MULTI-STOREY RESIDENTIAL TIMBER CONSTRUCTION: CURRENT DEVELOPMENTS IN EUROPE

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ABSTRACT

This is a research paper with a focus on technical aspects of timber and on recent case studies, discussing the use of timber as multi-frame for multi-level residential buildings in Europe. The authors see this as a relevant topic within the context of the current environmental debate and the use of sustainable materials and construction methods. The conclusion suggests that timber is a high performance construction material adequate for multi-storey residential buildings, even in an urban context.

KEYWORDS

Ecological awareness, pre-fabrication, light-weight structural systems, fire protection, medium-rise structures, timber constructions in urban environments

1. INTRODUCTION

> *Where can we find more structural clarity and coherence in material, structure and form as in the old timber houses?* (Ludwig Mies van der Rohe)

Building with wood is gaining in popularity. Numerous modern insights in innovation can be seen in multi-storey timber homes all across Europe. Increasing ecological awareness, rising expectations with regard to the health and comfort of home environments, and interesting new products from the wood industry provide a basis for modern construction designs in the urban context. If we take a holistic look at energy consumption and the material cycle in the building industry, we find that wood offers many advantages. It has excellent insulation characteristics, has ideal values of embodied energy, is relatively easy to recycle and timber's insulation qualities are superior to either metal or concrete. The use of timber can help to keep the embodied energy content and use of material resources low. It offers advantages for the use of load-bearing elements, e.g. when a beam penetrates the façade, the resulting cold bridge is much less critical.

Forests in Central Europe are increasing in size every year due to more wood being grown than is used. During its growth phase, wood binds carbon dioxide to it and retains it for many years, even when the wood has become a building material, thus preventing carbon dioxide from re-entering the atmosphere.[1] Depending on how it has been worked and processed, wood can assume manifold characteristics and can positively influence the climate and atmosphere of a building. How we can design with the material, how it can visualise the structural principles and how it is used in the urban environment are exciting challenges for today's architects.

New building regulations (e.g. the 'Musterbauordnung', the Building Regulation for Prototypes, a Performance-based Code, 11/2002 in Germany, and similar developments in other countries)[2] will in the future allow building timber constructions of up to five storeys high. Load-bearing components of Building Category 4 (floor of top storey <13.0m) must be highly resistant to fire, i.e. they must be able to withstand fire for a minimum of 60 minutes. To this end, the 'model guideline for technical fire protection requirements for extremely flame-retardant wooden construction components' (the M-HFHHolzR, in

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Germany) offers solutions by which flammable components can be fully encapsulated.

2. ASPECTS OF PLANING WITH TIMBER

Generally, we need to differentiate between wood, timber, and lumber. Definitions for use in this paper are:

- Wood: the hard, fibrous, lignified substance lying under the bark of trees. It consists largely of cellulose and lignin. Wood is a natural material and is, therefore, irregular by nature.
- Timber: the wood of trees cut and prepared for use as building material (e.g. beams, posts).
- Lumber: timber cut into marketable boards, planks or other structural members, and which is of standard or specified length.

With these definitions on mind we can look at an overview of some new ways of using timber, which has developed in a much more sophisticated way compared to the use of timber in the past.

2.1 Construction Systems

In recent years, modern approaches to timber construction in Central Europe have undergone innovative changes. Traditional approaches, such as block and half-timbered constructions and the balloon-frame and platform-frame constructions seen in North America, have given way to today's frame, skeleton and solid constructions. The main difference between these systems lies within the hierarchy of the load bearing elements of the building structure as selective or linear elements. These constructions are characterised by the method of assembly of prefabricated structural elements and the structure of the envelope.[3] General building systems consist of similar wall and ceiling elements, though these elements can also be used in combination to form a building structure. For example, the applications of solid wood elements in ceilings of frame work structures.

Different wall and ceiling elements are produced in various industrial manufacturing processes during which the performance and, to some extent, the structural properties of load-bearing components are optimised.

Wall (Vertical Structural Element)

- Framework: i.e. cladded post and beam structure
- Solid wall panels: i.e. stacked board elements, glue-lam elements
- lid wall plates: i.e. cross laminated boards, veneer laminated plates.

Ceiling (Horizontal Structural Element)

- conventional beam structures
- combined timber elements: hollow box girder
- solid ceiling elements: stacked board elements
- solid ceiling panels: cross laminated plates
- combined concrete timber elements.

