Climate impacts of wood/timber as a building material – investigated on three urban quarters in Germany (CIW)

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Abstract. Due to the current discussion about the shortage of resources and the excess of greenhouse gas emissions, timber construction is experiencing a renaissance in Germany. As a renewable resource, wood can replace emission-intensive building materials and, if left long-term in the construction, lead to negative balances, i.e. carbon sinks at the construction phase (LCA phase A1-A3). This means that more carbon could be stored in the construction than is emitted during production. This study analyses different buildings ranging from row houses to high-rise buildings that are envisioned as timber construction of three so called timber-quarters (Holzbauquartiere). For all buildings, the current design/construction, a conventional as well as a timber+ construction (maximum possible timber use in construction) variant have been evaluated. The calculations were conducted with eLCA the LCA tool of the Bewertungssystem Nachhaltiges Bauen (BNB) (German Green Building System) and the data sets of the German ÖKOBAUDAT[11]. The results are given per m² gross floor area per user, per building and per neighbourhood. The investigations show the importance of the material choice regarding the climate gas emissions of the buildings and how large the proportion of wood must be in order to design the building envelope (KG 300 (cost group for architectural elements) in a climate gas neutral way. Planning parameters for a climate gas neutral design and construction of buildings are derived from the analysis.

Keywords: Climate impacts of wood/timber as a building material, life cycle assessment, timber construction, carbon neutral buildings, LCA, timber-quarters/ Holzbauquartiere

1. Introduction – context

The building sector in Germany is responsible for 40% of CO₂ emissions [1]. In addition, 90% of the extractions of mineral raw materials are consumed by the construction industry [2]. In the RESCUE study 2019, the Federal Environment Agency (UBA) calls for a 95% reduction in greenhouse gas emissions and a 60% reduction in the extraction of raw materials by 2050 [3]. Consequently, the building sector must be massively transformed by 2050 to enable living within planetary boundaries. The goal of building with timber is to turn cities into carbon sinks [4] and to decarbonize the building sector. Federal German states such as Baden-Württemberg, Nordrhein-Westfalen, Berlin and Brandenburg and cities such as München, Hamburg and Bremen are launching initiatives for timber construction and are
aligning their award guidelines accordingly [5]. The trend towards timber construction is also reflected in the current figures for building permits. Approximately 20% of all building permits in Germany today concern buildings that predominantly use timber as a building material [6]. The proportion is growing continuously, with the focus currently on residential buildings in building classes 2 and 3 [7], i.e. single-family and terraced houses, and is only slowly reaching multi-storey construction. The topic of climate gas neutrality in the building sector has focused over the year on the operation phase and thus on reducing the energy demand and supply via renewable energy sources. With the increasing achievement of these goals in the area of new construction and completely renovated buildings, the focus is now shifting to the generation of greenhouse gases during construction and maintenance. Within the framework of holistic considerations such as the "Sustainable Building Assessment System (BNB) of the Federal Ministry of Housing, Urban Development and Building (BMWSB) [8], life cycle analyses (LCA) are carried out and the climate gas emissions during construction, operation and at the end of the life cycle are considered. These are increasingly being applied as a mandatory part of public sector construction projects [5].

1.1 Aim of the study
This study analyses the potential climate gas neutrality of the building envelope of residential buildings constructed in timber. Comparative life cycle analyses (LCA) were carried out on the basis of three quarters currently in planning or under construction:
● Ellener Hof, Bremen, mixed neighbourhood, different building types and classes related to German building law/ fire regulations (Gebäudeklassen).
● Schumacher Quartier, Berlin-Tegel (reuse of a former airport site) dense, urban quarter
● Kokoni One in Berlin-Prenzlauer Berg, terraced houses
The calculations analyse climate gas emissions and potential carbon sinks. This study does not consider the extraction of raw materials. The aim is to evaluate the effect of the use of timber as a building material in these buildings or quarters in relation to different German building classes.

