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How Building with Wood Can Be Linked to Sales of Building Plots: Results from an Exemplary Site Development in Munich, Germany

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Abstract: Cities today seek ways to comply with national climate targets. The urban authorities responsible for city planning are therefore responsible for defining the eco-efficiency of cities for decades to come. They need clear guidelines on how to reduce greenhouse gas emissions from the building stock in a specific area. The use of sustainably sourced wood in construction plays an increasingly vital part in the transition towards eco-cities. Drawing on an exemplary development site in Munich, this paper describes how the sale of building plots can be connected to an agreement to build with wood. Based on an actual research project, site-specific target values regarding greenhouse gas emissions and the amount of renewable material for specific building plots were developed by studying life cycle assessments for different buildings. Wood is introduced as a building material to achieve a minimal environmental footprint. The focus is set on linking the sale of building plots to an agreement to build primarily with wood. Target values for the buildings were developed in close cooperation with the city and were linked to the tendering of the plots. The proceedings and its implementation are shown in this paper.

Keywords: life cycle assessment; timber building; environmental footprint; carbon storage; tendering process; greenhouse gas reduction

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1. Introduction

Following the agreements of the Paris Climate Conference 2015 [1], Europe in general and Germany in particular defined ambitious climate protection goals to be reached by 2050. Implementing these goals requires involving all subareas—from industry and infrastructure to buildings and cities. The building sector was hereby identified as a major player for reducing greenhouse gas emissions in Europe. Additionally, goal 7 of the UN Millennium Goals present—ensure environmental sustainability—specifically cites the integration of principles of sustainable development into national and regional policies and programs to reverse the loss of environmental resources (goal 7A) [2]. This clearly leads to the integration of these ideas into urban planning. Cities and municipalities are therefore searching for ways to comply with national climate targets, which will greatly impact planning choices in the coming decades. Sustainable city planning or planning eco-cities specifically designed in consideration of their environmental impact represents one subarea for reaching the overall climate reduction targets. Although no predefined set of criteria to define an eco-city exists, environmental, economic, and social needs should, in any case, be satisfied. An ideal eco-city has been described as adhering to the following requirements in [3–5]. The main targets are creating a carbon-neutral energy production from renewable sources, a self-contained economy from locally sourced resources, a maximized efficiency of water and energy consumption, a zero-waste system, and additionally, a sustainable public transportation system with priority on walking, cycling, and public transportation. Affordable housing for all socio-economic groups and improved job opportunities for disadvantaged groups are targets to be additionally satisfied as a social requirement. Other important issues are promoting voluntary simplicity in lifestyle choices, decreasing material consumption, increasing awareness of environmental and sustainability issues, and supporting local agricultural production and consumption.

These criteria represent a holistic vision of new targets for city planning. Cities around the world are currently trying to achieve some of these requirements when designing new urban areas. There are case studies that describe the implementation of this approach in general for the UK [6] and on a more limited scale in China [7]. The role of timber in future urban development as a contributor to balancing carbon emissions is described in [8] for a case study in New Zealand.

Regarding sustainable city planning and because the building sector has been identified as a major contributor to a city's environmental pollution, this paper only addresses the topic of buildings and how buildings can contribute to creating environmentally friendly cities. The building sector consumes about 40% of the world's total energy [9], which, of course, means it has a major environmental impact. Moreover, the building industry also accounts for 40% of the world's raw material consumption [10]. Optimizing the environmental impact over a building's total life cycle is thus a significant aim in the context of sustainable development.

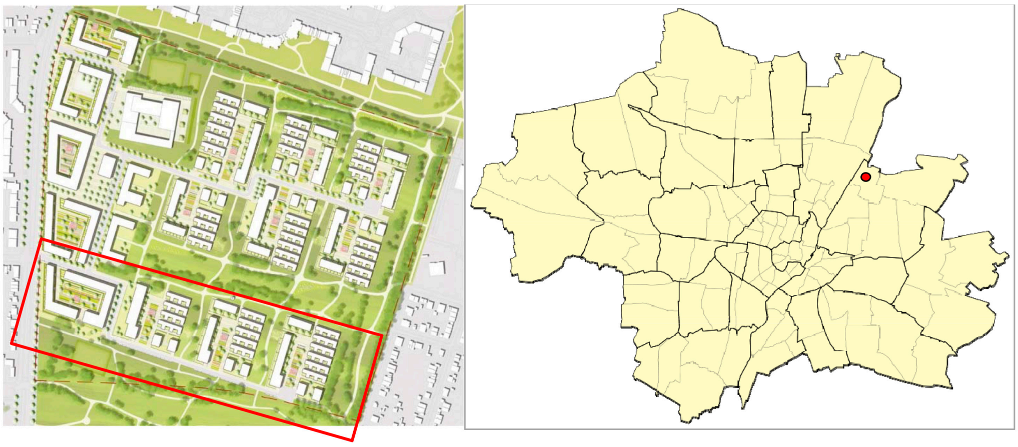
City authorities are responsible for urban planning and therefore they are also responsible for defining the eco-efficiency of cities and their buildings for decades to come. They are the gatekeepers of both building permissions and ensuring that buildings meet environmental goals. Hence, as local authorities' guiding role in energy efficiency issues and low carbon building grows, they will require more advice on methods and better tools for the design process. Urban planners therefore need specific guidelines on how to reduce greenhouse gas emissions of the building stock in a specific area for the use phase. The Energy Performance of Buildings Directive and the Energy Efficiency Directive [11] in Europe are the main legislation covering the reduction of the energy consumption of buildings. Under this directive, all EU cities are required to use energy more efficiently at all stages of the energy chain, from production to final consumption. This includes the production stage and hence the selection of building materials. Therefore, increasing the use of sustainably sourced wood in building construction and in the building elements could be one issue that could play a vital part in the transition towards eco-cities. Although the theoretical advantages of such an approach have been outlined, in terms of practical implementation, concrete information is lacking on how wood-based sustainable development could be realized.

