# USE OF WOOD IN MODERN RESIDENTIAL ARCHITECTURE. APPLICABILITY IN THE BULGARIAN CONDITIONS

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**Abstract.** Wood as an ancient and traditional building material is experiencing its new rethinking and revival in the context of the development of new technologies, as well as the new requirements for increased comfort and sustainable development of the urban environment. Residential architecture is a traditional and primary use of wood as a building material. The modern development of the residential environment, both in low-rise buildings and in multi-story apartment buildings, poses new tasks and creates new opportunities for the expanded use of wood and wooden structures. The article examines the problems and opportunities for energy-efficient and sustainable renovation of multi-story residential buildings by examining examples from global practice. The applicability of the approaches in Bulgarian conditions is evaluated.

*Keywords*: sustainable development, energy efficiency, apartment buildings, laminated wooden structures.

## 1. INTRODUCTION

With the development of urbanization processes on a global scale, migration to cities and the related need to provide new housing is a constant phenomenon. The severe shortage of affordable housing in economic development centers is a persistent and growing problem. The housing shortage continues to put pressure on housing prices and rents, reducing affordability, especially

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for households with modest incomes. Realizing the potential for economic development globally depends to a large extent on whether societies can provide more affordable housing options for households now and in the future [1].

In this sense, housing policy is gaining increasing importance for the development of societies, but it is not the subject of this article. Besides the institutional, regulatory and financial aspects to increase the supply of mass, affordable, comfortable and sustainable housing, there are architectural, technological and functional solutions related to the use of wood as the most efficient renewable building material. Some of these possibilities are discussed in this article.

## 2. USE OF WOOD IN MASS APARTMENT BUILDINGS

### 2.1. New Construction

Globally, North America is the region where the research and practice of using massive timber structures in high-rise buildings has been the most prevalent in recent decades. The US Housing Coalition's 2020 annual report shows that rents are unaffordable for nearly everyone working in the bottom 50% of the national wage distribution [2]. Because housing is at the intersection of many societal problems -social, financial, racial, political, and cultural – solving the housing issue is of utmost importance. In his research "Creating Affordable Housing Opportunities with Mass Timber" [3] Jeff Spiritos summarizes the history of both affordable housing and light wood multi-family housing, illustrates the challenges facing affordable housing today, and presents the 340+ Dixwell project – a Passive House construction of affordable housing in New Haven, Connecticut. Jeff Spiritos compares the 340+Dixwell project to traditional U.S. lightweight housing, showing that solid wood buildings are a viable and cost-effective solution to meet the affordable housing needs of the U.S. [3].

In most of the United States, multifamily mass housing is constructed of light wood-framed structures. This technology is spread by over 70 years, as a result of the construction of the American suburbs after World War II. Over time, builders made improvements to the process, such as using ready-made prefabricated walls and precast joints between them. However, the height of lightweight wood buildings remains limited. When built at ground level, their height is limited to 5 stories, and when built on a two-story concrete podium – up to 7 stories. Studies done in the USA show that the use of solid wood is a possible solution for the construction of affordable housing, thanks to its many advantages:

- to be used in combination with lightweight timber frame structures to further improve the performance of timber buildings up to 5 stories;
- for the construction of wooden buildings from 6 to 12 floors, instead of those with steel or concrete structures - an opportunity for which there is growing interest.

Solid wood construction is characterized by the use of large panels of solid wood to build walls, floors and roofs [4].

### 2.2. The 340+ Dixwell project for New Haven

New Haven, Connecticut, like many cities in the US, is experiencing a significant shortage of affordable housing. The project "340+Dixwell" (Fig. 1.) is the result of the idea to provide housing that reduces the impact of poverty and destruction and recovery of the concept of the family community. The project is a multi-family residential building for rental housing made of solid wood – approximately 70 units. Solid wood will provide a sustainable, energy-efficient, healthy and attractive lifestyle for the Dixwell community. The team of Schadler Selnau Architects, an established Connecticut affordable housing and passive house firm, and GOA, an architectural firm designing solid wood units, have been selected for the project through a public procurement procedure.