1.2 Timber buildings and timber quarters
Even if we often talk about timber buildings, in many cases, especially in the area of multi-storey buildings, we should rather talk about hybrid buildings. Even traditionally, there are few buildings that are constructed purely from one material. In particular, the foundation, as a component in contact with the ground, is usually a concrete component, which makes a significant contribution to climate gas emissions.

This study defines timber buildings as buildings that consist of or are made of timber for more than 50% of the volume (m³) of the construction and insulation materials used.
Timber quarters have been specified as quarters, whose buildings/usable areas consist of or are made of timber for an average of more than 50% of the volume (m³) of the construction and the insulation materials used.

Buildings that have mixed construction e.g. concrete, steel, brick and timber have been determined as hybrid buildings. This study defines the buildings whose construction above the foundation consists of a combination of concrete and timber as timber-concrete hybrid buildings if the proportion of timber in the built volume of the construction is > 50% or as concrete-timber hybrid buildings if the proportion of timber is < 50%.

1.3 Fire protection as a limiting requirement
Timber construction had lost importance in the age of concrete since World War II and suffered from the reputation of poor shacks or the simplest prefabricated houses that were built in the 1960s and 1970s.

It only regained importance with the ecological building movement from the 1980s onwards, but was mainly used in the area of German building classes 1 and 2, one family- or terraced houses. It was not until the 1990s that research projects and new guidelines such as the "Model Guideline on Fire Protection Requirements for Building Components and Exterior Wall Cladding in Timber Construction", or M-
HolzBauRL for short (July 2004) [9], again made it possible to build stories up to building class (GK) 4, buildings up to five storeys in timber construction. After the turn of the millennium, the first prototypes were built in building classes 4 (up to five stories) and 5 (up to seven stories), which, however, were usually encapsulated, therefore clad with gypsum boards for fire protection reasons. At the end of the 2010s, a trend towards visible, i.e. non-encapsulated, constructions began in these building classes, after the building code was increasingly adapted in favour of timber construction. Nowadays constructions are only possible in GK 5 via deviations, which must be laid down in the fire protection concept and approved by the inspection engineer. After the German model building code (Musterbauordnung) with changes to reduce the obstacles for timber construction is increasingly introduced in the federal states, timber construction is developing accordingly. Since the mid of 2021, the new M-HolzBauRL also regulates building components for GK 5 and for solid timber construction generally as encapsulated constructions, which can now be realised via the simple verification without deviation.

Visible timber constructions are still possible via deviations and are usually dimensioned for combustion without, for example, implementing complex sprinkler systems. Visible constructions reduce construction costs as well as associated greenhouse gas emissions by dispensing with fire protection claddings and utilise the building physics as well as atmospheric advantages of the material, thus contributing to healthy and robust construction and allowing the material wood to fully develop its potentials.

2. Method - Comparison of variants via life cycle analyses (LCA)

This study analyses the potential of climate neutrality in the context of building construction during the phase of extraction, transport and erection (A1-A3). For this purpose, the software eLCA [10] of the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) was used.

This software uses the data records of the Ökobaudat. With Ökobaudat, the BMWSB provides all stakeholders with standardized data sets for the life cycle assessment of buildings [11].

Within the scope of the study, buildings were examined in their life cycle phases according to DIN EN 19789. The operational phase (B6) was excluded. According to the specifications of the standard, all plastic and wood materials go into thermal use after 50 years. This leads to the carbon storage of the timber being dissolved. In order to present the potentials for climate-neutral buildings and climate gas storage, the results were partly presented in a restricted manner for the manufacturing and building phase (A1-A3), and partly the results were presented as an overall balance with and without thermal utilisation (phase C3) in comparison.