In developing a new quarter in Munich, the above-mentioned components of sustainable urban planning were central to the city administration's goals. They led to the decision to build one third of the new development site as an eco-city and therefore to define specific requirements for these buildings. To achieve low carbon emissions, the buildings must at least reach a high standard in Energy Saving Regulation, must be supplied using only renewable energy sources, and must use predefined building materials for construction. The quarter also meets further requirements for an eco-city. It is well connected to public transportation, some buildings have been reserved for social housing, and special target groups were also addressed. Thus, the case study incorporates various eco-city targets. This paper therefore presents one possible means of achieving greenhouse gas emission reduction goals through building with wood. The overall objective of this paper describes how the sales of building plots can be linked to an agreement to build with wood.

The present paper is structured around two studies which are connected by the implementation in a case study area. The first study describes life cycle assessment (LCA) for building with wood and develops target values for the case study. The second study describes the process of implementation of the results in a case study project in Munich.

2. Case Study in Munich, Germany

The city of Munich is currently planning a new residential quarter with 1800 units on a former military site in the north of Munich. The goal was to develop much needed social housing and, at the same time, to address issues of energy efficiency and environmental impact with innovative approaches. The location in Munich and the development plan for the new quarter is shown in Figure 1. It shows a wide variety of buildings.



(**a**) (**b**)

Figure 1. Masterplan for Prinz-Eugen-Park in Munich; (**a**) red line indicates the section reserved for the Eco-City; (**b**) the location in Munich.

The southern part of the area is designed as an Eco-City. This sector—outlined by the red line in Figure 1—consists of around 500 apartments. For the specific site, a mix of single family and row houses, and up to seven-story residential buildings containing up to 50 units was fixed by the city planning board. Munich's Eco-City framework includes using an innovative energy supply with renewable energy, building in plus-energy-standard, building with wood, a mobility concept, and shared facilities. The building area is owned by the city of Munich and will be sold only to specific target groups. Only housing societies, cooperative building associations, and joint building ventures are permitted to bid on these sites. Sales are organized in a two-stage process and acquisition is bound to the commitment to the agreed upon predefined criteria.

The city administration also aims to showcase its pioneering role in building with wood to minimize the environmental footprint of buildings. As the landowner, the city administration therefore wants to link the sale of building plots to an agreement to building with wood and to other specifications. The arrangement for restricting building materials in this part of the development to the use of wood is connected to the environmental benefits of the material and the idea of creating a temporary carbon storage through the buildings. The underlying principle is based on the already existing environmental criteria-guideline by the city of Munich [12], which sets vague minimum requirements to reduce resources, energy output, and CO_2 emissions. To implement these specifications, precise targets and goals need to be described. Furthermore, the implementation of timber buildings in an urban context of this size demands high standards in preliminary planning and in all other building stages. For example, the adaptation of fire regulations in this context needs prior consent of both planners and fire prevention authorities.

3. Carbon Footprint as an Instrument for Building with Wood

While past discussions on climate change in the building sector concentrated on energy efficiency, the focus has now been broadened to include the sustainability of materials. Having largely achieved increased energy efficiency in the use stage, the focus has shifted to primary energy consumption of products and the greenhouse gas emissions in the production stage. As a renewable material that stores carbon temporarily, wood has the possibility for cascade use and it offers one way of further reducing greenhouse gas emissions. In general, timber buildings have some carbon mitigation benefits: As trees sequester carbon as they grow, the carbon is stored long-term in the wood until the wood reaches the end of life and is burned [8]. Given the advantages of temporary carbon storage in long-life timber products such as buildings, timber has a second advantage of substituting other materials which have higher greenhouse gas emissions (GHG) in the production process. Various studies [13–18] were conducted that compare conventional buildings and timber buildings to ascertain specific advantages and specificities of the latter. On the one hand, these studies all differ in approach, system boundaries, database, and scope, and therefore cannot be easily compared. On the other hand, they all demonstrate that, on the level of construction material in the production stage, wooden material has advantages in terms of carbon storage capacity, therefore resulting in lower GHG gas emissions and additional lower GHG emissions in lifecycle.

Looking at GHG emissions indicators and other outcomes of LCA, it was predicted in that study that timber construction demonstrates more environmentally friendly properties than conventional materials in buildings. After researching this hypothesis, the development of an assessment for wood construction in the form of a rating system is described.

3.1. Scope of Study and Procedure

Based on the results of the research project "Development Method to Specify Target Values for CO_2-equivalent and Primary Energy Input", funded by the DBU—German Federal Environmental Foundation, this study presents an actual research project on general LCA values for timber buildings in Germany and their implementation in city planning for an exemplary plot in the city of Munich, Germany. The project started in the summer of 2014, with the development of environmental reference values for the erecting buildings to be used for the tendering process for the sites. The proceedings and results of the tendering process for the exemplary site are shown in Section 4.

