World Conference on
Timber Engineering
Oslo 2023

RESOURCE-EFFICIENT MATERIALIZATION | SUSTAINABILITY FUTURE TRENDS

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ABSTRACT: The growing enormous number of mid-rise timber buildings in European metropolitan areas leads to the investigation of a possible optimization potential in the use of timber in combination with other building materials.
Within the framework of the Master's Course "Resource-efficient materialization" the Department of Structural Design and Timber Engineering at the Vienna University of Technology developed a multidisciplinary course including design concepts, feasibility studies and performance assessments of the timber components in order to improve the overall performance.
Due to this process, the focus in the development of a Master's Course lies on the feasibility and optimization of the structures on overall component level on the one hand, as well as on the normative realization aspects of innovative timber-based composite structures on the other hand. The Master's Course "Resource-efficient materialization" has formulated the integration of the natural building material timber to the current requirements of the construction industry as a parent research objective.
This paper shows the results of the studies and the conceptional design. The objective of the studies is to develop application-optimized timber systems with a special focus on the sustainability. A construction-optimized design with increased resource efficiency can be achieved.

KEYWORDS: Education, Sustainable building, Wood-based building systems, Life cycle assessment, Quality control

1 INTRODUCTION

In the past twenty-five years, an increasing number of timber-based buildings have been constructed in Europe. In fact, nearly all European countries allow at least six-story buildings in timber as regular solutions and pilot projects had been built up to twenty-four-stories.
In Austria, timber construction has increasingly gained market share over the last 20 years. Currently around one quarter of the construction volume in building construction is made of timber [1]. In the study [1], it is assumed that buildings with a timber content of 50 percent or more are classified as timber constructions. Here, only the statically supporting parts (wall, floor, roof) are used to assess this classification. Based on the total constructed usable space in the building sector, it has increased from 14 up to 24% between 1998 and 2018. Further increases are to be expected, especially for large-volume buildings (residential and public buildings). The timber-based proportion in housing construction is distributed to 53% (newly built single and multi-family houses as well as extensions and conversions) and 47% in non-residential construction (public, commercial and industrial buildings as well as agricultural buildings). At the residential segment, the proportion of timber-based construction has risen particularly strong with an increase from 10 up to 23% in the mentioned period [1].
The analysis in [2] show that the share of multi-story residential buildings between 2008 and 2019 was below 2% in Vienna, slightly above 3% in the other federal provinces and around 10% in federal province Styria (because there is a politically enforced timber construction quota).
Parallel to this, the number of start-ups of companies in timber construction is growing. On the whole, they are small: on average, five employees work in the companies. 83% of the companies have nine or fewer employees [3].
Not only the depicted timber-based building sector is under continuous change, but also the related building codes are in constant revision. Due to this process, the focus in the development of a Master's Course lies on the feasibility and optimization of the structures on overall component level on the one hand, as well as on the normative realization aspects of innovative timber-based composite structures on the other hand.

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https://doi.org/10.52202/069179-0600

1.1 TEACHING A COMPREHENSIVE SET OF SKILLS

The Vienna University of Technology (TU Wien) is Austria's largest research and educational institution in the field of technology and natural sciences. More than 4,000 scientists are researching "technology for people" in five main research areas at eight faculties. The content of the studies offered is derived from the excellent research. More than 27,000 students in fifty-five degree-programs benefit from this. As a driver of innovation, TU Wien strengthens the business location, facilitates cooperation and contributes to the prosperity of society [4].
At the TU Wien, teaching and research are closely intertwined: excellent teaching depends on excellent research, and only leading researchers in their field are able to take the students forward to the next levels of science and technology [5].
TU Wien has been conducting research, teaching and learning under the motto 'Technology for people' for over 200 years. TU Wien has evolved into an open academic institution where discussions can happen, opinions can be voiced and arguments will be heard. Although everyone may have different individual philosophies and approaches to life, the staff, management personnel and students at TU Wien all promote open-mindedness and tolerance [4].
Aiming for relevance to practical applications is an essential component of teaching at the TU Wien, giving students a rich learning experience. The university also gives its students a great degree of freedom in choosing their curricula to promote a sense of personal responsibility for learning at the university and throughout life. This method-oriented solid foundation gives students the tools required for lifelong learning. Involving students in ongoing research programs at the TU Wien is key to train young scientists and to prepare them for future challenges in academia, industry, or business [5].

For several years, the Department of Structural Design and Timber Engineering (ITI) at the TU Wien has been offering neutral expert advice on the planning of multi-story timber construction projects. In the course of this expert advice and numerous discussions with developers and project managers, it has become apparent that no compactly summarized answers are available for the most common questions. In most cases, decisions with far-reaching consequences have to be made in a short time during planning and execution. Therefore, that proven processes, materials and methods are often relied upon, leaving little time and scope for new ideas.