In a first step, the three quarters were analysed and divided into building typologies. In the second step, the constructions of the buildings were analysed in detail via components and building elements, quantities were determined and LCA calculations were carried out. In order to identify the potentials of timber construction, both a conventional variant (reinforced concrete, sand-lime brick and inorganic insulating materials) and a timber+ variant (maximum possible timber use in construction) with identical orientation and cubature were developed. The same technical requirements for sound insulation, thermal insulation and fire protection were applied at the component level in order to evaluate buildings of comparable quality. The planning quality of the selected constructions corresponds to the planning on an advanced quality of the service phase 2 according to the Fee Structure for Architects and Engineers (HOAI) [12] incl. guiding details for all standard structures and their variants. It is important to note the very different planning status of the various quarters and buildings, which are only in the design phase (Schumacher Quarter) or already in the execution phase (Ellener Hof). Within the scope of the study, some assumptions and simplifications were made in order to achieve comparability. For example, the window areas were only roughly entered via a window area proportion, surface coatings of walls or floors were partly not taken into account and no connecting devices in the constructions were calculated.

In addition, the wood content (in m³) was determined for the current planning of all buildings. For this purpose, however, only the supporting structure and the insulation were investigated, since reliable
information on the interior construction was not already available for all the buildings investigated.

Investigations have shown that the proportion of insulation in the building structure is about 40%. If the building were to be evaluated in terms of mass in KG, the proportion of insulation in conventionally constructed buildings would be about 2% due to the low density. In the case of a wood construction, this share would increase to about 10%, since the actual building construction is lighter. However, according to the studies, the share of insulation in the global warming potential is more than 20%, which is why the comparison in m³ was chosen as the standard of analysis, since the influence of thermal insulation on the global warming potential cannot be neglected.

It is noticeable here that construction and insulation together are responsible for only about 50% of the greenhouse gas emissions, which is why a pure consideration of these two components does not allow a fully comprehensive statement on the ecological quality of the building. The windows and the interior fittings contribute a not inconsiderable share to the greenhouse potential of the building, despite their small mass share. For the comparison of the variants at the building component level, the environmental impacts of the entire life cycle of one m² building component each (with and without thermal recovery) were calculated.

![Figure 1. Exemplary component comparison Gut Buchholz](image)

The results at building level were also determined in the three variants: current planning, conventional and timber+. The timber+ variant considers a maximum possible timber content for the specific building today. Buildings realised in Germany serve as a reference for the possible timber content. The following parameters were determined:

- complete LCA incl. phase C3, balance per square meter and year for all three variants
- greenhouse gas potential in kg CO₂ eq. over the entire life cycle of the building, with and without phase C3 for all three variants
- the greenhouse gas potential per capita and year in kg CO₂ eq. based on the maximum occupancy of users for all 3 variants
- the wood content (in m³ volume) of the current planning related to the building shell and the thermal insulation
Based on the results of the buildings, the entire neighbourhoods were modelled and evaluated, an average value was created across all buildings/areas, and the potential to reduce climate gases was determined.

3. Description of the quarters

3.1 Ellener Hof, Bremen

Ellener Hof is a mixed new housing development in a densely populated location, 20 minutes east of the centre of Bremen. Approximately 500 apartments for different age and income groups are being built on an area of almost 10 hectares. The aim is to build a model quarter in timber construction. It is planned to use 70% wood in relation to the volume of the building components that are not in contact with the ground (construction and thermal insulation). Based on the urban design of DeZwarteHond, different housing typologies are being created on 15 construction fields, ranging from the "Bremer Haus", a special form of terraced house in building class 3, to multi-story apartment buildings in building class 4 and a student residence in building class 5. The high diversity of the urban design results in a range of building types that must be considered individually. The pilot buildings in construction area 1 and adjacent construction areas are currently being completed.

3.2 Schumacher Quarter, Berlin-Tegel

The Schumacher Quarter is being built on a total of 48 hectares, a partial area of the former Tegel Airport. A total of over 5,000 apartments for more than 10,000 people are to be built. The "new Berlin mix" offers space for housing, retail, services and non-disruptive commercial activities. Rental apartments from state-owned housing associations, cooperatives and student housing are planned. The dense urban quarter envisions blocks in building class 5 and individual high-rise buildings up to 60 meters. The quarter is promoted as the world's largest quarter in timber construction. Based on the urban design, a representative block with three different building types was selected for analysis. On this basis, the entire neighbourhood can be modelled. Due to the high density of the quarter, basement rooms, e.g. as bicycle parking spaces, cannot be avoided and generate the corresponding climate gas emissions.
The construction site is scheduled to start in 2022, the first residential buildings and the educational campus are expected to be completed in 2027, and completion is planned for 2030.

