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DEVELOPMENT OF FUTURE-ORIENTED CONCEPTS FOR AGRICULTURAL CONSTRUCTION WITH WOOD

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ABSTRACT: This paper presents the interdisciplinary project "Development of future-oriented concepts for agricultural construction with wood - from planning to deconstruction" (ZukunftLaWiBau). The aim of this project is to increase the share of agricultural buildings in wood construction by means of future-oriented concepts, taking into account technical and socio-economic issues. The result of the project will be a planning guide "Agricultural Building with Wood in the 21st Century". The guide includes current issues of climate protection, animal welfare, regional value creation, durability of wood as a building material, resource efficiency and economic viability as cross-sectional fields. An interdisciplinary research team is working on the issues in a holistic manner. In the following, this interdisciplinary cooperation and the goal will be explained in more detail.

KEYWORDS: Agricultural buildings, timber buildings, wood, circularity, sustainability

1 INTRODUCTION

The goal of becoming nearly emission-free in the building sector by 2045 is important and ambitious, not only because the sector, which includes the construction, maintenance and operation of buildings, is responsible for around 40 % of all greenhouse gas emissions in Germany. Particularly in agricultural construction, large potential is seen in the use of wood, a regionally available and already historically used raw and as construction material. In Germany, the diverse, sustainably managed forests and domestic wood are currently not reflected enough in agricultural construction. The timber construction quota in agricultural construction in Germany was only 35% in 2021 [1]. The use of wood in agricultural construction has been obvious for a long time, as farms often also own forests and could thus utilize their own wood.
To ensure sustainable land management, regional cycles should be included and made usable. An economic evaluation in this respect has been lacking up to now.

2 PROJECT

The use of wood in agricultural construction has a very long tradition. However, in recent decades, the importance of wood decreased compared to other building materials [1]. Regionally, there are differences in the size and typology of the category grouped as agricultural buildings. From the data of the Federal Statistical Office on new non-residential buildings, it is to recognize that there is a tendency for agricultural buildings to be larger in the north and smaller in the south, but that the number of buildings in the south is significantly higher. Farmers traditionally often own (small) private forests, which could provide wood supplies at least for their own needs. Various studies show that the use of domestic wood raw materials can consolidate regional value chains in rural areas [2]. In the current structures, however, there are too few incentives and implementation possibilities to use this potential for own buildings.

The difficulty for the application of wood in agricultural construction, especially regarding the use of spruce in agricultural buildings without preventive chemical wood preservation measures (according to DIN 68800), could already be reduced within the research project of the TUM and the LfL "Agricultural buildings in timber construction without preventive chemical wood preservation (use class 0" [3]. Within the scope of the project, it could be shown that, with a few exceptions (potato storage halls), a classification of all forms of use in livestock and storage through constructive measures, in conjunction with the recommendation to use kiln-dried wood, seems possible in service class 0 (according to DIN 68800). However, the proof of these positive, but still selective results for the breadth of the typologies of wood structures used in agricultural construction in Germany is still pending. Technically, wood can be used in most agricultural buildings, but there are additional requirements for individual components.

However, a central open question with regard to the sustainable use of wood or wood products in livestock farming is the predominantly negative assessment of the hygiene status on the part of the official veterinarians As representatives of public interests in the context of the building permit procedure, but also in their control function for current facilities, they repeatedly complain about barn facilities made of wood or point out that they must be removed and burned in the event of an epidemic. In some cases, requirements are placed on the surface finish that do not comply with the relevant hygiene regulations.

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There is also uncertainty about the storage of harvested products due to requirements from the relevant regulations. As a result, farmers who build new buildings or remodel existing ones often opt for plastic or steel. Scientific studies on the hygiene status of tools and wooden surfaces (e.g. cutting boards in large slaughterhouses), on the other hand, confirm that certain types of wood have the best germ-inhibiting or killing effect. However, in view of the relevant guidelines, this is obviously not sufficient for the transfer of these results into practice. The situation is aggravated by the fact that no research projects have been carried out on this issue in the last 20 years.