**Fig. 1.** 340+ Dixwell, Source: GOA and Schadler Selnau Architects

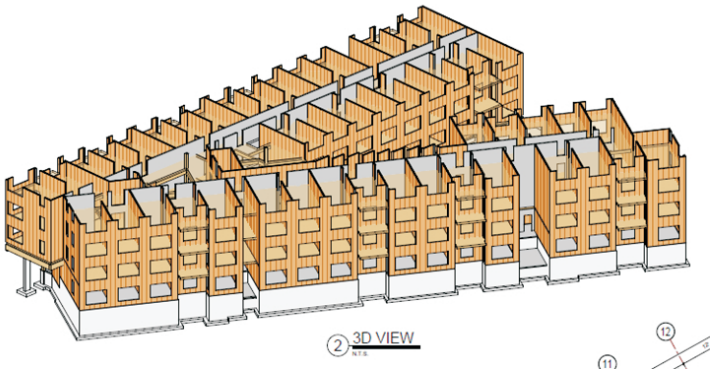


**Fig. 2.** 340+ Dixwell, 3D view from Orchard Street. Source: Odeh Engineers

The project consists of two buildings connected by a parking lot on Orchard Street (Fig. 2). A maximum number of 1-, 2- and 3-bedroom dwellings is planned, ground-floor retail space for neighborhood businesses, tenant space and parking are provided. Open common spaces are provided for all tenants and balconies for the 2- and 3-bedroom units. A solid wood, passive house design with rooftop solar panels for energy production is used to demonstrate how affordable housing can be energy efficient, durable, faster to build, natural, healthy and environmentally friendly, with up to largely comparable costs and benefits.

More important 340 +Dixwell design principles:

1. Solid wood construction, with all its advantages compared to light frame or traditional high carbon construction systems
2. Load-bearing system of cross-laminated timber (CLT) spatial modules.
3. Passive house design air and watertight enclosure construction with additional insulation to reduce the need for heating, ventilation and air conditioning and to provide energy recovery ventilated air (ERV) in living and sleeping areas 24/7 a week, which will lead to improved indoor air quality and health benefits
4. Balconies for all 2 and 3 bedroom apartments, with access from living rooms
5. Open public space for all residents
6. Solar panels on the roof to provide renewable energy and minimize the consumption of electricity from the grid
7. A typical room module (12.5') and a clear height of 9', to simplify the production of CLT panels, speed of installation and cost efficiency
8. Facade of CLT panels to reduce external joints and achieve external air tightness

9. Elevator and stair core walls also made of CLT solid wood

The modular CLT system is widely used in Europe in multi-family residential buildings in England, Germany and France. The advantages of the CLT modular system are due to the use of CLT panels for the external wall that helps to achieve passive house characteristics more easily, as there are much fewer joints to seal and as CLT panels are considered "solid walls" carrying higher insulation than framed walls. Also, thermal bridging is easier to eliminate with CLT exterior walls than with light frame walls because CLT is a solid wall.

### 2.3. Comparison with light timber frame construction

The majority of low- and mid-rise multi-story residential buildings in the U.S. are constructed with light frame construction—typically with a single-story concrete or steel podium that allows commercial use or parking underneath and provides structural column spacing to achieve the spacing, necessary for these purposes. These methods have been used for many decades and are known to be the cheapest way to build. Building with lightweight timber construction is much more environmentally and economically efficient than with materials with a higher carbon footprint such as steel and concrete. Even better, however, is the use of solid wood, which provides advantages worth considering as an alternative to light frame timber construction.

The main advantages of using solid wood as an alternative to light timber frame construction are:

10. Reduction in the number of parts and details – with solid wood there are fewer elements to assemble.
11. Greater height – the light structure can be a maximum of 5 stories above a concrete or steel podium; solid wood can reach up to 18 stories.
12. Less impact on the site – solid timber uses fewer details in construction, hence requires fewer supplies and less transport traffic.
13. Effective team size – light construction requires 20-30 people compared to around 6 souls during installation of the solid wood elements.
14. Environmental benefits in terms of elevator and stair cores - these building elements are usually made of concrete or concrete blocks for framed buildings, and solid wood offers the opportunity for these elements to use materials that store carbon, not release it.
15. Eliminate waste and clutter – light frame construction involves cutting timber, sheathing, etc. on site that takes up space, creates safety issues and generates waste – these problems are reduced or eliminated with solid timber.