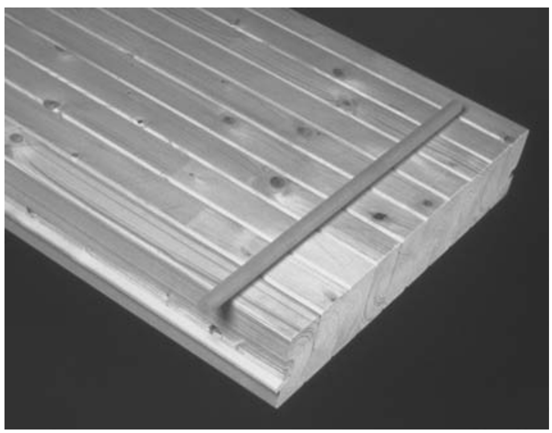
2.2 Industrial Elements

Examples of the variety of industrial elements built from wood and other materials will be specified in the following chapter. Below are some examples of industrially manufactured timber construction elements that offer interesting opportunities for application, as they are widely available in Europe.

Stacked Board Elements (figure 1). Vertical panels of board are nailed together or conjoined using hardwood pins. The underside of the element is planed smooth and the individual boards can be profiled to enhance the acoustic properties of the interior.

Material:	usually spruce
Overall height:	up to 240 mm
Width of element:	up to 2.5 m
Area of use:	ceilings, walls

FIGURE 1. Stacked board element (photo: FG Holzbau, TU Munich).



Solid Cross-laminated Timber Boards (figure 2). These consist of at least three layers of pinewood board bonded or pinned together crossways, each layer having a thickness of between 15 mm to 30 mm. Thanks to its resistance, solid wood panelling is dimensionally highly stable and can be manufactured with ready-planed visible surfaces.

Material:	usually spruce
Overall height:	up to around 280 mm
Width of element:	up to 4.8 m
Area of use:	ceilings, walls

Hollow Box Girder Elements (figure 3). Hollow box girder elements consist of several boards (dimension lumber) or chipboard panels (e.g. 3S chipboard) that are bonded or bonded and screwed together. They are suitable for spanning wide areas. Various manufacturers have developed products with positive acoustic properties. This is achieved by perforating or filling-in the hollow elements. Some companies have developed specific building systems, such as the wall and ceiling panels of the companies Lignatur (see: www.lignatur.ch) or Lignotrend (see: www.lignotrend.de).

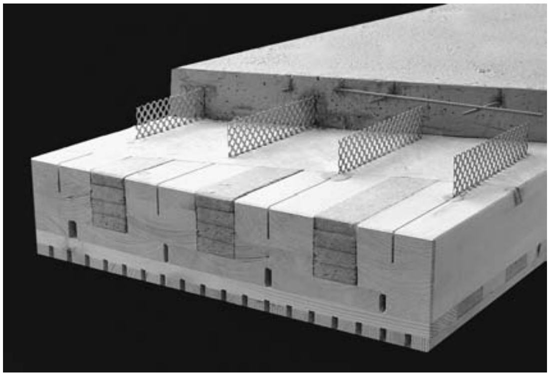
Combined Timber-concrete Ceilings (figure 4). The strong bonding capability of wood and concrete is used to optimise the load-bearing properties of ceilings and enhances their structural characteristics in terms of vibration, fire protection (F 90B, 90 minutes fire resistant), noise reduction and room acoustics. The wood and concrete elements are interlocked by means of integrated shear connectors or via appropriate profiling of the wooden layers.

The application of these elements offers a great variety of possibilities, though some facts regarding the utilisation within construction systems should be mentioned.

FIGURE 2. Assembly of prefabricated floor and wall panels on site (photo: FGH).

FIGURE 3. Image of the hollow box girder elements, partly filled with insulation (photo: FGH).

FIGURE 4. Combined timber-concrete ceiling elements (photo: Lignotrend).