A continuing obstacle is the lack of a broad database for the environmental assessment of agricultural buildings and their use of resources. This is necessary in order to make the data usable for calculating the product store of carbon in wood products and thus to be able to meet the requirements of agricultural construction in the 21st century with regard to climate protection. The project "Development of forward-looking concepts for agricultural construction with wood - from planning to deconstruction (ZukunftLaWiBau)" therefore aims to increase the proportion of agricultural buildings in timber construction again, taking into account technical issues. To this end, planning principles for agricultural buildings are being brought into the 21st century on the basis of model buildings. For this purpose, planning principles for agricultural buildings are used on the basis of a small and a large hall. Regional value chains in rural areas will be taken into account, current issues of hygiene and wood products will be considered and possibilities to use the potential of existing wood will be proposed. In addition, the database on climate and resource protection of agricultural buildings made of wood will be updated and deepened and made usable for the Charter for Wood 2.0 process in Germany.

The result of the project is a planning guide "Agricultural construction with wood in the 21st century". The guide incorporates current issues - climate protection, animal welfare, regional value creation, durability, resource efficiency and economic viability - as cross-cutting fields. Since the subject area is so broad and the expertise of very different stakeholders is needed, a structure with interlocking work packages was developed to be able to answer all questions holistically (see figure 1).

3 PROJECT PARTNERS AND WORK PACKAGES

An interdisciplinary team of project partners is working together to develop a holistic guideline for future agricultural construction. This team consists of the Chair of Resource Efficient Construction at the Ruhr University Bochum (RUB), the Technical University of Munich with the chair wood Science (TUM-WS) and the chair Timber Structures and Building Construction (TUM-TS). Furthermore the Bavarian State Research Center for Agriculture with the Institute for Agricultural Engineering and Animal Husbandry, the working group Agricultural Construction, the Department of Veterinary Medicine, Institute for Animal Hygiene and Environmental Health at the Free University of Berlin and the Friedrich-Loeffler-Institute with the Federal Research Institute for Animal Health are involved.

In order to deal with the interdisciplinary topics in a holistic manner, work packages (WP) were developed (see figure 1). The results from these work packages are linked in the planning guide. The starting point (WP1) is an integrated inventory analysis and data collection of the main building types currently used in agricultural construction in Germany (what is currently being built, including a map of regional differences in construction methods). These data form the basis for a comprehensive analysis in the following areas: Status-quo Analysis (WP 1), Life cycle assessment (LCA) buildings (WP 2), resource potential (WP 3), wooden products (WP 4), hygiene (WP 5), durable constructions (WP 6), design for reuse (WP 7) and economic structures (WP 8). The results of these analyses, as well as the suggestions for improvement derived from them, will be discussed and synthesized. The results from analysis, optimization, discussion and consolidation will be incorporated into the guide .

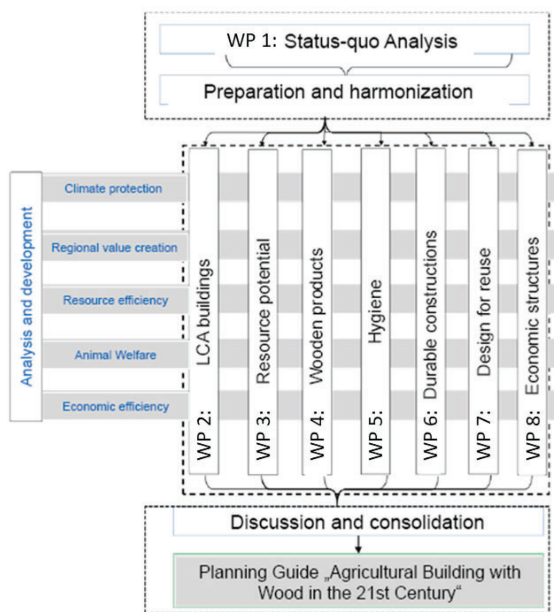

Figure 1: *Work steps within the framework of the development of the design catalog and associated work packages3.1 Status-quo Analysis (WP 1, LfL)*