A rigid framework for the LCA calculations was set. Calculations were done in accordance with the framework for LCA calculations in sustainability rating systems in Germany [19]. Calculations were performed for the entire lifecycle, all buildings were assessed with database ökobaudat.2011 [20] and calculated according to the LCA-tool Legep [21]. The production stage, as shown in this study, covers the cradle to gate processes for the materials and services used in the construction. Transport to building site and erection on site were excluded in accordance to the rating systems. The difference in transport to site for timber and mineral buildings is around 1% of overall GHG emissions according to [22]. The functional unit describes the quantified performance of a product system to be used as a reference unit. For this study, the functional unit is 1 m^2 of gross external area (GEA) of the building over a life cycle of 50 years. The energy mix for Germany from the year 2009 was used. Uncertainties may occur through the incorporation of the generic dataset ökobaudat.2011 and specific datasets (European Product declarations).

To generate robust data, more than twenty-four recently constructed buildings were examined. The buildings were calculated without basements, but including all foundations. As underground parking on the site is a prerequisite, we chose to leave basements out of our calculations to overcome massive skewing of the results. This system boundary was chosen because of the large influence of the basement on LCA results and because not all examined buildings had basements. Given the prerequisite of underground parking and storage facilities for bicycles, which is to be constructed in concrete, only the construction materials of the upper stories can influence the final results in the LCA calculation. The influence of the construction of the houses in terms of load-bearing construction and walls, ceilings, roof etc., was instead sought to be shown. All construction material and technical equipment was included in the bill of quantities. All buildings have a high performance in the operational energy consumption (around 50 kWh/m^2 or less). The buildings that were assessed have various construction methods, from massive timber buildings, timber frame construction, hybrid buildings, to mineral buildings (brick, concrete with external thermal insulation composite system). Around two thirds of the buildings are wooden constructions. The size of the buildings varies between 176 m^2 up to 6152 m^2. Most are residential-use buildings. This paper only shows results of the production stage according to EN15978 [23]. The analyzed buildings are shown in Table 1.

Table 1. Analyzed buildings divided in small (**a**) and large (**b**) residential buildings.

(a)				
Small Residential Buildings (Number)	**Primary Construction**	**Floor Area GEA (m^2)**	**Number of Floors**	**Year of Erection**
1	mineral	215	2	2012
2	mineral	176	2	2008
3	mineral	176	2	2008
4	mineral	245	2	2011
5	timber frame	176	2	2008
6	timber frame	184	2	2011
7	timber frame	190	2	2011
8	timber frame	127	2	2011
9	timber frame	198	2	2011
10	CLT	379	2	2012
11	CLT	215	2	2012
12	CLT	176	2	2008

(b)				
Large Residential Buildings (Number)	**Primary Construction**	**Floor Area GEA (m^2)**	**Number of Floors**	**Year of Erection**
1	mineral	1394	6	2013
2	mineral	7016	4	2007
3	mineral	1898	4	2010
4	mineral	6152	3	2006
5	hybrid	1172	5	2013
6	hybrid	3735	5	2008
7	timber frame	1394	6	2013
8	timber frame	2717	4	2013
9	timber frame	6152	3	2006
10	CLT	1919	8	2011
11	CLT	3735	6	2008
12	CLT	1257	4	2011
13	CLT	698	4	2010

All criteria are assessed by the functional unit of one m^2 of GEA of building and additionally per living area, living area being the unit which is relevant for the city of Munich. Calculations on the site and the number of buildable houses are always correlated with maximum living area to be built on each site. Detailed descriptions of the calculation method and complete results are shown in [22].

3.2. Definition of Timber Buildings

As explained in Section 3 and based on knowledge of a recent study [24], timber construction has benefits on carbon mitigation in terms of lower GHG emissions in lifecycle and additional carbon storage during the life-time of a building. But the benefits from timber buildings vary, depending on the amount of renewable material used in construction. This leads to the question of how a timber building is defined and how that could be specified.

First of all, the definition of timber buildings was divided into small buildings (single and row houses) and large buildings (all multi-story residential buildings). It was then easy to clarify the definition of timber buildings for small single-family houses and small residential dwellings, as buildings with loadbearing structure in timber are commonly defined as timber buildings. For large residential buildings, however, definition proves more difficult. Here, hybrid buildings—defined as buildings with timber used only in external walls—are often referred to as timber buildings. Although they also could be counted as conventional buildings with a wooden facade, these buildings are classified as having the minimum requirement (level 1, see below). In these buildings, however, greenhouse gas emissions in the production stage and over life cycle are not much lower than in conventional buildings. The advantage, however, lies in the higher carbon storage capacity through exterior timber walls over the building's lifetime. Real timber buildings, however, are constructed with its loadbearing-structure in wood or at least part of the walls and ceilings are timber-frame or mass timber construction. The construction depends on the structural design of the individual projects.

Thus, a discussion arose over how to devise a definition of buildings with wood for the site. The city had to decide more precisely what they wanted to be built in timber in that area and what the minimum requirement would be. Ultimately, three levels were defined that could be reached in terms of wood consumption, as shown in Figure 2. These levels were based on a Swiss study [25] on hybrid buildings. The minimum level (level 1) is a hybrid building, level 2 defines a building with at least part of the load-bearing construction in timber, and level 3 is defined when the whole load-bearing construction and exterior walls are made from wood. The requirements in Figure 2 are split in various construction parts as exterior walls, roof, ceiling, internal walls, etc.

	level 1 (minimum requirement)	**level 2** (improved requirement)	**level 3** (timber construction)
exterior wall	wood	wood	wood
load-bearing structure	mineral	mineral | mineral / wood | wood	wood
roof	mineral | wood	mineral | mineral / wood | wood	wood
ceiling	mineral	mineral | mineral / wood | wood	wood
internal wall: party wall / load-bearing wall	mineral	wood	wood
internal wall: not load-bearing	mineral | wood	mineral | wood	mineral | wood
horizontal arrangement	mineral	mineral | mineral / wood | wood	wood
staircase	mineral	mineral	mineral | wood

Figure 2. Definitions of timber building for the Eco-City in Munich, according to hybrid-building study [25].