Panel or Plate. Prefabricated timber frame wall panels are based on grid regularity with several different functional layers. The post and beam structure is the load bearing element for vertical loads and horizontal loads run into bracing elements, i.e. cladding, with large-sized composite boards (veneer boards, OSB etc.) or diagonal cladding with sawn boards. Furthermore, thermal insulation and moisture barriers have to be applied within the wall panel. Its advantage lies in its lightweight construction at the expense of a complex application of the described layers, with a rather negative impact on the disposal regarding the ecological life cycle of the building elements. With the possibilities afforded by industrially-fabricated large-scale solid timber elements, new construction systems have been developed in recent years. The plane elements consist of boards (glued, nailed or pined) and can be used as vertical or horizontal structural elements, which offer an efficient load bearing system. Cross laminated solid timber plates can be formed in two or even three dimensions and openings can easily be cut into the plates. Due to the advantages of large scale stable plates, their structural efficiency, their reduced number of layers, etc, solid timber plates are very suitable for multiple storey buildings.

Skeleton Construction and Pre-fabricated Modules. Timber skeleton systems are very efficient wide-spanning structures. The load bearing elements (post and beam) can be differentiated from wall and ceiling elements, thus offering great freedom to design individual space, a quality of multiple-storey homes or office buildings. Prefabricated space modules consist of structural elements (vertical and horizontal) of the systems mentioned. Size and transportation factors determine the dimension of the module and a high degree of detailing regarding the location and connection of installation and facing the demands for sound and fire protection is necessary. Industrial-scale, accurate pre-fabrication, coupled with fast and exact assembly facilitate the various phases of a building project. Intelligent prefabricated kits based on smart modularity and easy transportation, such as the 'take-away houses' by Gabriel Poole,[4] have enabled the user to choose from a wide variety and combinations of application. Lightweight structural systems in timber have the advantage of their limited weight and consequent reduction in foundation requirements; frequently, load carrying capacities are limited, especially in alteration and extension projects. The pre-fabrication of structural elements offer further cost savings by often eliminating the need for a crane on site and by using skills well known to the building trades.

2.3 Construction Physics: Efficient Protection

Regarding ecological issues and rising energy costs, the challenge lies in the design of energy-efficient buildings, combined with an appropriate climate-responsive concept.[5] Key timber construction strategies are:

- Sufficient thermal insulation to reduce energy losses in winter and prevent overheating in summer;
- High degree of air tightness of the building envelope to prevent construction damage by water condensation.

Designing timber buildings requires a larger amount of careful detailing and precise planning than does other construction methods. Generally, condensation can occur where moist air comes into contact with air or a surface of a lower temperature. Air always contains water vapour in varying quantities, its capacity to do so is related to its temperature—warm air holds more moisture than cold air. When moist air comes into contact with colder air or a colder surface (e.g. a timber element), the air is unable to retain the same amount of moisture and the water is released to form condensation in the element. The moisture from condensed water causes timber to decay, as the damp causes wet rot inside the walls. This is hard to detect and may not be noticed until mould growth or rotting of material actually occurs.

Consequently there is a need for a precise, correctly layered and high quality construction envelope to protect the timber structure from rain and water condensation. Only correct detailing will protect it from humidity and solve the question of surface treatment—to keep maintenance low and to 'pre-design' the ageing process and the appearance of the surface. European industries have developed several construction methods to deal with this issue. All of them are based on precise pre-fabrication processes in workshops where wall, ceiling and roof panels are built in transportable dimensions, taking advantage of ideal factory conditions to produce large-scale building modules for manufactured housing. Modern digital fabrication processes thereby allow lightweight structural systems with great variation in form and size.

Depending on the function of the building some important demands have to be specified and detailed in the construction phase documents:

- adequate sound separation in the joints of wall and ceiling;
- strategies to reach sufficient fire protection by means of encapsulation or separation of gaps and hollow spaces (refer to the 'model guideline for technical fire protection requirements for extremely flame-retardant wooden construction components', the M-HFHHolzR, in Germany)

3. TIMBER STRUCTURES IN THE CITY STAND FOR SUSTAINABLE, COST-EFFECTIVE ARCHITECTURE

The results of the recent 'wienwood 05' architecture competition show that wood is meeting with a positive reception, even in an urban context. A total of forty projects were submitted for Vienna's first competition for wooden constructions, and half of them were in the 'residential buildings' category. The quality of the architecture was generally so high that the jury had difficulty arriving at a decision. For instance Vienna's first four-storey timber residential building has received an award for its bold design and innovative use of timber. It is regarded as a pioneering project, paving the way for future initiatives in the field of timber construction in urban environments. The 2001 amendment to Vienna's building regulations permits multi-storey buildings to be constructed from wood; previously wood was mainly used in large quantities for roofing-out trams and for attic constructions. Since the amendment, wood is increasingly being used as a construction material in communal building projects. The first communal developments are finished, while construction on a further seven has already commenced or is about to begin. All in all, 400 multi-family developments are being erected either entirely from timber or mixed timber/concrete.