**Fig. 3.** 340+ Dixwell, structural detail, Source: https://www.woodworksinnovationnetwork.org/en-ca/projects/340-dixwell-ave


**Fig. 4.** 340+ Dixwell, View from construction site, Source: https://www.woodworksinnovationnetwork.org/en-ca/projects/340-dixwell-ave

16. Speed – with light frame structure, construction takes more time than when using solid wood.
17. Risk of fire during construction – bulk timber is more susceptible.
18. Construction risk insurance costs – may be higher on light frame due to construction risks (safety and fire) during installation.
19. Durability – light frame constructions are subject to more movements and atmospheric influences.
20. With chests of light construction, they require covering the wooden surfaces with other materials.

21. Health benefits – exposed wood has been shown to reduce asthma and stress, lower heart rate and blood pressure and improve concentration.
22. Lower cost compared to timber frame construction.

## 3. USE OF WOOD IN THE RECONSTRUCTION OF MASS MULTI-STORY DWELLINGS

### 3.1. Project: ACME Timber Lofts [New Haven, CT]

ACME Timber Lofts is a project to preserve, restore and upgrade an existing 3.5-story, 150-year-old, non-reinforced building through a new cage staircase and solid timber elevator core and a two-story cross-laminated timber (CLT) superstructure with exposed internal and external CLT walls and ceilings. The renovated building was also designed in accordance with passive house standards. In combination, strategies using solid wood and passive house are the most effective ways to decarbonize buildings – to make them ecological, healthy, natural and durable. The five-story redevelopment project contains 18 apartments, ground floor retail space, a basement gym, bike room and trash room, as well as tenant entertainment space and rooftop solar panels. Located at 33 Crown Street in Ninth Square Historic District downtown,

**Fig. 5.** Project ACME Timber Lofts, Source: [6]

the ACME Building served as the headquarters of the ACME Furniture Company, used for several generations, and is located near the New Haven Railroad Stations, Yale New Haven Medical Complex, Yale University and the city's growing biotech hub.

### 3.2. Danish-Russian project in Litkarino

In the nineties, the Russian Ministry of Housing Construction designated Litkarino area (about 50 km from the center of Moscow) for an experimental zone for the reconstruction of 4–5-story apartment buildings (the so-called "Khrushchevki"), with the assistance of the Danish skylight company VELUX. Such massive apartment buildings built in the 60s of the $20^{\text{th}}$ century are widely distributed throughout Russia, which enables, if the project is successful, its potential replication on a large scale. The philosophy of the pilot project envisages an upgrade of the building – the existing flat roof is reconstructed by making a superstructure containing a new living space on one or two levels, ending with a pitched roof. The resulting new residential area is

