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# UTILIZING WOOD RESIDUES FOR HIGH ADDED-VALUE MODULAR BUILDINGS – A CASE STUDY

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**ABSTRACT:** The purpose of this experimental building is to carry out research and continuous monitoring on insulation material, wood paneling and cladding as well as on load-bearing parts, and to use the building as presenting area for the results of research and testing. We used oak wood residues wherever possible - triangular lath for cladding, residual veneer for interior paneling, wood bark for insulation of exterior walls, and ash wood for load bearing beams and columns. Measurements of thermal conductivity of exterior walls with oak bark have demonstrated its suitability as insulation material in a moderate continental climate. In addition, measurements of thermal conductivity and acoustic properties of paneling products proved their suitability for interior paneling.

**KEYWORDS:** oak wood, veneer, paneling, cladding, bark insulation

## 1 – INTRODUCTION

It is well known that the integral yield from raw material to end use product in wood processing is often not more than 15% which can be considerably improved. Despite the fact that all residues of wood processing can be used (at least as energy source), we wanted to identify all residual materials in a wood processing company that have the potential to be converted into high added value products thus increasing the overall yield of high-quality veneer logs. Within the frames of a bigger research project we conducted several activities: (1) design of sandwich/construction of interior panelling, interior and exterior walls, (2) optimization of oak veneer production technology for wood panelling, partition and load-bearing walls, (3) Life-cycle assessment (LCA) of newly developed products, (4) investigation of thermal and acoustic properties of different wood materials and components, (5) interior design solutions using veneer wall coverings with different natural appearances with the aim of increasing the use of veneer logs.

## 2 – BACKGROUND

Several large companies process oak wood and produce decorative veneer that can be used for the production of wall coverings and partition walls in the interior. Wooden wall coverings and partition walls can be used in the creation and furnishing of exclusive interiors, and there are no manufacturers of such products in the Republic of Croatia. Furthermore, some of wood-based raw materials that are not suitable for the production of products like floor coverings, doors or furniture can be further refined through the production of load-bearing parts of partition and load-bearing walls, and the wood residues in the form of oak battens, thanks to their natural durability are suitable for the production of external wall coverings. These products may enable the transformation of several local companies into manufacturers of building components for the production of contemporary low-energy oak wood houses, which are currently not available in the Republic of Croatia. Thermal protection of buildings for permanent or temporary residence is particularly important in the Republic of Croatia, where large amounts of energy are consumed in winter for heating,

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but even greater is the consumption of electricity for cooling during the summer tourist season. Low-energy oak houses, due to their energy efficiency (we aimed for the passive standard), would be particularly suitable for installation in campsites in the coastal area, but also in other parts of Croatia. There are manufacturers of solid and prefabricated wooden houses in the Republic of Croatia, but none of them produces oak houses.

In order to achieve the project objectives and develop new products, we carried out the following activities:

1) Selection of basic and secondary materials for the manufacture of products, taking into account their ecological properties and environmental impact

2) Design of modular panel elements: partition and load-bearing wall, floor and ceiling assembly, external wall cladding

3) Design of the load-bearing elements and the whole structure including necessary instalations

5) Durability testing in the exterior and interior

6) Optimization of the panel structure

7) Full-scale testing and long term monitoring.

During the project we developed some typical solutions of wood panelling, partition (interior) and load-bearing (exterior) walls taking into account that all new elements / products are: **a. modular** - by combining ready-made modules it is possible to obtain structures of a different size; **b. lightweight** - elements with smaller own mass are easier to manipulate and energy consumption in transport is lower, thus having a more favourable impact on the environment and **c. economical** - by careful selection of materials, we wanted to achieve elements of the smallest possible thickness and size to satisfy all physical and mechanical properties of the building (load bearing capacity, thermal and sound insulation, ventilation,...) for the purpose of optimal use of space and obtaining the largest possible useful surface in the gross developed area of the building.

Wooden wall coverings can be used in the creation and furnishing of exclusive interiors, and there are no manufacturers of such products in the Republic of Croatia. Due to their energy efficiency (we are aiming for a passive standard), low-energy oak houses would be particularly suitable for setting up in camps in the coastal area, but also in other parts of Croatia and wider.

## 3 – DESCRIPTION OF THE STUDY

### 3.1 LOAD BEARING ELEMENTS

The main wooden load-bearing structure is designed from fir/spruce wood of strength class C24 with a moisture content below 18%. In theory the building elements can be produced from ash wood or some other botanical species, provided that the mechanical properties are the same or better those in the project. The load-bearing structure is made from elements with cross-sections of 4.8 cm x 20 cm, 9.6 cm x 20 cm and 14.4 cm x 20 cm. The positions for the application of each cross-section are visible in Figure 1. The connection of the temporary wooden prefabricated structure with the ground is achieved using reinforced concrete footings. A temporary concrete footing