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3.1 Status-quo Analysis (WP 1, LfL)

In WP 1, typical procedures in agricultural animal husbandry and storage in Germany are recorded and systematized for status quo recording and compared with the associated building typologies and building geometries. In the process, not only utility buildings in timber construction are recorded, but also buildings and barn facilities in all otherwise common materials (e.g. concrete, brick, steel, plastic). The resulting catalog serves as the basis for all further work packages of the project partners. Starting with the compilation and allocation/categorization of inventory data (including planning and construction documents, publications, consulting documents) on agricultural buildings for livestock and storage (from the 1970s onwards), the second step is an initial assessment of the substitution potential for non-wood materials with wood products or a comparison of the same processes/building typologies in non-wood construction or wood construction. In the following, the entire data material will be processed (in electronic form) for further use in the following work packages and the selection of sample buildings and processing for further use, especially in WP 2.

3.2 LCA buildings (WP 2, RUB)

In WP 2, the functional unit "building" with its system boundaries is defined in accordance with DIN EN 15978 and the systematics for agricultural building types is adapted and defined by all project partners. For this purpose, the necessary building material data will be updated if necessary and transferred to the LEGEP software and the results on building level will be generated in a calculation program and validated by a critical review according to DIN EN ISO 14040 and ISO TS 14071. The life cycle assessments necessary for calculating the environmental impact of timber buildings and their alternatives in the defined market segment as well as estimating possible efficiency improvements will be calculated. Scientific publications will be developed over the duration of the project, continuously updated data from ÖKOBAUDAT will be entered into the calculation software. The system boundaries and the functional unit for LaWiBau will be defined and standardized according to DIN EN 15978. Data for data acquisition and mass determination of functionally identical LaWiBau are procured and the calculation software LEGEP is adapted accordingly. In the next step, data is collected to form the data basis and enlarge the building data pool. The creation of the data basis takes place by the data acquisition and by the mass determination of functionally identical agricultural buildings. For this purpose, building data from different sources must be obtained, compiled and standardized. Different reference sources, such as the building pool of the LfL, KTBL data sets or also construction plans of already implemented agricultural farm buildings, which contain a proportion of wood in the construction, form the building data pool. The differences in use (e.g. dairy barns, horse barns, machine sheds, etc.) are taken into account in the categorization of the LaWiBau building pools. The LCA of the procured data are calculated over the entire building life cycle using the LEGEP calculation software and subsequently validated via a critical review. The environmental parameters such as GHG emissions, primary energy consumption, raw material use, etc. are worked out and presented for the individual types of use. The existing LaWiBau buildings are mostly formed by hybrid constructions in the existing HolzImBauDat building pool. In a detailed investigation, the environmental influence of the mineral material concept of individual building components on the building will be determined. For example, the influence of individual steel columns (or reinforced concrete columns) in wooden barns on the load-bearing environmental balance is clarified in comparison with an overall structure in wood. The aim is to create economical load-bearing structures while taking environmental aspects into account.

As a result of this work package, the substitution potential in the building sector is presented, which is the savings in greenhouse gas emissions that result when a functionally equivalent wooden building is constructed instead of a conventional building. This is based on standard-compliant calculations of life cycle assessments at product and building level. It also shows the carbon storage, which shows the storage of biogenic carbon in the wood products, represented as global warming potential (GWP) biogenic.

3.3 Resource potential (WP 3, TUM-WS)

In work package 3, resource potentials, in particular of the farmers' own rural forest, are identified for agricultural construction with wood. Existing and potential value chains (Fig. 2) will be analyzed with regard to structure and success factors and evaluated by means of environmental (life cycle assessment) and economic (including value creation) indicators as to whether and how construction with wood can be strengthened, in particular through the involvement of regional actors. Example regions for the analysis of value chains are available through an master thesis of the TUM-HFM (Oberallgäu/Bavaria, Hochsauerlandkreis/North Rhine-Westphalia, Vulkaneifel/Rhineland-Palatinate, here with focus on buildings for dairy farming) as well as further contacts through the LfL (Saxony etc.).