Wood is beginning to establish itself again as a completely 'normal' and sustainable building material in Vienna and in the minds of the city's population. Recent demonstration projects show that sustainable construction using ecological materials with optimum usage of energy can produce results that are both architecturally elaborate and economically efficient. The new community centre in the town of Ludesch, Austria, completed in 2006 by Architect Hermann Kaufmann, is a perfect example of another innovative and cost-effective ecological building project. The project was part of the 'Building of Tomorrow' sub-programme sponsored and documented by the Austrian Federal Ministry of Transport, Innovation and Technology. As well as creating a passive building, the objective was to halve the specific primary energy consumption of the main building compared with similar, conventionally built, passive buildings, while simultaneously reducing the ecological manufacturing outlay to at least half of that required for a non-optimised construction. Dual, and thus comparable, tenders meant that a direct comparison could be made between the 'conventional' and the ecologically desirable construction; the added cost for using ecological building materials was only around 1.9%. The positive experience gained encouraged all parties involved to take on other challenging projects of this kind.

3.1 Some Demonstration Projects

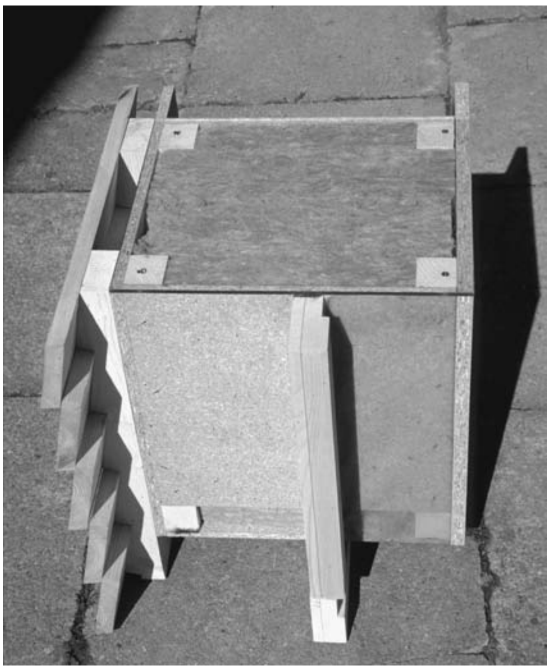
Some recent European examples of multi-storey, residential timber buildings illustrate in a remarkable way the application of wood in architecture. The following six case studies are low impact buildings with a small ecological footprint. They have all won architectural awards for their design quality and are now influencing many others in their choice of material, as an alternative to masonry or concrete.

Project 1: Ölzbuendt Residential Development in Dornbirn (Vorarlberg Region), Austria, 1997 (Architect: Hermann Kaufmann, Schwarzach), figures 5 and 6. This three-storey building is situated on a narrow plot of land within an estate of detached properties and is designed as passive house. The twelve apartments (six 2-rooms, six 3-rooms) are compact in design. The combined kitchen, eating and living areas extend through the entire depth of

FIGURE 5. View of the building's western facade (photo: H. Kaufmann).

the structure. At the southern end of the building is an additional residential and office unit spanning all three storeys. The project objectives were to minimise construction times to 4.5 months by using prefabricated wooden units wherever possible, to use as little energy as possible and to use ecological materials without adding to overall expenses. The insulated

FIGURE 6. Detail of the highly insulated wall panel (photo: H. Kaufmann).



shell encapsulates the compact volume of the building. Ölzbündt is a skeleton construction featuring wooden pillars and suspended, gravel-filled hollow box girder elements. Standard 2.40 m square, prefabricated wall elements, insulated with 350 mm-thick mineral wool are mounted in front of the structure to form a building envelope free of friction. Concrete wall-inserts help to make the building rigid and demarcate the individual fire zones. The project in Ölzbuendt was designed as a passive house. To reach this objective, the architect chose a highly insulated, air-tight shell as timber frame construction with narrow posts which is free of thermal bridges and helps minimise heat loss.