Within the framework of the Master's Course “Resource-efficient materialization” the ITI at the TU Wien developed a multidisciplinary course including design concepts, feasibility studies and performance assessments of the timber components in order to improve the overall performance.

2 TEACHING METHODS

Timber construction requires a different planning and construction process than mineral construction. Due to the high degree of prefabrication, decisions have to be made in the planning phase in order to benefit from all the advantages of timber construction.
The approach in timber construction differs from the conventional construction processes in mineral-based solid construction. In mineral solid construction, it is economical to erect the shell of building in first step and then to install the windows and façade, as well as the building services and interior fittings.
In timber construction, on the other hand walls are produced in the workshop, irrespective of the weather. Windows, façades and interior cladding can be already ready for installation. This guarantees a high quality of workmanship and reduces installation time on site.
Prefabrication requires a different approach from design to construction. Many decisions have to be made at the beginning, in the planning phase. Prefabrication brings a high degree of planning, scheduling and cost reliability. It reduces the transport of materials to the construction site, the coordination of the trades on the construction site and the space required for construction site equipment (construction containers, material storage, debris troughs ...) [6].

Therefore, the Master's Course “Resource-efficient materialization” deals with the materialization of supporting structures and building envelopes in dense urban construction; special attention being paid to the use of resource-saving building materials, especially natural building materials.
The focus is on the interaction between choice and use of materials and the architectural, technical and ecological requirements to be met in the design and implementation.

The course offers a selection of solutions for implementing technically and economically successful projects and shows a way into the world of timber housing as well as helps to break down entry barriers due to a lack of knowledge among students. Investigated topics thereby are related to a wide range of structural and building physical indicators, such as strength and weight properties, thermal and noise insulation properties, as well as fire protection properties, always under a simultaneous focus on an optimized sustainability of the developed systems.

After having successfully completed the course, students are able to

1. define and apply criteria for sustainability and energy efficiency, acquire a technical way of thinking with the criteria of sustainability and energy efficiency, which have a direct impact on the design in an interdisciplinary exchange.
2. to acquire architectural and design possibilities of hybrid construction in the context of the requirements for flexible and adaptable building;

 https://doi.org/10.52202/069179-0600

3. to learn the possibilities for the production and assembly of large-volume hybrid structures and to use methods for quality control Rationalization is addressed as well as the question of costs.
4. to deepen oneself in background and in design and calculation methods of hybrid construction (static, physical, ecological and economic aspects).

2.1 CONCEPTUAL STUDIES

The course teaches the basic skills of architectural design. It pursues an integrative approach that introduces students to all the central practical fields of architecture - from building design, structural and detailed planning to urban planning and landscape design.

The basis of the course is formed around the project-based learning, learning by doing and blended learning education methodologies. This will lead to the transfer of new innovative educational practices, where critical thinking, problem solving and flexibility will be implemented in multicultural group work.

Working in multidisciplinary groups students increases their knowledge and will obtain a wider overview in present and future challenges of design and construction of timber buildings. The intensive learning course consists of two main parts: theoretical face-to-face lectures (25% of all hours), practical teamwork on project (75% of all hours). Project work of students are guided by prepared assignment book, site visits and instructors.

In close succession of presentations and demonstrations of practice-oriented solutions, a flexible feedback culture is established in order to consolidate the student's ideas. While the student's group is working different ways of solving problems, special emphasis is placed on providing them with impulses in the right direction through practical inputs given by experts from business, industry and research at the appropriate time. In doing so, the students are encouraged to pursue the challenges independently instead of simply accepting prefabricated systems.

3 LEARNING OUTCOMES

The course conveys an understanding of the tasks of architecture in society, of its aesthetic, technical, economic and ecological foundations, and of the interaction of various disciplines in planning and construction processes. The focus is on the training of technical, aesthetic and intellectual competencies that enable the successful handling of complex design tasks. Methodological clarity and conceptual thinking are just as much a part of this as the ability to communicate and cooperate in a team.
Learning outcomes describe the knowledge, skills or competences students acquire until the end of the course. The skills acquired provide the best prerequisites for starting a successful professional career after graduation.

The students work on real hybrid timber building projects and share different skills according to their specialization and prepare proposals that will include project program, location and floor plans, façades and sections, room and wet room layouts, structural design, fire precautions, floor and wall partitions, acoustic airborne and impact sound, moisture and cold bridge prevention, building services pathways, choice of materials and building components, important key assembly details (sketches to scale), façade cladding, roof construction, balcony design and construction, external building components insulation and stair enclosure and stairways etc. [6].