**Fig. 6.** The existing building before reconstruction, Source [7]

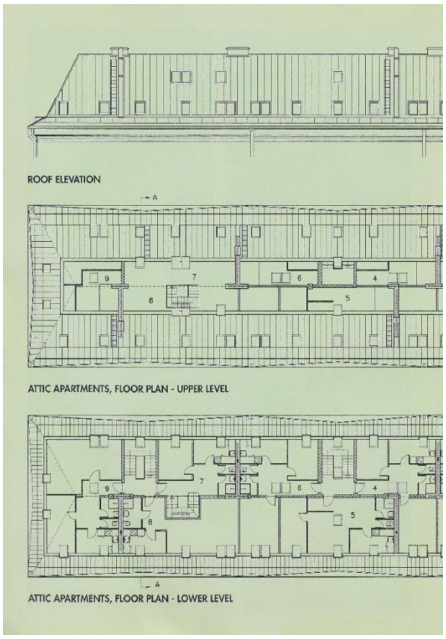


**Fig. 7.** Layout of upgraded – not ungraded stories, Source [7]

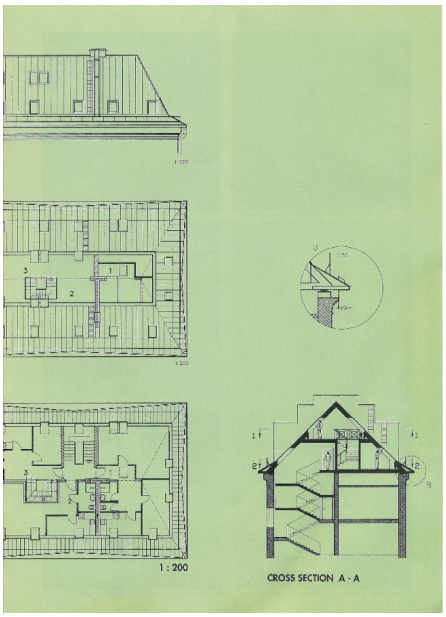


**Fig. 8.** Cross-section with the additional stories with the detail of the roof cornice [7]

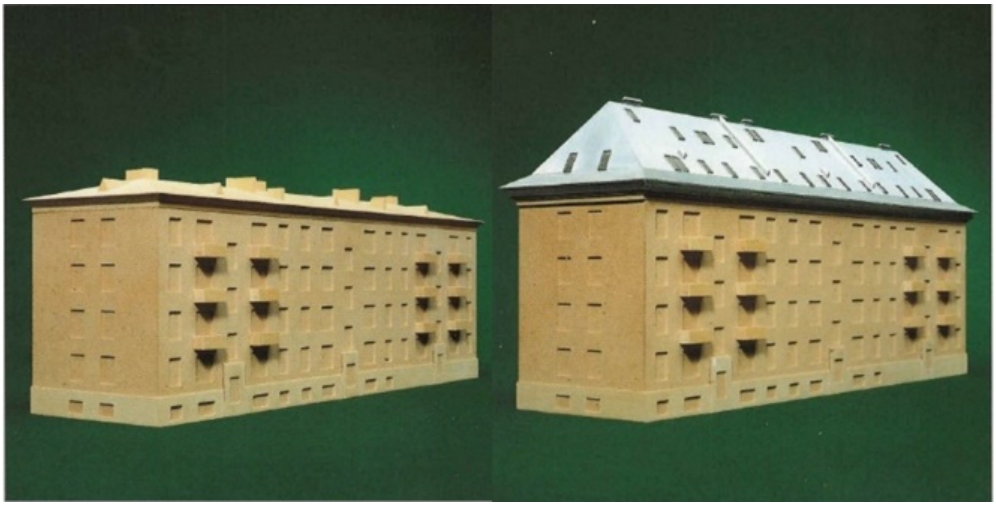

**Fig. 9.** Model of the existing building and the building after renovation, Source [7]

sold to an external investor, with the proceeds being used for energy-efficient renovation of the building.

In accordance with a 1993 memorandum between the ministries of housing of Denmark and Russia, a transfer of Danish expertise on the construction principles of the pilot project has been agreed, including:

- 45-degree slope of the newly built pitched roof;
- lightweight wooden structure for the superstructure, cheaper and more convenient to transport and install, with the roof beams being assembled on site;
- residents can stay in the building during the entire reconstruction period;
- energy-efficient reconstruction and thermal insulation of the building envelope is carried out.

The principles of construction are also harmonized with the new Russian building regulations (SNIP), as well as with fire regulations. The existing building of the pilot project had 4 floors. With the reconstruction of the flat roof, 9 new apartments have been added to the existing building and infrastructure. The area of the new apartments varies from 44 to 72 $m^2$. The total area of the roof that can be built on is 680 $m^2$. Throughout the construction period, measures have been taken to ensure maximum safety for the existing residents who do not leave the building. In connection with the remodeling of the attic space, the heating systems have been improved in order


**Fig. 10.** Pictures from the construction stage, Source [7]

to save energy costs. Good natural light and ventilation are the criteria for the newly created living areas in the new under-roof space with installed VELUX skylights. The first reconstruction was carried out in 1997, and several more buildings were subsequently reconstructed based on the experience of the first

**Fig. 11.** Picture from the interior of the upgraded space, Source [7]

pilot project.