The individually controllable, decentralised ventilation system manages the flow of fresh air while doubling as a heating system. Fresh air enters the building via a geothermal heat exchanger, while waste heat from the kitchens, bathrooms and WCs is recycled via a plate-type heat exchanger. A central solar heating system supports the production of warm water. The balconies on the west side of the building and the open walkway with the stair-well on the eastern side are light steel constructions. The character of the façade is defined by the serrated weather-boarding in larch, which underscores the block-like appearance of the construction. Changes in colour and texture of the permanent untreated wooden cladding were taken into account in the planning process.[6]

Project 2: Senior housing complex in Neuenbuerg (Stuttgart), Germany, 1996 (Architects: Mahler-Guenster-Fuchs, Stuttgart), figure 7. This serviced housing complex for the elderly consists of thirty units in four identical buildings along the banks of the River Enz. The four storey structure is a mixed concrete/timber structure (a 'wood-concrete hybrid'). The main structure is a reinforced concrete core (staircase walls) and concrete skeleton clad with timber, and is extended with a timber post and beam structure as balconies on both sides. However, the architects are confident they could have built the project entirely as a timber structure, and want to try this approach with another client.

The long balconies run the entire length of the building and act as a shading device, especially on the long western façade where they offer protection

FIGURE 7. View of the four residential buildings facing the river (photo: C. Richters).

FIGURE 8. View of the five-storey residential building in Norway (photo: J. Musch).

from the strong afternoon sun. The large sliding elements add a delightful taste of irregularity to the elevations. A series of enhanced fire safety measures were realised, including a 90 minute fire resistance level construction for all primary structural elements of the balconies, which are also access and escape routes. The surface of the Douglas timber used remained untreated, unpainted and requires no maintenance. The roof is clad with plates of polycarbonate, which is translucent and allows daylight to penetrate. Underneath this layer are solar collectors. The whole project is a good example of a simple and affordable construction method with a strong tradition in vernacular buildings as well as in German Modernism. It implies not only straight forward structural solutions in an unsentimental way, but also considers daily functions and usability.

Project 3: Svartlamoen multi-apartment building in Trondheim, Norway, 2005 (Architects: Brendeland & Kristoffersen, Trondheim), figure 8. One of the most remarkable, and probably tallest, timber buildings in Europe can be found in Trondheim, Norway. When a competition held in 2002 demanded that timber be used as the main construction material, architects Brendeland & Kristoffersen responded in style with a convincing concept that was also cost-effective to implement. 'We wanted to make sure that the houses didn't look as though they'd been built by hobbits,' explained Kristoffersen in a recent interview for a lifestyle magazine.[7]

Two buildings were built with an overall area of 1030m^2. The ground floor of the main five-storey building, which measures 6m × 22m at a height of 17m high, contains rooms that can be commercially used. On the four upper floors, units of 120m^2 in size can be used by groups of up to six people. Compact individual rooms lead to attractive community rooms with large windows facing south. The auxiliary building draws reference to the complex as a whole, turning the ensemble into a protected courtyard with six individual apartments and a generous patio area.

The entire construction was made out of solid cross-laminated timber boards produced by the Austrian company Santner, and cladded with Norwegian larch. The untreated timber surfaces of the load-bearing elements are visible inside at all times.

Ecological and flame-retardant aspects played a crucial role in the choice of GLT elements. After being granted a special dispensation, the architects were able to create a timber building five storeys high instead of the maximum three storeys usually permitted in Norway. As the solid GLT elements were defined as firewalls, each floor could be treated as an independent fire zone. The load-bearing GLT panels, which are visible from inside the rooms and were supplied with ready-textured surfaces, are integrated into the façade and thus give rise to a freely-definable floor layout without any obstruction from pillars. The separating walls made from 96mm thick GLT panels are not part of the static system. The sandwich structure of the outside wall consists of a 200mm thick layer of mineral wool surrounded by gypsum fibreboard and is clad in untreated larch. The timber construction means that the weight of the building is only half that of a similar building made from concrete, which entirely simplified the construction of the foundations. The use of pre-fabricated elements reduced the construction time significantly: Ground was broken in June 2004 and the two buildings were completed in April 2005. Through the efficient assembly of the timber elements, four workers managed to erect the main structure in just ten working days.