An optimized ratio of investment costs to utilization costs should be reached by means of construction and technical measures.
In the design concept the manufacturing, operating and maintenance costs are to be taken into account by the appropriateness of the construction measures (especially area efficiency, building form, supporting structure, façade, etc.).

Additionally, working on real hybrid timber projects results in a number of synergies, such as the exchange with the people involved in outstanding projects or the opportunity to take part in national and international competitions.

3.1 ENERGY AND ENVIRONMENT

The ever-increasing demand for energy affects both the extraction of resources and the climate and environment. Alternative energy sources must be further developed, reliable solutions to climate issues must be found, and there are still some serious problems relating to harmful substances that have not yet been solved. Although significant progress has already been made in these areas, there are still many outstanding questions that are almost impossible to answer using traditional technological approaches.
Currently, the required energy standard for buildings in Austria according to the Building Standards Act is at the low-energy residential level. With the introduction of the Energy Performance of Buildings Directive, the European Council has created the basis for a harmonized assessment. These directives state that buildings must be sustainable, the building materials and components used must be recyclable and the use of environmentally friendly resources and secondary materials is desirable [7].
The high level of thermal insulation in timber construction saves on investments in heating, ventilation and air conditioning (HVAC) as well as operating costs. This means that the necessary technology can be implemented much more simply, is less prone to errors and takes up less space. The fewer water-carrying pipes in the building, the lower the risk.

https://doi.org/10.52202/069179-0600

High thermal insulation, even a thermal transmittance (U-value) of about 0.1W/m^{2}K, is easy to achieve in timber construction with little additional expense. With suitable insulation, less heating is required in the winter and less cooling in summer. This also affects the HVAC. The amounts of energy required for heating and cooling are significantly lower than in a conventional building. In high-efficiency buildings, because of the low power the proportional distribution and circulation losses are particularly high. In the case of central water heating, these amount to up to 85% of the energy demand. Therefore, decentralized water heating can be can be more efficient [6].

In order to address not only the ecological and resource-efficient aspects of sustainable construction, but also to contribute to the discussion on climate-resilient construction, studies and analyses have been carried out. Simulations already carried out in [8, 9] discusses the main factors influencing the overheating of buildings in summer.

The zone overview in Figure 1 shows that the average temperature values vary greatly in relation to individual zones (rooms). The temperature difference between the coolest and warmest room is approx. 2.5 °C. Nevertheless, when comparing the individual room temperatures due to different construction methods, the difference is hardly noticeable.

In all simulated scenarios, these show a maximum difference of only 0.2 degrees Celsius between the individual building types. On the other hand, as the scenarios studied show, increased shading and effective air exchange can reduce the average summer temperatures by several degrees Celsius.

As an effective storage mass, the centimeter inside the building component is particularly important. Deeper layers do not participate significantly in the 24-hour buffering. Building simulations show that the masses act symmetrically. Heavy buildings react slower, light buildings react faster. Both have their advantages.

3.1.1 Investigation of influencing parameters

The case studies on existing buildings in the course include various thermal simulations in the cities Vienna and Wels (Austria), Bochum (Germany) and London using the 3D online simulation tool Thesim 3D [10]. Thesim 3D simulates the thermal behavior of a room in a steady-state, periodic condition (period length: 1 day). It is therefore particularly suitable for standardized summer overheating tests according to EN ISO 13791 [11] or ÖNORM B 8110-3 [12].

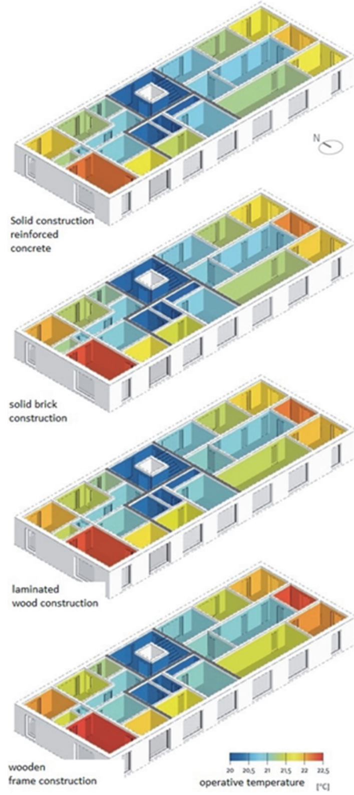

Figure 1: *Analysis model Temperature averages of the individual zones for the four construction methods (© proHolz Austria and the authors **[8]**)*

The framework conditions in several European cities are unquestionably different. The simulations in the cities Vienna and Wels, Bochum and London with regard to different constructions made of timber, reinforced concrete and brick as well as their summer overheating variants are intended to cover a wider range of climatic conditions and lead to more differentiated solutions. The following factors are identified as influencing a proper investigation: orientation and size of windows, g-values of window panes and awnings.