Similar projects with the support of VELUX are also implemented in the Czech Republic, with one of them – the Attic Flats Project winning the World Habitat Award in 1990.

## 4. TRADITIONS AND POTENTIAL FOR THE USE OF WOOD IN MODERN RESIDENTIAL ARCHITECTURE IN BULGARIA

The use of wood in residential architecture in Bulgaria has a centuries-old tradition. The Bulgarian wooden house goes through a long and complex path of development and reaches perfection in the functional-plan and volume-spatial composition, occupying an exceptional place in the history of Bulgarian architecture from the Renaissance era. Wooden residential architecture is formed in three large groups: pre-Renaissance; early Renaissance and high Renaissance. The pre-Renaissance wooden house was widespread in the $16^{\text{th}}$–

**Fig. 12.** New wooden-concrete apartment building in Sofia, Source [9]

$18^{th}$ centuries. One of its important features is that it is mostly on one floor. The Early Renaissance house is found mainly throughout the $18^{th}$ century and the beginning of the $19^{th}$ century. It is characteristic of it that it is built on two floors. The volume-spatial composition is distinguished by opening to the yard through the porch. It is built in different geographical regions of Bulgaria and has specific local features – it is widely distributed in Zheravna, Tryavna, Koprivshtitsa, etc. settlements in the country. The High Renaissance house was built mainly in the second and third quarter of the 19th century. It is a gated townhouse. It is developing in several prominent urban centers of the country – Plovdiv, Karlovo, Samokov, Nessebar, etc. The High Revival house marks one of the peaks in the development of Bulgarian Revival architecture. In these houses, artistic elements in synthesis with the architecture are widely used – carved ceilings and walls in the interior.

Wood, unlike stone, allows the construction of variable planning, volume-spatial and artistic forms and concepts. The development of structural systems in traditional wooden residential architecture in Bulgaria shows two stages: the early wooden house was built from whole beams connected at the corners of a "wreath" (static system); in the second stage, the stair-step construction is developed, making it possible to achieve different shapes and details (dynamic system). Among the characteristic structural features of the wooden folk house

in Bulgaria is the wide eaves. It protects the building from the influence of the sun and water, which is why it has an important functional importance. At the same time, it has an aesthetic meaning, creating an accent in the architectural image of the building. The wooden column has an important place in the structure of the house. On the one hand, it participates in the supporting structure of the building, and on the other, it participates in the artistic design of the veranda and the interiors. Knowing the constructive possibilities of wood, folk craftsmen create houses distinguished by safety and beauty.

Regardless of the available objective prerequisites, the modern use of wood in residential buildings in Bulgaria is still not as widespread as in countries with developed economies and a corresponding construction industry. In recent decades, only prefabricated low-rise wooden houses have gained intensive development and popularity among investors. Regulatory obstacles still exist – for example, fully wooden buildings are only allowed up to two floors [8]. Among the few examples of medium-rise residential buildings with the predominant use of wood, we can note that of arch. Vladimir Rajnovski – a 4-storiey residential apartment building in Sofia with a hybrid wood-concrete structure – its completion is expected in 2023. (Fig. 12). The floor slabs will be made of CLT in combination with concrete, CLT also serving as remaining formwork (saving time during assembling). CLT-concrete floor slab becomes composite material, which is the most effective combination of materials advantages – the wood positioned in the zone of tension and concrete – in the zone of pressure, leaving the floor slab structure with minimal reinforce steel and concrete amount [9]. As advantages of the building, arch. Rajnovski reports saved carbon emissions in the amount of 40 tons of $CO_2$ from reduced use of concrete and reinforcement and saved "locked" in the building 60 tons of $CO_2$ from the 60m$^3$ of wood used in the building.

