyses the circular concept in the context of wood as a building material and the associated implications on the value chain. In addition, possible market opportunities and the effects on the individual stakeholders are discussed. Based on an overview of existing research desiderata, circularWOOD [6] focuses on essential interrelationships regarding the entire value chain of wood.

Wood is a biotic material that originates from a closed material cycle. Untreated wood rots after its use and releases the CO₂ that it absorbs in the course of its growth. Wood thus represents a CO₂-neutral cycle. Currently, the share of wood that flows directly into thermal utilisation is about 50 percent [7]. Since wood is a renewable resource, it also counts as a renewable building material and energy source. However, the use of wood to produce thermal energy is not uncontroversial among experts [8]. Wood is a carbon store, but during thermal utilisation, CO₂ that has already been absorbed is released again. One argument in favour of wood energy is that, compared to fossil materials, wood, when burned, only releases the CO₂ it absorbs during a comparatively short growth phase (compared to coal, etc.). Opponents see long-term conflicts of usage in the different areas of application of wood and argue for the longest possible conservation of value in material use [9]. In recent decades, the cascading utilisation of wood has been extended [10]. This implies the successive use of the material over several stages in various material applications. The energetic use, i.e. thermal utilisation, features at the end of the utilisation cascade. Cascade utilisation increases resource efficiency, prolongs carbon storage and thus increases the added value of the material. The potential of cascade utilisation in wood is currently hardly exploited. Only one third of the waste wood in Germany is used as a material in chipboard. Cascade utilisation can reduce the greenhouse potential by up to 10% [11]. Much greater advantages can be gained by saving primary resources, which are substituted by the use of waste wood. Furthermore, the mobilisation of waste wood assortments as construction material can lead to the substitution of fossil-based products. The resource wood can be utilised sequentially without complex recycling processes.

Thereby, forests as suppliers of wood are under increasing pressure: the forest is key to carbon storage and serves to preserve biodiversity. At the same time, it serves as a recreational environment for humans, regulates the microclimate and provides clean water as well as oxygen. The multi-functionality of forests and the associated need for adaptation of the forest ecosystem are the basis of the European Green Deal and have found their way into coalition agreements of the German government. The associated adaptations will lead to a change in bio-based material flows. They require maximising the yield of biomaterials, which will lead, among other things, to multiple uses of wood as a material: "The strategy supports the most climate- and biodiversity-friendly forest management methods, emphasises the need to keep the use of wood biomass within the framework of sustainability, and promotes resource-conserving wood use in line with the cascade principle." [12]

The limited availability of fossil resources and growing market will lead to an increasing demand for wood as a raw material. In order to meet this increasing demand, it is important to keep wood in the material cycle for as long as possible. This means that wood on the one hand should be used again and again for the same purpose without being changed (reuse). On the other hand, the aim must be to recycle. In this process, the same level of quality of the original product must be maintained.

Circularity mostly follows economic and ecological considerations. As the literature research shows, this also induces or necessitates changes at a socio-cultural and political-regulatory level. While research on the circularity of buildings already makes clear distinctions between the various categories (reuse, recycling, further-use, down-cycling, etc.) [13][14], this differentiation has not yet been made in current legislation [15][16]. This lack of consistent classification and definition on the one hand, and inconsistent

application of existing regulations on the other, hinder consistent, consensual and strategic implementation according to concrete, uniform instructions and rules.

M Geissdoerfer et al analyse different definitions of Circular Economy in academic discourse. Both in the context of sustainability and in academic discussion, they point to a focus on economy with ecological aspects. Following the question, how circular economy is conceptually related to sustainability, M Geissdorfer et al identified the missing social concept in circular economy approaches. [17]. R Boch et al [18] also criticise the lack of implementation across society. This need to change linear economies has been heard both in politics and in wide sectors of society. However, the transition to a circular economy will be accompanied by massive transaction costs. In order to achieve the social acceptance necessary for this, and besides facing the challenge of putting a political structure in place and holding the positive vision of a circular economy, it is essential to establish a new system of values and standards [19][20].