Project 4: Spoettelgasse residential development in Vienna, Austria, 2005 (Architect: Hubert Riess, Graz), figures 9 and 10. The building is Vienna's first four-storey timber residential construction and has received an award for its bold design and innovative use of timber. It is regarded as a pioneering project, opening the way for future initiatives in the field of wooden construction in the urban environment.

This pilot project was implemented in the wake of the 2001 amendment to Vienna's building regulations. The new laws permitted buildings of four storeys with outer walls of wooden construction, provided that the ground floor is made from mineral construction materials. Fire protection requirements played a central role in the building's planning and, in close collaboration with the appropriate authorities, criteria were laid down to ensure such requirements were met.

The judges of Vienna's first competition for timber buildings wrote the following about the project:

FIGURE 9. The building seen from the courtyard (photo: H. Riess).

FIGURE 10. Image of on site assembly of stacked board ceiling elements (photo: KLH Austria).

'This, the first four-storey timber residential property (in glued-laminated timber) on a solid timber base in Vienna, is particularly impressive on account of its bold and pioneering design. It was thanks to the work and dedication of the planning team that both the building developer and the city authorities were ultimately convinced of the feasibility of a project to build a multi-storey timber home within the framework of the current legal provisions. We would also like to emphasise the interdisciplinary approach adopted in project development and the largely constructive application of wood.'[8]

Project 5: Muehlweg residential development in Vienna, Austria, 2006 (Architects: Hermann & Johannes Kaufmann, Schwarzach, Vorarlberg Region), figure 11. In December 2003, the 'Land Provision and Urban Renewal Fund' in Vienna invited tenders from developers for a construction project focusing on 'wood and mixed wood/concrete constructions'. One hundred public-sector apartments were to be built on each of three inter-connecting plots at the Muehlweg site, with the emphasis on the optimum exploitation of the ecological and economic benefits of timber and mixed constructions. The winners were Hubert Riess, Dietrich/Untertrifaller, and the construction cooperative Hermann & Johannes Kaufmann architects.

The new development is one of the pioneering projects in the field of multi-storey wood or mixed wood/concrete constructions. Within the site, each project developed its own urban character.

FIGURE 11. View from the courtyard, facing the buildings (photo: B. Klomfar).

The terraced house and the L-shaped building surround an internal courtyard, offering a free area for communal use. The four-storey buildings offer two different solutions. The north/south-oriented terraced concept, with its maisonettes, has a two-storey timber construction on the second floor erected on top of a ceiling of reinforced concrete. The timber maisonette ceiling between the ground and first floors is inserted. Contrasting with the above are the three-storey superstructures made from pre-fabricated GLT elements built on top of the concrete basement of the east-west-oriented units. The entire four storeys of the building are clad in larch. The obligatory fire protection belts lend the building a horizontal layering. The many floor-to-ceiling French windows provide an eye-catching contrast to the naturally ageing wooden façade.

It was built to an impressive tight schedule: Ground breaking was in August 2005. Off-site pre-fabrication of elements and the resulting optimised construction process meant that the apartments were ready for occupation by October 2006. The project turned out to be a success, first and foremost, because planners and representatives of the public authorities succeeded in working together on a consistent basis. In an interview, Johannes Kaufmann explained the necessity of an early dialogue with the authorities in order to discuss and develop alternatives and to share specific knowledge on timber construction on a competent and open basis.[9]

Project 6: Holzhausen multi-family home in Steinhausen, Switzerland, 2006 (Architects: Scheitlin-Syfrig & Partner, Luzern), figure 12. The new fire protection standard in Switzerland, introduced in January 2005, permits the construction of timber buildings of up to six storeys with a 60-minute fire-resistance capability. The Holzhausen MFH in Steinhausen, Switzerland, designed by architects Scheitlin-Syfrig & Partner (in collaboration with manufacturer Holzbau Renggli AG), is Switzerland's first six-storey timber building (with a four-storey timber framed construction TFC on top of a concrete base). The project replaced an existing two-storey building and makes more intensive use of the 1600m^2 site area. Each storey accommodates two spacious apartments 149m^2 or 166m^2 in area, with the main rooms and large balconies oriented to the south and west. Cedar wood, anthracite coloured windows, fibre cement cladding (produced by Eternit) and corrugated sheet panels on the balconies characterise the building's appearance. The basement and ground floors are solid mineral constructions. Highly heat insulating, pre-fabricated outside-wall elements made from wood form the thermal skin on the ground floor. From the first floor onwards only the central core, consisting of the staircase and the lift, are made from reinforced concrete, while the walls are a frame construction and the ceilings are acoustically decoupled, beamed constructions. The timber-metal windows feature triple-glazing with a very good u-value. The comfort ventilation system, with waste-heat recovery, reduces heat loss through