## 5. APPLICABILITY OF WOOD IN THE RECONSTRUCTION OF MASS MULTI-STORY DWELLINGS IN BULGARIA

The unsatisfactory condition of the existing multi-storey apartment buildings in the big cities of Bulgaria has been known for a long time. These condominium buildings, mostly built using industrial technologies between the 1970s and 1990s, were erected in response to increased housing needs due to immigration flows to the big cities during that period. These buildings have a "birth defect" because immediately after their completion, the state sold them to their occupants at subsidized prices without providing an adequate

**Fig. 13.** Completed pilot building in Zaharna Fabrika , Source [11]

mechanism for their subsequent maintenance and management. Subsequently, after the political and economic changes in Bulgaria and the pressure of real market prices on the costs of operating the housing, their degradation intensified. Since the beginning of the new century, efforts have been made to reconstruct apartment buildings with a focus on improving their energy efficiency. A number of pilot projects are underway, but they are small in scope, rely exclusively on public subsidies and do not create a sustainable model for large-scale replication.

Among these pilot projects, the only one that stands out is the one in the district of Zaharna Fabrika, Sofia (Fig. 13), in which sustainability principles are laid down, creating the potential for large-scale replication in city districts:

- limited public support - the subsidy is limited only to a low-interest loan for the implementation of the reconstruction;
- the potential/resource of newly created additional living space is used when upgrading the building;
- when upgrading the building, wooden structures are used, which shortens

the time and reduces the budget of the construction works.

The pilot project in the Zaharna Fabrika estate was published in a number of Bulgarian and foreign specialized publications, as well as in Bulgarian daily media [10], but unfortunately the principles laid down in it did not receive the necessary development due to the lack of adequate support by the state and municipalities, especially in terms of regulatory and organizational provision.

As a result of the development of construction technologies and technologies, based on the use of renewable energy sources - RES (wind generators, photovoltaic plants, geothermal steam and heat plants, etc.), there are currently opportunities to overcome a number of existing obstacles and intensify activities, related to the reconstruction of mass apartment buildings in Bulgaria with the application of foreign best practice. The existing good global practices, as well as the Bulgarian experience from the project in the Zaharna Fabrika estate to upgrade the apartment buildings using efficient lightweight wooden structures, can be upgraded by integrating RES (mainly photovoltaic panels) into the refurbished building roofs.

Current approaches to the reconstruction of apartment buildings in the modern Bulgarian context should take into account:

- use of timber structures in upgrading and construction of pitched roofs;
- use of RES integrated in the reconstructed buildings;
- using innovative financing schemes to cover renovation costs from various sources, including the resource of newly built living space and energy savings;
- legislative changes are needed;

## 6. CONCLUSION

In Bulgaria, there are established traditions and experience in the use of wood in the construction of homes, which refer to different historical periods - starting from deep antiquity and reaching its constructive and aesthetic apogee in the era of the Bulgarian Renaissance ($17^{\text{th}}$–$18^{\text{th}}$ centuries). The experience, aesthetic and constructive traditions, combined with the favorable local climatic and geographical conditions for the reproduction of wood (renewable building material No 1), combined with the new technologies for the production of highly resistant wooden structures (CLT), create favorable opportunities for the development and spread of the new construction of multistorey residential structures based entirely or predominantly on wood. The development of our settlements with extended use of wood will have undeniable long-lasting effects in social, economic and environmental aspects.

There are also major opportunities for the use of timber structures in the renovation of a significant part of the existing mass apartment housing (built mainly according to industrial technologies) in Bulgarian cities, by replacing the existing flat roofs and upgrading the buildings with one to two floors using light efficient wooden structures. The reconstruction should include energy-efficient measures for the building envelope, as well as the installation of RES (photovoltaic panels) on the newly constructed pitched roofs. This will have the following effects:

- increasing residential comfort;
- environmental benefits - reduction of energy consumption and the use of building materials with a high carbon footprint;
- multiple economic benefits.

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