In the building sector, lack of acceptance in user circles is very common. This lack of acceptance is due both to a lack of experience and to the extant linear economic system in which new is equated with unused. At the same time, the quality of used products and the partly non-existent adaptability to technical renewal cycles currently hinder their subsequent use.

Shortages of raw materials and reduced availability on the market are increasingly leading to economic risks. Wood as a building material is traded internationally. The shortage of round and sawn timber on the European market in spring 2021, caused by high demand on the international market, has led to considerable price increases [21] and supply bottlenecks. At the same time, the share of approved residential and non-residential buildings has risen consistently in recent years and currently stands at nearly 21% in Germany [22][23]. In light of political demands for increased use of renewable materials in the construction industry, the pressure on wood as a resource is increasing [24]. The crisis and the increasing demand for wood as a building material highlight the relevance of securing long-term availability of resources.

The definition of the circular economy implies different aspects of circular use. Although aspects of recycling or reuse are equally relevant, this paper takes an in-depth look at the reuse of building components, structural elements or the individual material components. This means that a used product is reused for the same purpose while retaining its product form. The reason for this selection is the goal of maintaining the value at its highest possible level with the lowest possible material and energy consumption. Prefabricated timber construction is characterised by the use of elements and the associated logic of joining large-format building elements. These are good conditions for the actual reuse of entire building components, building elements as well as individual components beyond thermal utilisation or cascade utilisation.

Under the premise of the economical use of resources, the extension of the useful life of buildings is an essential driving force for circular construction with wood. "*Flexibility in architecture refers [...] to the ability of a building to respond to new circumstances in a short time with reasonable effort and at reasonable cost.*" [25]. Primary and secondary construction, façades, technical building equipment, but also investment models are central elements in this context as they enable long-term value retention and low life-cycle costs [26]. Following this logic, flexibility at the level of the individual building components must be further considered for circular construction with wood. This includes the standardisation of building components. But also, the systematic division into structural elements and easily exchangeable layers of use and their consistent implementation to enable repair work and reuse in other buildings [27]. The lifetime of the individual systems must be taken into account. The particular challenge for timber construction is that, for example, the load-bearing structure is not separated from the building envelope structure, as is common in other construction methods. The load-bearing structure is mostly integrated into the façade with regard to the exterior walls.

In this context, this paper deals with the opportunities and challenges of the circular use of wood as resource for the building sector. The first task is to frame the different aspects of the circular economy for building with wood.

2. Methods

As part of the methodological implementation, there was a desktop research, which served to gather the status quo and the thematic classification.

Furthermore, a stakeholder analysis was carried out. The insights of the stakeholder analysis provided insight that concern economic and structural aspects of a future implementation of circular approaches in prefabricated timber construction. The stakeholder analysis is based on guided and narrative interviews. For this purpose, stakeholders which are relevant in the value chain of prefabricated timber construction in Germany were identified. Additionally, a reference group of actors in Switzerland and one actor in the Netherlands were selected. The criteria for this selective sampling were based on the specific experiences of the interviewees in the field of planning and execution in prefabricated timber construction with a high affiliation to sustainability and innovation. A special attention was also paid to their different professional backgrounds in order to ensure different perspectives on the issue. The approach with narrative interviews is particularly suitable for exploratory research in a field where expertise is not yet widespread. So far, eleven interviews have been conducted with experts to ensure a sufficiently broad scientific perspective on the branch (see Table 1). The interviews focus on the implementation of the circular economy in the working environment of the interviewees and the attitude of the interviewees towards the topics economic and structural aspects for implementation.

Furthermore, the interviews addressed their interests and motivation in the context of the various aspects of the circular economy, and possible or necessary incentives that could lead to a change of the current system.

Table 1. Overview stakeholder interviews August 2021 - April 2022.