The Swiss study includes both timber-frame buildings and massive wood buildings in the term timber building, as both are constructed with main load-bearing structure in wood. Differences are determined by structural design and requirements for fire safety and sound insulation.

3.3. Method

Minimum, average, and target values for renewable material and for the maximum of permitted GHG emissions for building construction were defined. To achieve this, LCAs for buildings in different use categories were studied. Reference values were generated from selected newly realized timber buildings and buildings with mineral construction. The indicator global warming potential (GWP) and amount of used renewable material—as an indicator of temporary stored carbon—were determined sufficient to describe the timber buildings.

The calculation of environmental reference values for the erection of buildings proceeded as follows: After having defined the term timber building, criteria were set up with the city of Munich that could be used in the procurement process for selling the plots. GWP, one of the most researched indicators in LCA calculations, was chosen. Additionally, the amounts of renewable material and carbon storage are factored in, as they can best highlight the specific properties of timber buildings.

3.4. Results

GWP—divided into mineral buildings, timber frame, and massive wood construction—is shown for small buildings in Figure 3, and for large buildings in Figure 4. All results are shown here per m^2 GEA and for production stage only. Results show negative GWP for massive timber construction and low to negative values for timber-frame construction. In comparison, mineral buildings display high GWP per m^2 and GEA for small buildings. Large buildings demonstrate similar results but show smaller variations in the results. Here, hybrid buildings are introduced, producing nearly the same results in GWP as mineral buildings. Only massive timber construction can reach negative values in GWP in the production stage. Results for large buildings differ from those of small buildings as values of GWP are generally higher for all constructions due to higher overall material input required by fire regulations, sound insulation, and other technical requirements.

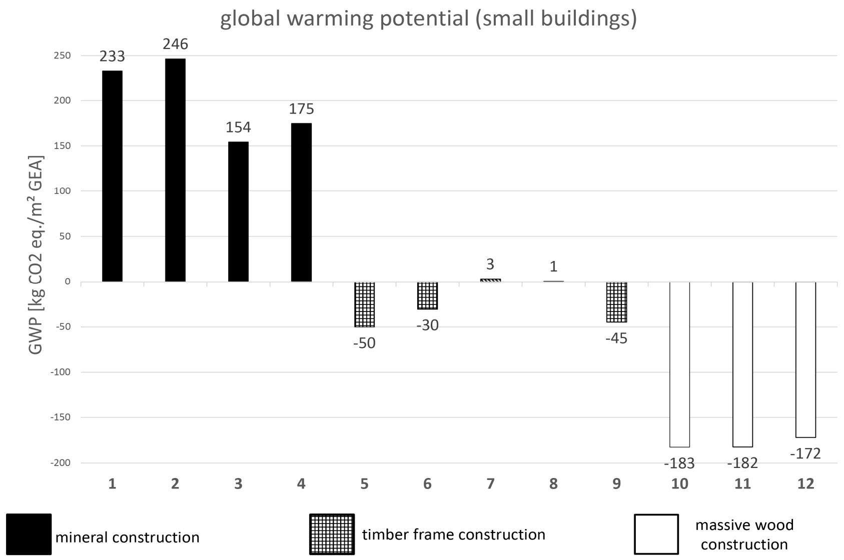


Figure 3. Global warming potential for small buildings in Germany in production stage per m^2 GEA.

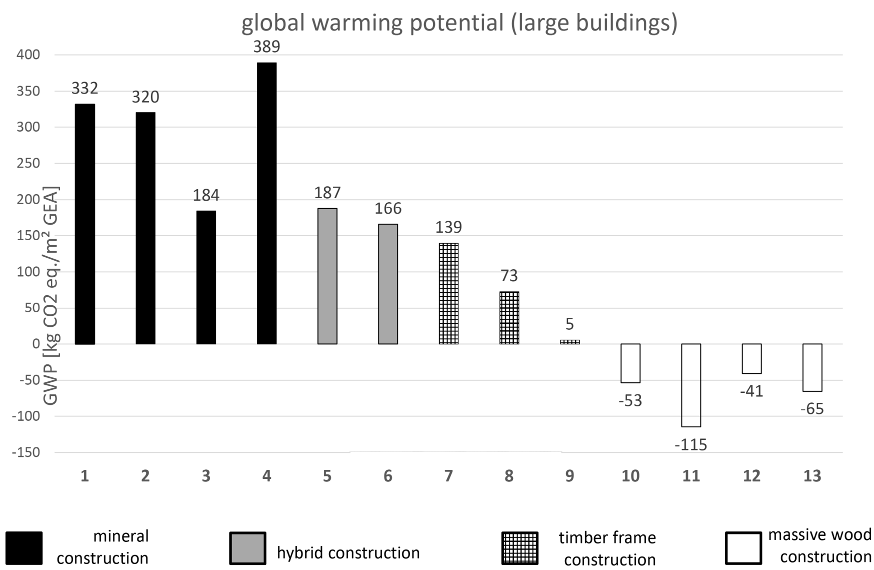


Figure 4. Global warming potential for large buildings in Germany in production stage per m^2 GEA.