3.3 Kokoni One, Berlin-Prenzlauer Berg
A resource-optimised housing development is planned on a 23,000 m² site in the Berlin district of Pankow. A total of approximately 18,000 m² GFA will be built by 2024 using open construction methods in 83 semi-detached houses and groups of houses consisting of end-of-row and mid-row terraced houses.

The resource-optimised neighbourhood aims to achieve a positive carbon balance overall. For ecological and health reasons, the buildings will be erected in pure timber construction. The very similar building types are differentiated into 20 mid-row and 63 end-row row houses.

4. Building types and their climate gas effect
Site requirements, building designs and building classes bring different requirement that influence the use of building materials.

4.1 Ellener Hof, Bremen
The Ellener Hof neighbourhood has a large number of building types and thus has a great diversity.

In the following, exemplary building types are analysed on the basis of which the entire neighbourhood can be modelled.

4.1.1 Residential and commercial building, construction field no. 1. Like the residential buildings G2 and G4, the residential and commercial building is adjacent to a covered parking garage. Parts of the first floor and the development are therefore only possible in reinforced concrete construction or sand-lime brick. Parts of the first floor will be used as basement replacement rooms in the rear area. The planned arcade for access to the 1st floor is also only possible in reinforced concrete. Also for reasons of fire protection requirements, the exterior walls facing the garage will be insulated with mineral wool and clad with non-combustible building materials. Due to these specific requirements, only a limited use of timber and wood-based materials is possible.

- does not meet the criterion of timber construction in the planned design. (34%)
- is almost climate gas neutral in the planned design in the phase, LCA up to A3
- would have the potential of a climate gas sink of $-441.5$ t CO$_2$ in the timber+ variant LCA up to A3

![Section](image)

**Figure 3.** Evaluation on the building level, residential and commercial building

4.1.2 Building 38, mixed use residential and nursery. The building is used as a nursery on the first floor and 2nd floor. The other three upper floors are occupied by apartments. The building stands on a reinforced concrete floor slab and has no basement. All building components not in contact with the ground are theoretically possible in timber construction. The thermal insulation can generally be made
of natural fibres. The development core was built in cross laminated timber (CLT). The ceilings are designed as CLT-concrete composite ceilings due to the span, exceeding suitable dimensions for timber construction.

- meets the criterion of timber construction in the planned design. (62%)
- is climate gas neutral in the planned design in the phase, LCA up to A3
- would have the potential of a climate gas sink of -417.8 t CO$_2$ in the timber+ variant

![Figure 4](image)

**Figure 4.** Evaluation on the building level, Building 38

### 4.2 Schumacher Quarter, Berlin-Tegel

The very dense quarter provides block-like structures that are repeated in a similar form. As an example, a typical block with three building types was selected to enable transferability to the entire neighbourhood.

#### 4.2.1 Südzeile.

Due to the very dense neighbourhood, bicycles and other functions cannot be accommodated in the outdoor space. These will find space in a basement. The high concrete content and inorganic insulation in the foundation have a significant impact on the CO$_2$ emissions of the building in building class IV with 5 upper floors. The building, which is otherwise planned in pure timber construction, thus loses its potential of climate gas neutrality.