	Interviewee	Affiliation, position	Field of work
1	Andreas Dengl	Gumpp & Maier GmbH Project Development and Sales	Timber manufacturer (Germany)
2	Alexander Leib	Die Holzbau Ingenieure Managing Partner	Timber construction engineer (Germany)
3	Daniel Müller	Pirmin Jung Schweiz AG Member of the Executive Board	Timber construction engineer (Switzerland)
4	Gerd Prause	Prause Holzbauplanung Managing director	Timber planning engineer (Germany)
5	Thomas Rau	RAU Architekten Managing director	Architect (The Netherlands)
6	Pius Renggli	holzprojekt gmbh Co-founder	Timber construction engineer (Switzerland)
7	Michael Schär	Schaerholzbau AG Managing director	Timber manufacturer, (Switzerland)
8	Markus Steppeler	Derix GmbH & Co Sales Manager	Timber manufacturer (Germany)
9	Dr. Jan Wenker	Brüninghoff GmbH & Co. KG Project Manager for R&D	Timber manufacturer (Germany)
10	Jörg Finkbeiner	Partner und Partner - Architekten Managing director	Architect (Germany)
11	Franz Hauzenberger	Künzli Holz AG Division Manager Timber Construction	Timber manufacturer, (Switzerland)

3. Results

3.1. Economic stakeholder perspectives

The discussions with different actors lead to initial findings, which are summarised below:

All interviewees agree on the potential of prefabricated construction with wood to support the circular economy. When asked about their motivation to engage with the topic and possible implementation strategies, both material manufacturers and also some timber construction companies, emphasised securing the availability of materials. The increasing shortage of wood as a resource has accelerated the debate on the issue of recovering primary raw materials. Economic interests are at the forefront for the interviewees. At the same time, all respondents are aware of the ecological requirements. In addition, there are increasing political demands that require reorientation. Ecological challenges and political demands, which go hand in hand with the achievement of climate goals, further the planners' thematic involvement.

The special potential of timber construction is seen by all respondents both in the possibility to disassemble prefabricated building components and in the separability of individual component layers. Only one claimed, that other industries (glass, plastic, etc.) realized a liberation from the self-imposed pressure of maintaining form and structure and thus are able to freely design new products [28]. For all others, the large formats associated with prefabrication offer added value. In the area of structural ceiling and wall elements, there are already concepts from individual manufacturers who take back used constructions after disassembly in order to reuse them in other projects. At present, this mainly concerns cross-laminated and glulam timber. These large-format elements are particularly suitable for reuse. Disassembly is possible without major destruction, provided that removable connections were used. This corresponds to the current state of research [29], which shows that particularly in the area of cross laminated timber constructions, connections can be disassembled without significant damage.

Greater challenges are emerging in the area of timber panel construction, which currently makes up the largest market share in Germany. In the residential building sector, around 85 percent of approved buildings fall into the category of prefabricated construction, which is characterised in particular by panel construction [30]. There is still a need for improvement in most of the currently implemented solutions. This applies not only to the choice of materials, such as not using foils, but also to the mounting. With a cycle-optimised layer structure that takes into account the material quality, its separability and corresponding mechanical fastening, wooden panel elements can be disassembled and, in a further step, also separated. Relevant examples can already be found in prefabricated residential construction [31]. As regards scaling for multi-storey timber construction, current research and individual companies are looking into the range of options as to how timber frame construction elements can be optimally fed back into the value chain. In these considerations, resource protection and the availability of raw materials are the main focus. The planning industry operates on the basis of responsibility in combination with the aim of creating a competitive advantage in the long term.

Few scalability considerations can be described as specifically timber construction-specific. These include, for example, the lack of technical solutions for connecting methods, which, however, also apply to other construction methods (cf. steel construction). In order to speed up these developments, the importance of legal obligations was emphasised several times in some interviews [32][27]. Such obligations would help to accelerate the development of circular technologies. Other interviewees, however, emphasise that the implementation of legal foundations and related normative processes take too long. The mechanisms of the market driven by the pressure of increasing positioning towards sustainability can drive changes as well [33].