Therefore, differentiated measures are developed to avoid summer overheating and to save energy while maintaining sufficient natural light.

The building design contributes significantly to the desired indoor climate in summer. Thermal-dynamic building simulations investigate the placement of exterior windows, the reduction of window area and the effects of balconies and canopies. The zones with the highest solar radiation are mainly located in the southwest.

https://doi.org/10.52202/069179-0600

In simulations carried out on passive house standard buildings in reinforced concrete skeleton construction combined with wooden panel shells (U-value = 0.7W/m^{2}K; g-value = 0.48 coated 3S insulating glass) in Bochum (Germany), the temperature remains comfortable as long as night ventilation (20:00 to 8:00) and sun protection provided by a sun shade system (the shading factor Fc-value = 0.27) are assumed.

The average summer temperatures in Bochum are cooler than in Vienna. However, when the building is placed in Vienna, it can be observed that the indoor temperature is hot but still does not reach the limit of 27 degrees (cf. Figure 2). This shows that the surface elements and window sizes are well designed even in hotter conditions. In Vienna's outdoor climate, efficient night ventilation also proved to be an effective measure against summer overheating of indoor spaces.

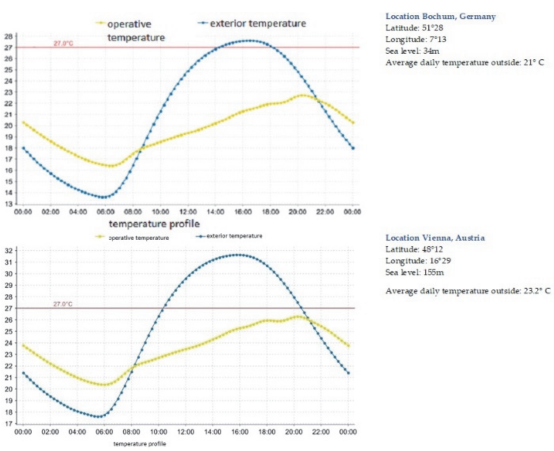

Figure 2: *Thermal dynamic building simulation in Bochum (left) and Vienna (right) (© ITI/TU Wien)*

Thermal simulations on existing buildings show that the construction method has no significant effect with a good U-value. Orientation, night ventilation and sun protection have been shown to have significantly higher effects and have been investigated.

In Wels (Austria), solar radiation is almost constant throughout the year due to the low horizon elevation. In the simulations, no shadows from surrounding buildings influenced the study area, as the surrounding houses are built relatively low.

All common rooms in the building have high daylight quotients. This is at least 2% for all common rooms. In Austria, a daylight quotient of at least 1.9% should be achieved [13]. Basically, this means a pleasant quality of life even in a north-facing room. There are no pure north-facing flats, essentially as a result of the good placement of the flats in the overall floor plan.

The bedroom in the attic, which is to be regarded as a problem room in this calculation, is characterized by two external walls (south-west) and south-facing windows. The room size is relatively small at around 11m² and can quickly overheat. However, due to the smaller room volume, it can cool down more quickly during the night. At first, different combinations of night ventilation (20:00-8:00) and blind use with direct sunlight (Fc value = 0.27) are compared in the current state of the building. A comfortable indoor climate is only possible if ventilation is provided during the night and the blinds are automatically closed when the sun is shining. Consequently, it is preferable to keep the blinds closed if the flat is not visited for a longer period of time (e.g. when travelling). However, the room heats up to 37°C even when the blinds are closed (cf. Figure 3).

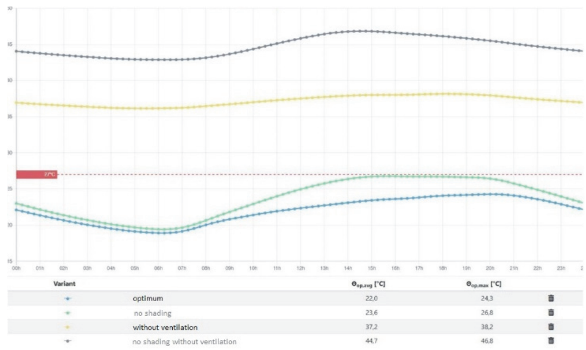

Figure 3: *Thermal dynamic building simulations of the building in Wels; comparison of optimization measures (© ITI/TU Wien)*

The next step is to compare the different constructions for optimal ventilation and blind use. Lightweight timber constructions are hottest during the day, but coolest at night due to their low storage capacity. Reinforced concrete structures provide the less heating during the day but more heat accumulation at night. This is due to its high heat storage capacity.