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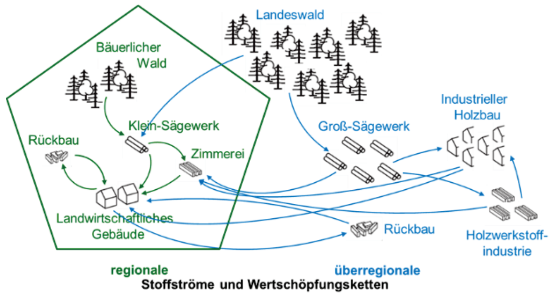

Figure 2: *Illustration of possible value chains for agricultural construction with wood (using Wegener et al. 2010).*

The basic characterization of agricultural farms will be carried out together with WP 1 nationwide with regard to their needs and possibilities of building with wood, using the annual nationwide survey of the test farm network of the BMEL (by means of an additional short questionnaire with regard to characteristic values of forest area, wood types, agricultural building types, priorities in the choice of building material) as well as the annual telephone survey of the small private forest of state authorities in several federal states. From this information, farms in sample regions will be selected and subjected to in-depth quantitative and qualitative analysis. The resource potentials are determined in the example regions, in particular for the farmer with rural forest ownership, by comparing the wood supply (wood species, quantities, assortments), and the previous raw material use with the current raw material/wood use and the wood demand for future construction with wood of the example farms. Data sources are the Federal Forest Inventory (BWI), state statistics, data collections for the small private forest in adherence to the methodology of Wilnhammer et al. [4], as well as queries for realized and planned agricultural buildings (categorization), raw material use of selected building categories (wood species, building materials, components, quantities, costs), and implementation of timber construction (raw material, building material origin, implementing wood processing and timber construction companies). With regard to the analysis of the value chains for agricultural construction, the actors of the value chain used so far as well as the material flows are first determined and interviews are conducted with regard to success factors and obstacles. In doing so, the possibilities of integrating regional actors as well as actors not yet considered are analyzed. For the environmental assessment of the value chains, the regional conditions of the production of the wood products including transport routes are taken into account [5] In this way, possible advantages of the regional value chain can also be considered in the life cycle assessment of the buildings. For the economic evaluation, the cost accounting of local/regional actors (mainly farmers with their own forest, carpentry shops) will be included in cooperation with WP 8 and compared with those of supra-regional actors (mainly state forest, industrial timber construction companies). Based on this, the (supra-)regional value added is calculated [6]. Finally, the potentials of building with own or regional wood will be presented as well as recommendations for an optimization of the value chains especially in the regional context and the feasibility for farmers.

As a conclusion and recommendations for action of this work package, the statement can be made that, in principle, regional, often also farm-owned wood is available for agricultural construction in Germany. The use of other tree species than spruce for the constructive and also non-constructive area offers regionally specific potentials, but due to the regional differences for the promotion of agricultural timber construction a regionally specific approach is necessary.
Furthermore, it can be said that the use of own wood in agricultural construction often shows a cost-efficient and sustainable solution with high potential and especially smaller construction projects can be more easily realized with own / regional wood. In order to ensure the profitability of using own wood, the provision of wood from own forest has to be recognized as eligible. Important success factors in agricultural timber construction are competent and regionally available actors in the value chain as well as support and technical expertise from private and public construction consulting and planning. Building with own / regional wood increases the regional added value by involving a large number of actors, secures jobs and income in rural regions and promotes climate protection by reducing transport distances.