- does not meet the criterion of timber construction in the planned design. (36%)
- is not climate gas neutral in the planned design in the phase, LCA up to A3
- would have the potential of a climate gas sink of -108.7 t CO$_2$ in the timber+ variant

![Figure 5](image)

**Figure 5.** Evaluation on the building level, Südzeile

### 4.2.2 High-rise Building.

The high-rise residential building of high-rise group II has 17 floors and a height of almost 60 meters. As a concrete-timber hybrid building, it has a reinforced concrete core or
skeleton, timber-concrete composite ceilings and an exterior wall in timber frame construction. The non-
load-bearing interior walls are also planned as timber-frame construction. Even in the timber+ variant,
according to current regulations, significant parts of the building must be built in reinforced concrete
and the building would only just become climate-neutral during construction.

- does not meet the criterion of timber construction in the planned design. (31%)
- is not climate gas neutral in the planned design in the phase, LCA up to A3
- would have the potential of a climate gas sink of -699.5t CO$_2$ in the timber+ variant

**Figure 6.** Evaluation on the building level, High-rise Building

### 4.3 Kokoni One, Berlin-Prenzlauer Berg

All houses consist of two full stories and an attic. Basements were omitted for ecological reasons. Beyond the floor slab in reinforced concrete, the houses are built in pure timber construction using cross-
laminated timber and exterior walls in timber frame construction. Natural fibre insulation, probably straw, is used as insulation. The exterior components are planned to be diffusion-open, i.e. climate-
controlling. The row end house (64 units) differs from the row middle house (20 units) by an additional outer wall.

#### 4.3.1 Row end house

- does meet the criterion of timber construction in the planned design. (78%)
- is climate gas neutral in the planned design in the phase, LCA up to A3
- would have the potential of a climate gas sink of -41.7 CO$_2$ in the timber+ variant LCA up to A3

**Figure 7.** Evaluation on the building level, Row end house
5. **Summary**

5.1 **Results of the quarters**

The buildings and quarters considered achieve very differently the goals in the planned variants. The Schumacher quarter performs the worst. According to the criteria of this study, it cannot be called a timber building quarter and climate-neutral in construction (LCA A1-A3). Ellener Hof can be narrowly described as a timber building neighbourhood on the average of usable space/buildings and also narrowly achieves climate neutrality in the construction phase. However, it clearly falls short of both criteria at the level of multi-story buildings. Thus, multi-story buildings in particular, which could have an advantage due to a good ratio between foundation and the construction, do not achieve the ambitious goals of the Ellener Hof quarter. Kokoni One meets both criteria very well due to its very ecological design.

5.2 **Results building level**

The building class 3 buildings of the Kokoni One project and in the Ellener Hof Bremer Haus meet both criteria in the planned variant and are the best buildings in terms of m² floor space. Kokoni One is a little better than the Bremer Haus because of the house partitions in cross laminated timber. The multi-storey buildings perform significantly worse. This is due to the directly adjacent neighbourhood garage in Ellener Hof in construction field 1. In general, however, optimized planning could contribute to improvement as shown by buildings G8, G10 and G38. The class 4 buildings in the Schumacher Quarter do not meet the goals mainly because of the basement, but in the case of the Westkopf also because of the low wood content. The high-rise building has more difficulty meeting the goals of this study due to current fire code requirements. All buildings would have further potential for optimization under current building codes and could be expected to be carbon-neutral in construction (A1-A3) with optimised design. This is shown by the inner star of diagram 10, which represents the timber+ variant.

![Figure 8. Overview evaluation building level](image-url)
6. Conclusion
With intensive use of wood and timber, the building sector can be designed to be climate-neutral in the construction and in the long-term retention of the buildings. The compensation of the climate gas emissions from the necessary concrete components in the construction phase is possible.

Lowering the climate gas effects via timber construction is possible, so up to 600 \([\text{kg CO}_2\text{-eq.}]\) per m\(^2\) NFA can be saved over the entire life cycle of 50 years compared to conventional construction with concrete and inorganic insulation materials. This is the result of the construction phase (A1-A3). However, this presupposes in the planning phase to use as little reinforced concrete as possible and, for example, not to realize a basement.

This study has the building as a system boundary and considers only the construction without operation. The traffic and supply infrastructure were not considered. Whether the infrastructure can also be compensated by the use of wood in the surrounding buildings was not investigated.

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