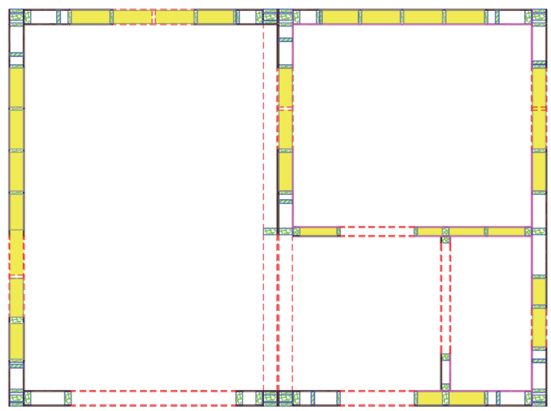

*Figure 1. Floor plan of experimental bungalow.*

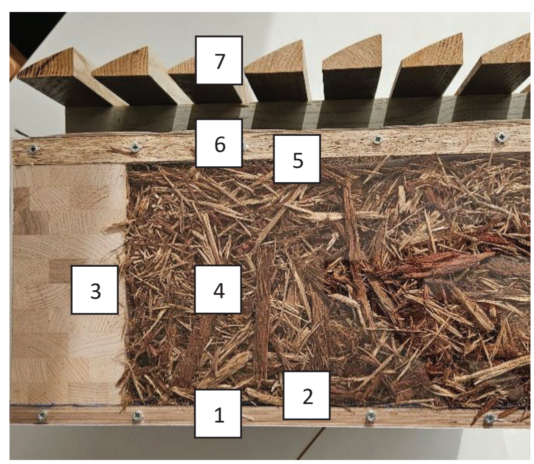


*Figure 2 Cross-section of the load-bearing wall with exterior cladding: **1**. Veneer plywood in interior side of the wall (2 cm), **2**. Steam dam, **3**. Ash wood laminated beam (9.6 x 20 cm), **4**. Oak bark insulation (20 cm), **5**. Vapour-permeable film, **6**. OSB panel in outer layer (2 cm), **7**. Exterior ventilated cladding*

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measuring 40cm x 40cm x 20cm is constructed below the height-adjustible steel post base. The temporary concrete footing in question was placed on a layer of asphalt on which a layer of geotextile was placed first so that the asphalt would not be damaged.

The design of cross-sections was carried out taking into account self-weight and imposed loads, snow load, wind actions, thermal actions, serviceability, durability and fire resistance of elements. All structural elements were designed for the appropriate loads given in the Croatian standards of the HRN EN 1991 series (so-called Eurocode EC1). The elements were designed according to the Croatian standards of the HRN EN 1992 and 1995 series (so-called EC2, EC5), all according to the applicable technical regulations.

During the design, we took into account the green building principles - passive design at the element level, sustainable heating and cooling systems, the use of renewable energy sources and total energy consumption at the facility level. The project documentation includes the architectural design and fire protection study, the mechanical resistance and stability, the water supply and sewage, the electrical installations, and the heating and cooling – all this was prepared prior to building the experimental structure itself.

### 3.2 PANNELING AND CLADDING

The basic material for the construction of wall pannelling, partition and load-bearing walls is oak – oak veneer and oak sawn timber. In order to achieve modularity, the elements of partition and load-bearing walls and floor and ceiling panels are designed as a kind of sandwich that consists of a load-bearing frame made of solid or laminated wood, filled with thermal and sound insulation materials, an external cladding that stiffens the frame and provides waterproofing, and additional cladding that (Figure 2), in the case of wall panels, represents an element of the facade in the exterior, or a decorative wall cladding in the interior (Figure 3). In the case of floor panels, a floor covering is additionally installed, and in the case of ceiling elements, a final roof waterproofing material is placed on the outside, and a decorative ceiling cladding on the inside.

During the research, we were investigating the availability, cost-effectiveness and ecological footprint of additional materials:

a. veneer and other panels produced locally or imported from neighbouring countries or more distant parts of the world (which are typical producers of panel materials on the world market),

b. adhesives for joining sandwiches and panels, and oils and varnishes for surface treatment and protection produced in the Republic of Croatia or abroad

c. thermal and sound insulation materials – e.g. sheep wool, mineral wool, thermal insulation coatings, other insulation materials

d. building hardware for assembling panels and the whole structure.

Figures 2 and 3 illustrate the main outcomes of our project. As an alternative to softwoods, laminated beams were produces of ash wood, which has even better mechanical properties but is difficult to be placed on the market in the form of other products. Oak wood bark, a natural insulator, was used instead of mineral wool. Residues from oak veneer production were used for exterior ventilated cladding. Thermal transmittance of the bark insulated wall measured in situ is 0,29 W/m$^2$K, and mineral wool insulated wall 0.20 W/m$^2$K. In parallel, interior panelling was developed in 4 appearance classes of interior panelling using residual veneer of small dimensions 7,5 to 30 cm width and 60 cm length. Figure 4 illustrates the end product – panelling and cladding.