3.5. Calculation of Environmental Reference Values for the Erection of Buildings

The amount of used renewable material in the production stage is shown in Figure 5 for small buildings, and in Figure 6 for large buildings. Renewable material consists almost exclusively of wooden material as the indicator is shown in mass per m^2 GEA. Due to its low mass, insulation from renewable sources represents only a minor input. Results allow a clear distinction to be made between mineral and timber buildings for both small and large buildings. The use of secondary material or recycled material was not considered in this study. For both groups, a crossover exists between timber-frame construction and massive timber construction in terms of amount of renewable material due to variations in realized timber structures and realized building construction. Hybrid buildings result in a few kg per m^2 GEA more renewable material than the best mineral building analyzed, which is due to a timber attic in building 3.

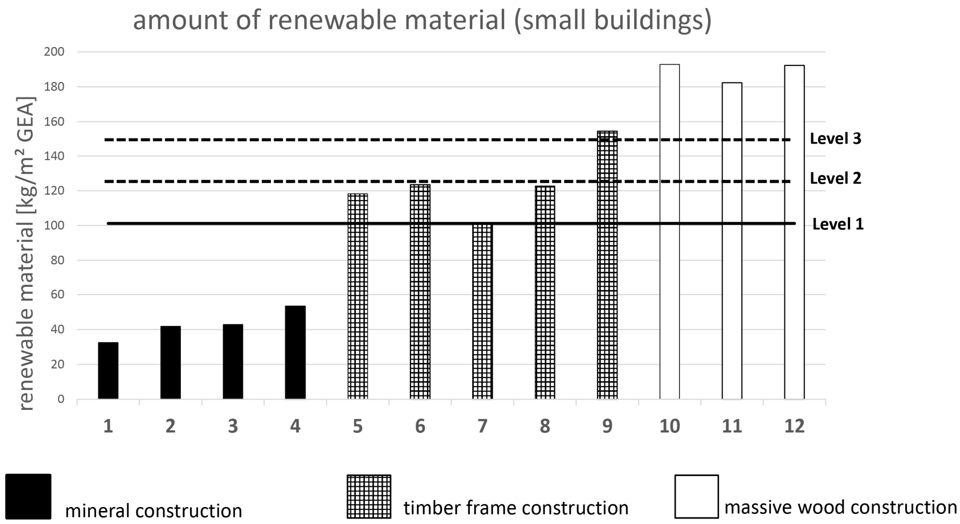


Figure 5. Amount of renewable material for small buildings in Germany with minimum value (level 1)/average value (level 2) and maximum level (3) per m^2 GEA.

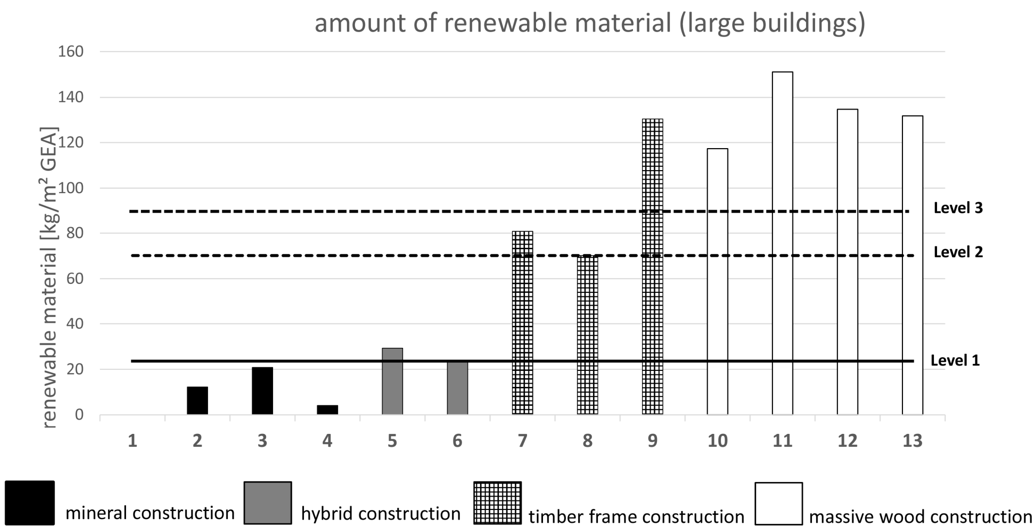


Figure 6. Amount of renewable material for large buildings in Germany minimum value (level 1)/average value (level 2) and maximum level (3) per m^2 GEA.

In the second step, the results were combined with the definition of timber buildings (see Figure 2). The three levels of wood use (level 1: hybrid building; level 2: improved standard and wood frame construction; level 3: Usually massive timber construction) were then defined according to the amount of renewable material. Minimum values, average, and maximum values were calculated across all buildings types, as shown in relation to the amount of renewable material in Figures 5 and 6. Individual characteristic values were thereby identified for small and large buildings. Additionally, the results of the specific values were compared to non-residential buildings from [26], which are in line with the values for large buildings and show close similarity to large residential buildings.

In the LCA calculations, a distinction was made between various construction methods (mineral construction, hybrid buildings, timber frame construction, massive timber /cross laminated timber construction (CLT)). Calculations of the same buildings with changed specifications in the construction of load-bearing walls, floors, and roofs were made to determine the requested values and how they could be achieved. The graphic analysis in Figures 5 and 6 show the results for each building type and are subdivided into type of construction. The calculated average value hereby correlates with the target value that should be achieved. As a minimum requirement, the minimum values must be achieved (level 1).