3.2 LIFE CYCLE ASSESSMENT

The ecological and resource-efficient aspects of sustainable construction are analyzed during the course. To ensure comparability, all values refer to 1m² of components and they have similar thermal transmittance values (U-values) and load-bearing capacities in each category.

The life cycle of buildings is analyzed according to EN 15978 "Sustainability of buildings - Assessment of the environmental performance of buildings - Calculation methods" [14], considering recyclability. The ecological properties of the building materials compared are taken from the databases "IBU-EPD" [15] and "ÖKOBAUDAT" [16]. Both are standardized databases for ecological assessment of the German Federal Ministry of Housing, Urban Development and Building (BMWSB) [16]. The considered criteria are the use of non-renewable primary energy (PEIne), the use of renewable primary energy (PEIe), the global warming potential (GWP) during a time horizon of 100 years based on the German Sustainable Building Council (DGNB) [17].

As an example, the analyses and optimization are presented on an existing building in France.
The corrugated sheet metal façade with the fastening steel angles, as well as the rock wool have the most impact in the production stage. The wood, on the other hand, has much less impact (Figure 4 und Figure 5).

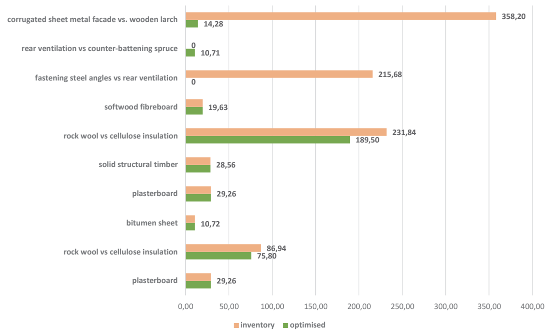

Figure 4: *Non-renewable primary energy (PEIne) [MJ] in production stage; comparison of inventory and optimization (© ITI/TU Wien)*

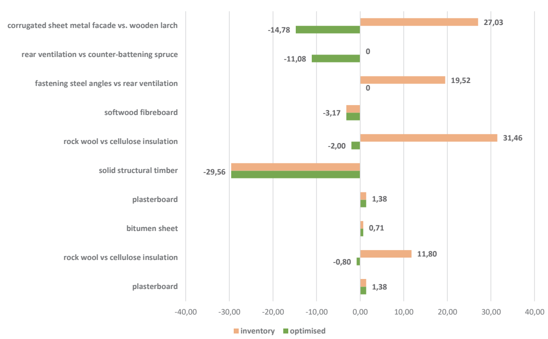

Figure 5: *Global warming potential (GWP) [kgCO_2 equ.] in production stage; comparison of inventory and optimization (© ITI/TU Wien)*

To achieve an improvement in the production stage, the outer wall is optimized. The corrugated metal façade is replaced by a wooden façade with counter battens and the rock wool is replaced cellulose insulation. Through these measures the values significantly smaller and improved (Figure 4 und Figure 5). Therefore, it is important to pay attention to the decisive materials to be considered and also to make appropriate economic decision.

4 CONCLUSIONS

Timber construction requires a different planning and construction process than mineral construction. Due to the high degree of prefabrication, important decisions have to be made already in the planning phase in order to benefit from all advantages of timber construction. For this purpose, more value and time must be put into the planning process itself in order to achieve improvements in the construction phase. This preliminary planning is elementary in wood-based architecture.

The Master's Course "Resource-efficient materialization" has formulated the integration of the natural building material timber to the current requirements of the construction industry. In terms of architectural and engineering questions, the focal point is the cooperation between all professions while integrating sustainability aspects. The intention of the course is to increase student's awareness of holistic lifecycle-oriented approaches. Interdisciplinarity is crucial to the success of the course.
This means that master students will be in a position to implement the principles of sustainability, inter alia, economic and ecological aspects in project development and design as well as realization, especially in the operation stage and demolition of building structures.

Through a sustainable materials concept, avoidance of high-maintenance building technology and low energy costs through reduced energy demand as well as optimized energy demand coverage sustainable solutions can be achieved.

ACKNOWLEDGEMENT

The course is a collaborative effort of the ITI/TU Wien and the working group of the Austrian timber industry proHolz Austria. The authors gratefully acknowledge the support of the TU Wien and the proHolz Austria.

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