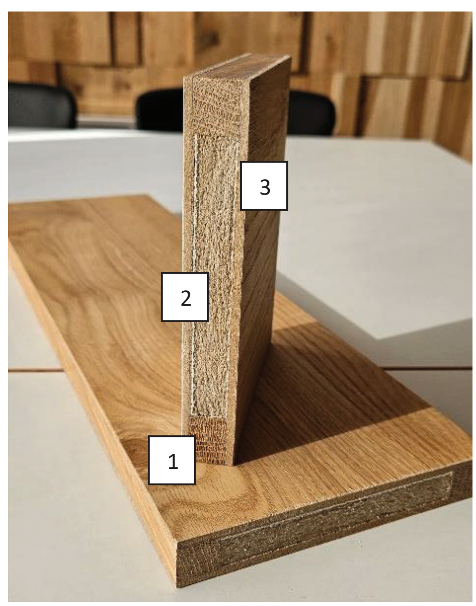


*Figure 3 Cross section of interior panelling: **1**. Oak wood frame (15 x 20 mm), **2**. Recycled mineral wool insulation (15 mm), **3**. Oak lamella 4 mm or MDF 3 mm with 0.6 mm veneer*


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*Figure 4 View of the finished experimental bungalow from outside showing ventilated oak wood cladding (left), interior view demonstrating different appearance classes of panelling (right)*

## 4 – BUILDING PROCESS

Structural and non-structural elements were laminated in length, width and thickness by gluing (Figure 5). Wall assemblies were prepared in the factory where the cavities were filled with insulating material – outer cavities with mineral wool, and inner cavities with oak wood bark (Figure 6). The experimental bungalow was assembled at the Faculty of Forestry and Wood Technology University of Zagreb. The preparation and building process is shown in Figures 7 to 9.

During the construction works, equipment was installed on the bungalow for long-term measurement and monitoring of temperature, moisture content, and relative humidity of air.

*Figure 6 Oak bark insulation layer*

*Figure 5 Beams laminated in length, width and thickness*

*Figure 7 Preparation of load bearing walls*

*Figure 8 Preparation of floor assembly*

*Figure 9 Installation of exterior cladding*

## 5 – IN-SITU TESTING

Before the finishing works we conducted the in situ tests in order to prove the functionality of the panels and optimize their properties in real conditions. The tests consisted of:

1. Blower door test (Figure 10) was conducted to determine the relationship between the pressure difference across the building envelope, ΔP [Pa], and the airflow rate through the building envelope, Q [$m^3$/h]. The obtained n50 value of the bungalow was measured to be 3.75 $h^{-1}$ (with $r^2$ of 0.92541), which is higher than the one prescribed in Technical Regulation on the Rational Use of Energy and Thermal Insulation in Buildings (3.0 $h^{-1}$ for this type of building). However, here it was essential to note that these were the first measurements before applying finishing covers on the walls, floors, and window sills. Also, places of potential leakage problems (door sill, cracks due to electrical and sensors installations) were discovered and sealed before finishing works.

*Figure 10 Assembly for blower door test*

2. Infrared thermography was used to determine the of thermal bridges and cracks (Figure 11). The lowest temperature was detected at the threshold (13.4°C).

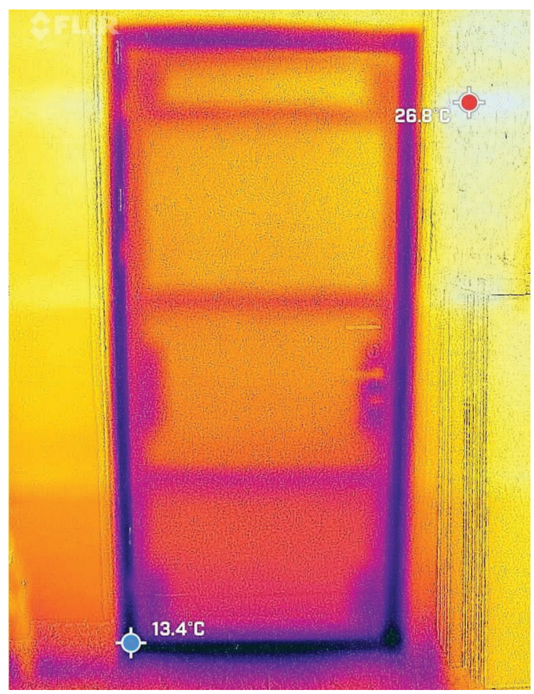


*Figure 11 Typical IR image showing the coldest point on the outer wall.*

3. Thermal characteristics, i.e. the heat transfer coefficient (U value) was carried out using the temperature-based method (TBM) and additionally with heat flow method, according to ISO 9869-1:2014. The


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average U values are 0.22 W7M2K for walls with mineral wool and 0,29 for bark insulated walls.

4. Temperature and relative humidity of air indoors are within narrow range of 24±1 °C and 45±4 %. Outdoor temperature during spring and summer 2024 was in the range 12 to 32 °C. Equilibrium misture content within the walls was 8 to 12 %.

## 6 – CONCLUSION

This study demonstrates that many of existing wood residues can be successfully used as additional raw material for high quality end use products thus increasing the yield and reducing the demand for additional raw material. Panelling and cladding products developed within the frames of this project can soon become commercial products, whereas further research is needed to optimize the properties and standardize ash wood beams and oak wood insulation panels. Overall, in situ tests demonstrated the market potential of newly developed products after some modifications.

## 7 – REFERENCES


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