In this research project, the values needed to be reached as a minimum requirement were calculated by adding safety factors. The suggestion was to set the safety factor to be 10% of the height of each value for amount of renewable material. The idea behind the safety factor was to equalize differences in design, actual state of the art in timber construction, and other requirements. The safety factor is included in the levels shown in Figures 5 and 6.

The LCA calculations proved that timber construction presents more environmentally friendly properties than conventional materials in buildings in terms of global warming potential in the production stage. With the findings of Section 3, it was possible to develop an integrated method for including quantitative environmental criteria in the tendering process of selling land. The drafted reference values for different building types for the preliminary design stage of a construction project are described in Section 3.5.

Focusing on LCA calculations, it is important to show a holistic perspective of the results. As a next step, all life cycle stages according to DIN EN 15978 [23] need to be evaluated. This means that beside module A (product stage), material impact in module B2-B4 (maintenance, repair, replacement in use stage), module C (end-of-life stage), and module D (potential benefits and loads) will also be analyzed. These holistic calculations can then properly show all the inherent material differences of various types of constructions. The additional carbon-storage indicator is outside the set of commonly agreed upon LCA indicators and is mainly of relevance for renewable materials.

4. Process of Implementation—The Tendering Process in the Case Study

The target values (described in Section 3) were developed in close cooperation with the city administration, and, in a second step, were linked to the tendering of the plots. These values now represent one basis for the procurement process of the building plot. Implementing these values will be monitored in the near future. Through documenting the research project, planners are provided with advice on how to reach the agreed upon benchmarks and how to comply with building regulations (for example, fire safety) in presenting exemplary construction details [27]. Reference values need to be developed both so that LCA calculations can be used for planning purposes and so that the influence of material choices in energy efficient buildings can be highlighted.

With these values, it is possible to influence the preliminary design stage. Modern timber construction can serve as a vehicle for implementing resource efficiency and for reducing greenhouse gas emissions. To this day, however, no integrated procedure exists to implement these environmental criteria over the entire planning process. This study therefore describes the implementation process.

The tendering process for the building plots was managed through a competition of concepts, measured with a clear rating system that was made public beforehand. Alongside other criteria, the rating system was based on the three levels defined in Section 3. The approach and the results of the tendering process are shown and concluding suggestions are offered for transferring the concept to other communities.

4.1. How to Proceed with These Values in City Planning

Given the city of Munich's goal of promoting timber buildings, they adopted the existing grant *CO_2-bonus program* [28]—especially assigned to wooden construction—for this Eco-City.

In cooperation with the city, a discussion was held on the values to define wooden buildings. To make the handling as simple as possible, the city administration decided to only use the indicator of the amount of renewable material. The first step in developing reference values was a broad discussion with the city administration on timber buildings. What are the minimum requirements for a timber building? How much wood must be used when speaking of a timber building for this Eco-City?

An Excel-sheet was then developed that enables planners to simultaneously easily calculate the required values and the possible grant. The programmed Excel-sheet was amended based on the Munich CO_2-bonus program. The sheet shows the amount of stored carbon and the height of subsidies as a result of various inputs. The planner must fill in the yellow cells with the amount (in volume) of used wooden material. A division is made between various wooden products such as massive timber, derived timber products, wooden insulation, cellulose, wooden floors, and additional timber windows and doors. For all material, volume must be signed in—only for windows and doors the number of units is required. The calculation-sheet then converts each material with predefined density and (where necessary) subtracts additives in used renewable material and then calculates the sum of subsidies. Average density and amount of additives are taken from ökobau.dat [20] to be consistent with LCA calculations in Section 3. The spreadsheet can be received from the author on request.

The spreadsheet is given to the planners. The planner can thus generate the numbers needed for this calculation in the planning stage without needing skills in LCA. The planners only need their drawings and tendering documents to estimate the volume used.

In the tendering process, an exact bill of quantities of the used wooden material can then be made. These exact calculations allow the application of a specific grant to be introduced to the quarter. To acquire this grant, the exact amount of wooden material in the building must be proven. Calculation is hereby performed through an exact bill of quantities and is verified by bills of carpenters. An additional proof of sustainable forestry for the used wooden material is necessary. This is important as only sustainably sourced wood has a positive effect on climate targets. Proof of sustainable forestry can either be shown with the labels of FSC or PEFC for each wooden product or proof must be given that the wooden material comes from forests within an area of 400 square-km around Munich. The introduced grant consists of a subsidy on timber in primary construction with €0.70 to €2.00 per kg stored CO_2.

4.2. Tendering of Building Plots and Environmental Reference Values

4.2.1. Starting Point

The minimum requirements were defined by the city administration and then confirmed by the city council. During this process, some limits were placed on the Eco-City concept for political reasons. High-energy performance required by the city was scaled back to the use of a local district heating network and no additional demands (like plus energy standard) were added. The environmental quality of the site was finally restricted only to the use of renewable building material, mobility concept, shared facilities, and possible limitation of living area. Although implementing a high energetic standard would appear important, only the actual standard from the Energy Savings Regulations for buildings was ultimately required.

Using the decision of the city council as a baseline, the research project [22] assisted the city in devising the tendering document for selling the building plots. Two plots were given to urban housing societies with the stipulation of building with the minimal amount of renewable material (level 1), which correlates to building houses in hybrid construction with at least an exterior wall in timber frame construction, and load-bearing structure and staircases in concrete. With this construction, the actual fire safety regulations can be met without adding extra regulations.