FIGURE 12. View of the six-storey building in Switzerland (photo: Renggli AG, CH).

ventilation, while, with correct usage by the inhabitants, an effective heat requirement ratio of just 20 kilowatt hours per square metre can be achieved. A heat pump, with a geothermal probe, supports the heating and domestic warm water systems. Fine-tuning of individual measures meant that the development was able to surpass the criteria laid down by the stringent Swiss 'Minergy' standard.

4. CONCLUSION: TIMBER—A CONSTRUCTION MATERIAL OF THE 21ST CENTURY

The environmental dimension has certainly enriched architectural thinking, shifting the attention to a search for long-term sustainable developments.[10] It is very likely that multi-storey timber-framed construction will make an important contribution to the future residential market, facing the challenges of sustainable architecture. Such innovative developments as presented will change the perception of timber as a 'low status' material (the notion of 'living in a timber box'). With all its sustainable qualities and various advantages, the authors suggest that wood is a construction material of the 21st century. Numerous multi-storey commercial and residential buildings throughout Europe demonstrate the manifold possibilities and exploitability of timber and its technologies. While it is true that biogenic construction materials are not cheaper than their conventional counterparts, the challenge is to use existing resources responsibly in order to create comfortable, intelligent and environmentally compatible buildings.

Larger projects in timber construction require a specialised consultant to avoid common mistakes in detailing and surface treatment. Often it can be observed that there is a decline in the client's commitment to building sustainably from the start to the end of a project. Therefore, clear objectives are necessary in the planning process. Timber is tailor-made for the task of inner-city residential projects, as the presented housing developments have shown. Wood structures are predestined to pursue this new course to become showpiece projects for sustained building solutions.

Over the last twenty years or so, Swiss architects Burkhalter & Sumi and Peter Zumthor; German architects Frei Otto, Thomas Herzog and Otto Steidle; Norwegian architect Sverre Fehn; as well as some contemporary Japanese architects (Tadao Ando, Katsuhiro Ishii, Shigeru Ban) have been forerunners in the rediscovery of timber as a contemporary construction material. They have combined it either with a vernacular, regional approach to design, or with innovative application.

In regard to sustainable development, Alexander Tzonis has noted: 'The long-term negative impact of the application of techniques and materials of construction on material resource consumption and environmental physical quality is now a prime concern in architecture. (...) The task of inquiry is just beginning.' (Tzonis, 2006)[11]

In the state of Vorarlberg, in Austria, there has always been a strong awareness of wood, one of the main resources available in that region. The results of traditional craftsmanship can still be seen in vernacular architecture. The experience of builders and architects in the last thirty years is now preparing the way for innovative approaches in building as well as in research activities.[12] The dynamic, giant roof structure by Thomas Herzog and Julius Natterer for the EXPO 2000 in Hanover ('the world's largest timber roof') is an elegant sculpture and an impressive demonstration of the structural possibilities for timber shells made from glue-laminated timber.

With the height restrictions on residential timber buildings being lifted, new methods of fabrication are been developed by industry in collaboration with architects. The aim is to fully mobilise the capacities of new manufacturing methods towards a more effective use of the unique characteristics of the material. As a result, new lightweight and high-performance components are being developed.[13] It is highly likely that the future will put even more requirements on the architect and engineer to use green materials in construction, and apply components that facilitate reuse and recycling.

The presented multi-storey examples have their own individual appearance as defined through the materials used in their construction. They look elegant and architecturally attractive. They are not only examples of aesthetic refinement; they also demonstrate that timber allows for an energy-efficient, sustainable architecture that can be adapted to provide the community with healthier buildings and a more sustainable building regime for our cities.