3.2. Stakeholder analysis: structural aspects

For the discussion of constructive aspects in the context of circular timber construction the relevant construction principles were listed: this includes all established ceiling and wall systems in timber construction, which will be differentiated in a further research step on the basis of various criteria. Deconstruction and reuse can be carried out with regard to disassembling capability on the building component level, which goes hand in hand with reuse of the respective building component for the same use. Taking into account easily exchangeable layers of use, the structural element is considered a construction element of the ceiling or wall structure. The building component remains in use by repairing and/or replacing the layers of wear.

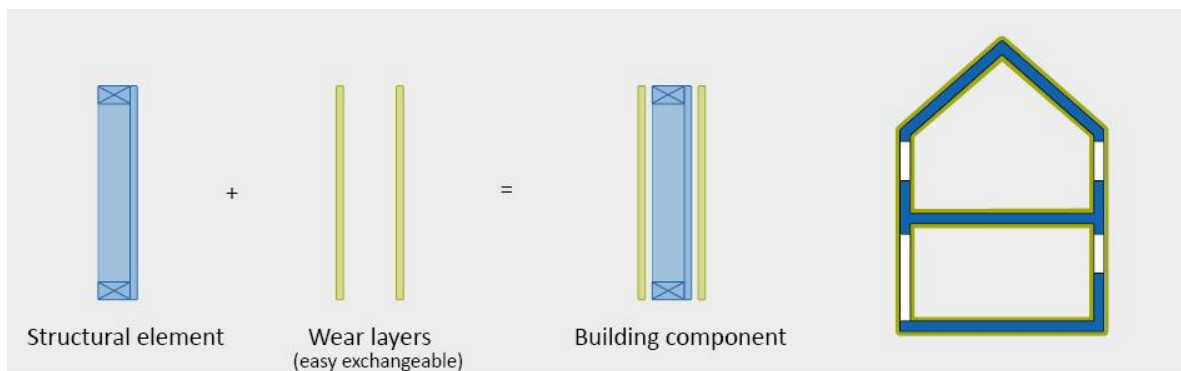


Figure 1. Structural design of a building component in structural element and wear layers

The prerequisite is that both statically effective connections and the connections of individual components are mechanical and removable. The latter describes the aspect of separability. The prerequisite for a necessary separation by type is, in addition to a suitable choice of material, preferably sheet material, using removable connections and avoiding gluing individual components. Adhesive bonds, such as those used to seal panel joints, play a subordinate role [34].

According to the stakeholders interviewed, both disassembly and unmixed separability currently represent a challenge that has not been solved. This requires both, changes in current planning solutions and the development of (structurally effective) connections for timber constructions that enable non-destructive disassembly and separability.

If we consider wood as a raw material that has not been modified and is intended for use in the building sector, we must first identify linear structural elements. Other structural elements, mostly used for construction purposes, are created by gluing different layers together, resulting in sheet-like layered materials that are mostly effective for building construction (glulam and cross-laminated timber).

Simple and non-destructive disassembly is the basis for the reuse of building components or individual components that have been installed. In addition to easily removable joining materials, the possibilities of digital production technologies must be increasingly used in the area of statically effective joints. Traditional form-fitting timber joints can be easily produced with the help of modern manufacturing technology. In addition, easy accessibility for dismantling, but also for reconstruction and maintenance of the individual components is important. Last but not least, the durability of the materials used must be considered for the period of use, which is related to their functional period. Planning for durability means making decisions about the composition and structure of materials that allow for a dynamic balance between gradual and rapid changes, between forces controlled from the outside and those controlled from the inside. The durability of building materials and the degree to which they are used in building components determine the simplicity or complexity of their repair or reuse. From the manufacturers' point of view, a technical implementation is possible, but the methods do not correspond to current manufacturing methods.