Apart from one plot that was sold to a cooperative building society, all the plots were exclusively sold to joint building ventures. A competitive procedure was implemented. The procedure was structured through an application process, where the potential buyers were required to submit a proposal with statements regarding the assessment criteria. The assessment criteria included environmental issues (minimum amount of renewable building material fixed to 3 different levels, usage of rainwater), mobility concept, shared facilities in the building and common roof gardens, and possible limitation of living space to accepted standards [29]. After assessing the criteria through a point range, the applicant with the highest score was offered the site for purchase. The price for the site was not subject to the process as it was fixed by the actual average price for land in Munich.

The criteria were as follows in Table 2, with headlines as written in the text for invitation for tender. The number shown in the table shows the maximum amount of attainable points in the tendering process.

Table 2. Criterial for the tendering process.

Criteria Name	Attainable Points
Economical use of living area	20
Environmental criteria: Timber construction	40
Environmental criteria: Use of rainwater	4
Environmental criteria: Biodiversity	1
Mobility concept	15
Community activity	10
Additional for joint building ventures only:	
Number of members for the joint building venture in the planning process	4
expertise with residential buildings	3
expertise with joint building ventures	3

Economical use of living area was measured by the size of the individual apartments. Five points are given if the size is not larger than the regulations for government-funded housing allows [23]. Twenty points can be reached, if the size of the units is around 20% below this value. Although this opens a discussion on appropriate minimum living area, the city avoids creating tenement-like conditions by requiring all apartments reserved for families of three to six persons to be an adequate size (for example, a four-person flat requires 120 m^2).

Environmental criteria mainly consist of the use of timber construction. Here, the three levels for the used amount of wooden material are applicable. The minimum level means building a hybrid building, the level 2 is building mainly with timer and level 3 can be reached when building the complete load-bearing construction in timber or building in CLT and combining it with concrete elevator shaft and staircases. The various constructions are combined to the levels are shown in Figure 2.

Criteria for the planning process consist of specific actions for the site and a concept for community activities like common rooms, guest apartment, common roof gardens, etc.

The final criteria deal with achieving a smooth process for planning and building procedures for joint building ventures.

4.2.2. Proceeding

The bidding of the plots proceeded in two rounds according to the city of Munich's established procedures. The first stage only required a questionnaire to be submitted. It includes an agreement to build in wood, and to incorporate shared facilities and a mobility concept. Additionally, limited living area is demanded. After the first round, around 10 bidders who fulfilled all criteria for the sites remained.

In the second stage, all remaining tenderers still biding for the site were asked for a detailed concept for the plot. Here, one of the three levels for amount of renewable material to be reached through the primary building construction had to be determined. A point range was given where the highest level is given for building in level 3, referring to Figure 2. On the one hand, the promised criteria were laid down in the legal buying agreement and a penalty was to be imposed if the criteria are not met. On the other hand, subsidies to support the planning and building with renewable material on an economic basis were available especially for this site, as described in Section 4.1.

4.2.3. Results of the Tendering Process

The plots passed through the tendering process in the spring of 2016. All sites were given to the bidder with the highest score. Results are shown in Figure 7. The buyers are obliged to discuss their proposals several times during the planning process with an expert panel. This is intended to help the bidder meet the set targets concerning the use and compliance with renewable material mass and to achieve an early integrated planning approach with respect to the structural framework and fire safety regulations in connection to building with wood. The aim is to prevent defective design. A catalogue with possible construction details for large residential buildings in wood was elaborated by Technical University of Munich [27].

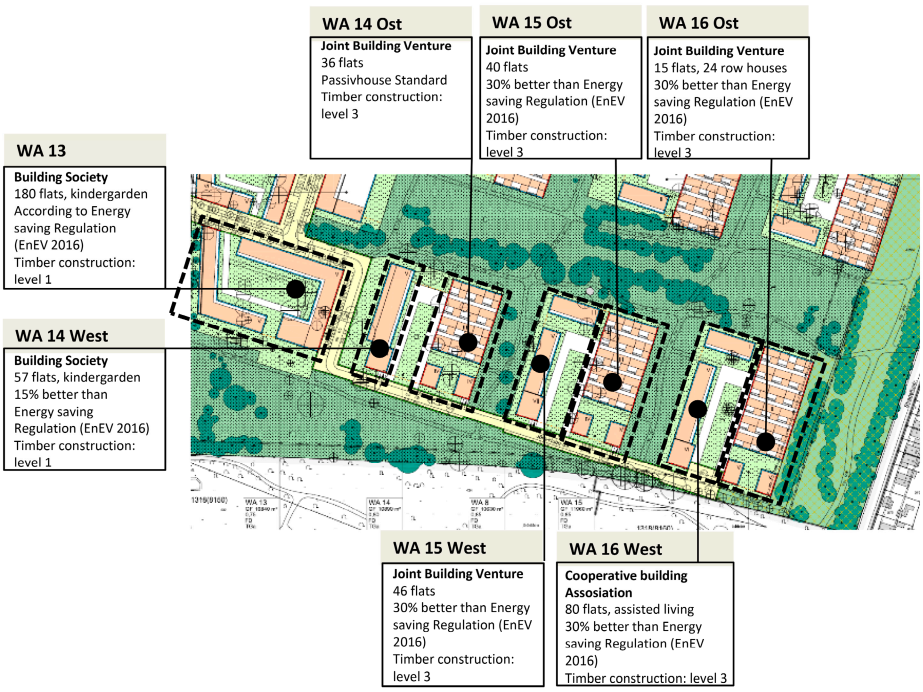


Figure 7. Development showing the winning bidder for each site with the agreed upon specifications: Type of buyer, the number of units, and the level of timber construction to be implemented.