3.4 Wooden products (WP 4, TUM-WS)

Work package 4 compiles the properties for wood products necessary for the special conditions of agricultural construction in a catalog. Existing knowledge as well as experiments and field tests for missing knowledge, especially for hardwood building materials, as well as new materials are used. For the analysis of the suitability of different wood species or wood products and their material properties with respect to specific requirements against gaseous, liquid and, if applicable, mechanical loads in the respective agricultural structures, literature as well as previous experiences of farmers are used for traditional wood products. With regard to the assessment of the use of innovative wood products and materials, not only from spruce, but also from pine (possibly larch and Douglas fir) or hardwood (especially oak and beech), for which no knowledge is yet available with regard to chemical-aggressive stress, laboratory experiments or test methods are used [7]. In worst case scenarios, samples are stored in model atmospheres and the surfaces are examined (e.g. pH, ATR-FTIR or microscopically) or emission measurements are carried out, e.g. by means of chemical sorbers and subsequent pyrolysis GC/MS. Since laboratory tests cannot always represent real-life conditions, field tests (on-site monitoring) are conducted to investigate the durability of wood structures made of selected wood products in agricultural environmental conditions (e.g. glulam, cross-

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laminated timber, laminated funicular timber, cement-bonded particleboard or thermowood) under different uses (bay/partition walls as well as exterior walls and ceilings). Based on the results of the laboratory and field tests/monitoring, farmers' previous experience with building with wood, and information from the literature, the advantages and disadvantages of each type of wood or wood-based material and their area of application are compiled in a wood type and product catalog based on selected criteria like the durability class for agricultural construction.

3.5 Hygiene (WP 5, FLI, FUB)

In work package 5, the properties of wood building materials are tested with regard to hygiene requirements. Wood building materials with different surface structures (smoothly planed, rough sawn, etc.) are contaminated with indicator germs (bacteria, fungi and viruses) and with viral animal disease pathogens and the disinfection effect of physical and chemical processes is tested in laboratories of the required biological protection level. Wood products with different surface structure (smoothly planed, rough sawn, etc.) are contaminated with viral animal pathogens (African swine fever virus, foot-and-mouth disease virus, bovine herpesvirus type 1, highly pathogenic avian influenza virus) and the disinfection effect of physical and chemical procedures is tested in laboratories of the required biological protection level. The resistance of the wood products used to the successful disinfection procedures is investigated.

As a result of this work package, the general legal basis as well as the specific legal basis for wood will be presented. In addition, a disinfectant suitable for wooden buildings and their different agricultural use will be proposed, as well as the procedure of barn cleaning and disinfection.

3.6 Durable constructions (WP 6, TUM-TB)

All analyses of damage to buildings in timber construction confirm that the execution of connections has a decisive influence on the durability of timber structures. The main task of this work package is to investigate the connection details used in agricultural timber construction today, which were recorded during the as-built analysis/data collection. The expected damage mechanisms affecting the supporting structure of agricultural buildings can be divided into three categories: mechanical, chemical, and biological-physical attack. Accordingly, topic maps are developed for each category to provide a brief overview of the problems and possible actions. The goal is the same for all topic cards: permanent protection from damage through structural/design measures. The basic hazards and the corresponding structural measures are considered. These topic maps are intended as a first, quick orientation aid, and show that simple and effective measures exist. In the planning process, all corresponding introduced technical building regulations, in particular DIN 68800-2:2022-02, must also be observed.

Other results from this work package include the realization that, regardless of the type of connection, sacrificial boards provide simple and effective protection against all attacks. In conclusion, it can be said that correctly planned and executed agricultural halls made of wood are a durable and sustainable alternative to steel and reinforced concrete halls.

3.7 Design for Reuse (WP 7, TUM-TB, RUB)

Design for recycling and enabling the reusability (= design for reuse) of building materials and permanent connection details are the requirements for the reuse of building components. They enable a cascade use of wood in the first place (Fig. 3). The data necessary for the deconstructability of the connecting materials and their manufacture and static design in relation to the overall structure as necessary basics will be developed in coordination with WP 6. The investigations on the recycling of the agricultural buildings are to prove the nature of this potential. In comparative analyses, open material flow loops of agriculture construction are investigated and modified in feedback with the (building) construction in order to raise the efficiency potential even further, if possible, and thus extend value-added processing to the end of life of product systems. For this purpose, a renewal and extension of the conceptual methods as applied in the investigation of building life cycles (processes) is aimed at.