The reuse of building components is associated with different assumptions. On the one hand, the resilience of the building component to further technical developments must be guaranteed. The easy separability of wear layers such as façade cladding or interior cladding offers the necessary prerequisite for a possible retrofitting or renewal of additionally required layers. According to the interviewees, with the appropriate choice of suitable fasteners, the interviewees do not see any major obstacles. A greater challenge is posed by the connections to neighbouring building components, taking into account their structural and building physics requirements. Furthermore, the use of building components requires a standardised system that assumes the fit of the dismantled components for other buildings. Such systems already exist in the field of temporary buildings. Concepts for the large-scale use of such systems have not been practised so far. There have been repeated attempts and efforts to establish such a modular system. Different building law requirements and adaptations to individual specifications, however, obstruct the process. Against the background of the circular use of entire building components, storage and logistics costs also have a considerable influence on economic efficiency.

When considering the structural elements in terms of their reuse, layered materials (CLT) have the advantage that they require shorter dismantling processes as the materials are monolithic and are thus more economically feasible as less labour is required. One manufacturer reports contractually agreed take-back scenarios for such components [32]. At this point, there are already systems in which solid wood elements are joined together without glue or metal and thus also allow mono-materiality in the joining technology. In ceiling constructions, primarily sound insulation requirements make a combination with mass-active building materials necessary, which makes it difficult to separate the elements for reuse. In principle, large formats that can be used in a modular fashion support reuse and further use. In addition to the preferred mono-materiality of all building materials used for the individual layers, these must be free of additives that are harmful to health or that impair recyclability [35]. Both, planners and timber manufacturers, emphasise the potential of timber construction and see possible solutions in the areas mentioned. The interviewees describe definite approaches relating to their respective professional background. However, a look at the entire value chain shows open questions and gaps in the entire process chain.

4. Discussion

Initial results show the special potential of prefabricated timber construction: a structure that follows the prefabrication and elementation logic improves the chances of later reuse or further use of the individual building components. The results show that circular economy in construction is already a widely diffused idea, but that its implementation still follows old routines.

Currently, the focus of circular construction principles is on new construction. Although this does create the principle basis for future circular resource use, the challenge of actual reuse is postponed to the future. Approaches such as installing used building components in current new construction fail to gain acceptance and cannot yet be mapped in current planning and building routines. The results of the stakeholder analysis also show that the future business models for the use of demountable buildings in a Second Life are not very specific or tested.

The first business models in timber construction are currently limited to taking back structural elements, especially cross laminated timber elements (for wall and ceiling constructions). Here, there is still no experience in practical implementation. Furthermore, a cross-sector strategy that goes hand in hand with changes within the value chain cannot be identified at present. In particular, strategies for timber panel construction, which is currently the most common type of construction in Germany, have been lacking up to now. There are no specific approaches neither with regard to the disassembling capability and further use of building components, nor with regard to separability into individual components by type. The aspect of separability also concerns layered materials (e.g. CLT), whose use is accompanied by a layered structure, for example in the field of façade constructions.

Reuse at the building component level is possible. However, the necessary storage and logistics processes are lacking. The size of the building components requires a comprehensive logistical concept and requires a standardised system that enables reuse. Possibly necessary storage presents a considerable economic challenge due to additional space requirements.

If the separability of the different layers is ensured by consistently avoiding the bonding of individual layers, both scenarios are possible: disassembly and reuse after minor repair work and replacement of wear layers. A non-destructive disassembly against the background of the reuse of the individual material components is currently economically difficult to realise due to the associated high labour input.

5. Outlook

The discussion shows that for implementation in timber construction practice, the specific transfer of circular construction logics into principles for timber construction practice must take place. Construction with high prefabrication levels takes place along assembly and joining logics that have great potential to facilitate circular construction in the future.

For the reuse of building components and materials, our previous understanding of building processes in timber construction must change entirely. New planning and implementation processes must be developed for reuse (from design and planning to tendering and realisation). New process structures and competitive bases must be prepared in good time and proactively and coordinated with

stakeholders relevant to timber construction. Also, consistent standards in the documentation of materials, building components and buildings must be able to provide information for reuse.

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