The expert panel consisted of members from the city administration, an expert for fire safety in wood construction, a structural engineer for timber construction, and an architect with expertise in timber buildings and the author of this paper. Discussions with the expert panel on the designs forced planners to consider all issues around timber construction in the early planning stage, giving them the chance to overcome weaknesses during the design phase, when changes in design and construction still can be easily made.

Figure 7 shows the different sites with the type of buyer and the number of units to be built with the amount of timber (level) promised to be implemented.

4.3. Transferability to Other Communities

The approach used in this case study could be transferred to other communities. Figure 8 shows the steps for transferring the results. The main steps are, first, setting–up of the grant and, second, developing implementation. In the first step, a choice of which criteria should be evaluated and of which type of construction should be considered a timber building must be made. Reference values then need to be adjusted according to the needs of the community. The described method for the city of Munich could serve as a reference, including the calculation sheet for the subsidies. In the second step, the adjusted environmental criteria need to be included in the tendering process. The implementation process, including the decision of the council to promote timber buildings and the publication of the tendering documents, took around 18 months in Munich. A broad timeframe thus needs to be set.

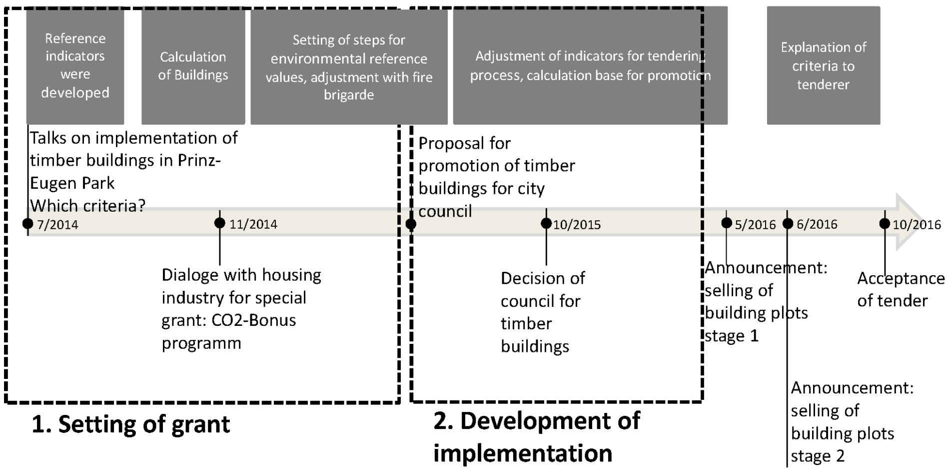


Figure 8. Transferability of concept to other communities combined with the timeline of the implementation in the case study.

5. General Discussion

This paper described how the sales of building plots can be connected to an agreement to build with wood. The developed environmental criteria, described in Section 3, were tested on an exemplary site development in Munich. The results show that, despite high requirements for the design and construction of buildings, the site remained competitive. The city of Munich's program for subsidies is of great interest for the buyers of the sites. Experience is still lacking with the requirements in terms of realized timber buildings. Monitoring the construction of the development would be an interesting issue for future research.

In Section 3, the study drafted reference values for different building types for the preliminary design stage of a construction project. Reference values also should help in the transition towards resource efficient Europe, as "clear environmental information" is requested in the "Roadmap for Resource Efficient Europe 2050" initiative. For exemplary buildings and their LCA calculations, the set target values are now brought together with requirements on fire safety. A list of possible timber and timber-concrete constructions [27] that meet the necessary fire regulations is adjusted for the site, providing an important planning instrument for planners. For planners, these abstract values and research findings need to be broken down to a very practical level.

The amount of renewable material as a single indicator for environmental city planning must be discussed critically. On the one hand, linking the tendering of building plots soley to the amount of renewable material used leads to maximum use of timber in the construction. On the other hand, although this type of construction maximizes carbon storage, in terms of resource efficient use of material, other material combinations, for example timber frame construction, might be better. Future discussions remain open to which method or which material combination is most sustainable. As the amount of wooden material is known, carbon storage is an easy indicator to use, and no additional calculations beside the calculation sheet are necessary.

There also needs to be an additional requirement for energy efficiency in terms of use of renewable energy sources and energy efficient construction. If the combination of the issues regarding energy efficiency in operation and energy efficient construction is not taken into consideration, only mediocre benefits will be incurred.

While the timber building rate in Germany is slowly increasing and has reached an actual level of 16% for newly constructed single family houses, this is true for only an average of 1.3% of newly built large residential buildings [30]. In terms of environmental benefits and temporary carbon storage, the introduction of these results could be of great interest, especially in newly designated urban quarters.

6. Conclusions

The building sector has been identified as a major player for reducing greenhouse gas emissions in Europe. As buildings become increasingly energy efficient in the use phase, the carbon footprint of building material comes into focus. Indeed, it is possible to implement target values for carbon emissions already in the procurement of building plots. From an environmental perspective, although wooden products have various advantages, they must always be studied with material efficiency in mind. Promoting timber buildings can contribute to reaching climate protection targets, and, at the same time, subsidies and grants can help to foster building with wood in urban areas, based on the requirement that the wood is procured from sustainable forestry.

In light of sustainable city planning, the explained indicator could be the key to achieving Eco-City standards. Energy and material choice from renewable sources must be looked at through the lens of resource efficiency and the local economy. Although truly sustainable Eco-Cities have not yet been fully implemented anywhere, introducing ideas and instruments to achieve urban climate goals, if only in part, is a worthwhile endeavor.

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