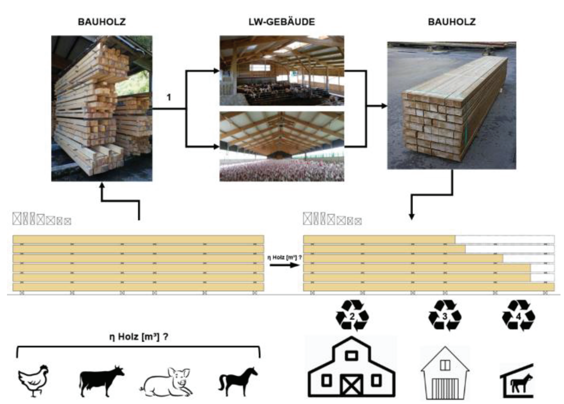

Figure 3: *Concept reuse*

First of all, an investigation of the connection methods of the building pendants takes place on the basis of the previously elaborated data with recording of the components with regard to their assembly and disassembly properties for different building types / materials. Then, the load-bearing structures in timber construction with their components as well as their connection alternatives with their respective manufacturing and assembly methods for the possible improvement of their deconstructability and the assembly and disassembly and the connections of the components are calculated according to constructional and life cycle assessment methods. The characteristic values about the material stock and to the utilization ways of the wood and wood materials in proportions and geometries are compiled and are available as information for the possible use in a second life cycle or for the cascade use. Finally, an investigation of the economic efficiency and resource efficiency of the hall types through secondary material use and deconstructability over the life cycle takes place. The type of agricultural use results in different heavily used areas in the building. Depending on the type of use, lower loads are present from a certain height in the building, which is addressed here in particular.

3.8 Economical supporting structures (WP 8, LfL)

From the point of view of farmers as building owners, agricultural construction is primarily the manufacture of production facilities, which are subject to high cost pressure due to competition in food production. At the same time, requirements from animal welfare or quality assurance of the stored goods, building physics, optimized work management, expandability, design and the landscape have to be taken into account during planning and construction. In WP 8, first a systematization of typical animal husbandry and storage procedures to characteristic functional, grid and axial dimensions as well as building geometries takes place, and then the development of structural variants, which are previously elaborated building typologies or standardized timber components adapted to an economic utilization, takes place.

Exemplary working drawings are developed for the supporting structures in wood determined from the static pre-dimensioning as a basis for the further investigation steps and supplemented with comprehensive material/parts lists. In the process, the material/parts lists for determining the material consumption (including cross-sections of the load-bearing components, timber requirements, timber fastenings) will be developed and the costs for the design variants will be determined using bills of quantities. The goal is also to develop criteria for estimating the cost consequences of specific design decisions. In addition, the implementation and evaluation of new software add-ons at the interface between CAD work and CNC truss planning for company-specific timber construction projects will be carried out in order to reduce the additional planning effort due to the lack of industry-specific software.

4 RESULTS

The result of the project is a planning guide, which is intended to provide planners and builders with the necessary information from a neutral source. The scientific findings are intended to contribute to implementation in building practice and to show farmers ways in which they can again make greater use of wood as a raw material for their own projects. In addition to a presentation of typical floor plans and load-bearing systems for the majority of agricultural uses, the guide contains reliable information on life cycle assessment, necessary quantities of building materials, individual fraction types and quantities for the reusability of building materials and durable connection details, as well as information on the hygienic properties of wood products as a basis for practice. The preparation of the planning guide is carried out under the condition to enable smaller, regionally working timber companies to participate again in agricultural construction with wood. In addition, politicians as well as industry can use the results, which concern the increase in the use of wood in agricultural construction, resource efficiency and the environmental impact of an overall increase in the use of wood, for an improved basis for decision-making, both in the planning of buildings themselves and in the evaluation of measures in the field of construction.

5 CONCLUSION

The research project "Development of future-oriented concepts for agricultural construction with wood - from planning to deconstruction" will run until the end of 2023. The planning guide mentioned here is currently being compiled and supplemented by a detailed final research report.

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