NOTES

1. Carbon dioxide can be safely sequestered through the natural process of forests that lock carbon up in trees and soils. However, a study reported in *New Forests* (2006) concluded that: 'An area covered with a plantation managed for maximum volume yield will normally contain substantially less carbon than the same area of unmanaged forest'. Hereby, native forests seem to be the best way to capture carbon. A similar study in Oregon found that 'a 450-year–old natural forest stored 2.2 to 2.3 times more carbon than a 60-year-old Douglas fir plantation on a comparable site'. Unfortunately, we cannot plant enough trees in time and not all soils are suitable. World Rainforest Movement calculated: to compensate for the carbon we are currently releasing into the atmosphere every year would require planting four times the area of the US with trees.
2. Similar changes in building codes have been made in the UK (1991 England and Wales Building Regulations) and in Australia (1996 BCA), enabling multi residential timber framed construction (MRTFC) beyond their historical height limitations into medium-rise structures, higher than four storeys.
3. Kolb, Josef (2007): *Holzbau mit System*, Birkhäuser, Basel.
4. Refer to: www.gabrielpoole.com.au of GEPDC Architects (Australia). The idea is to provide affordable and high-quality homes, so-called 'take away houses', which are factory built and developed in close collaboration with a manufacturer; see also: www.gatewaymanufacture.com . The ideas are based on modular timber houses developed by Richard Buckminster Fuller and Konrad Wachsmann in the 1950s.
5. Hausladen, Gerhard and others (2004), *Clima Design.*
6. For project documentation: see www.energytech.at—the platform for innovative energy technologies.
7. Journal *Haus+Garten*: 2005, 'Hochhaus aus Holz: Gemeinsam planen und wirtschaften', www.haus.de.
8. Journal *proHolz Austria*, wienwood 05, www.wienwood.at.
9. Journal *Zuschnitt* no.20, 2005; Seite 20, www.zuschnitt.at.
10. A definition of 'sustainable' is derived from the Latin verb 'sustinere', which describes relations that can be maintained for a very long time or indefinitely (Judes, 1996).
11. Tzonis, Alexander (2006): *Rethinking Design Methodology for Sustainable Social Quality*; in: Ban, J.-H. and Ong, B.-L.*: Tropical Sustainable Architecture*, Architectural Press.
12. There are several research institutes dedicated to innovative construction with timber. Some examples: Since 2002, the Austrian architect Hermann Kaufmann has held the Chair for Timber Architecture at the Technical University of Munich. Michael Flach from the University Innsbruck has developed significant teaching and research efforts, in collaboration with Hans Hartl, the Chair for Timber Constructions at the Technical University of Vienna.
13. Engineered wood products, such as the weather resistant Laminated Veneer Lumber (LVL) 'Kerto' from Finland (www.Finnforest.co.uk), are good examples of this development.

REFERENCES

Selection of websites on building with timber

www.wienwood.at
www.timber.org.au/
www.aitc-glulam.org/
www.cibworld.nl
www.beconstructive.com
www.worldwidewood.co.uk/
www.infoholz.de
www.dgfh.de
www.proholz.at
www.lignum.ch
www.forestplatform.org

Quoted companies on building with timber

www.finnforest.com
www.kaufmann-holz.at
www.klh.at
www.lignatur.ch
www.lignotrend.de
www.renggli.ch

Some quoted literature on building with timber

Building Code (2002): *Model Building Regulation* (11/2002).

Building Code (2003): *Fire protection requirements for extremely flame-retardant wooden construction elements* (M-HFHHolzR, 7/2003).

Federal Ministry of Transport, Innovation and Technology (2006): *Construction of a new ecological community centre in Ludesch*; Federal Ministry of Transport, Innovation and Technology, Radetzkystrasse 2, 1030 Vienna.

Dehne, M., and Krueger, U. (2006): *Fire Protection in Multi-storey Timber Construction*, in: *Detail* No. 10/2006, Germany, p. 1142-1144.

Kolb, Josef (2007): *Holzbau mit System*, Birkhäuser, Basel.

Natterer, Julius; Herzog, Thomas; Volz, Michael (1994): *Holzbau Atlas Zwei,* Institut fuer Internationale Architektur-Dokumentation, Munich.

Renggli AG (2005): *Holzhausen MFH in Steinhausen Switzerland: Switzerland's first six-storey timber building—project documentation of Renggli AG*, Sursee CH.

Websites of mentioned 'Timber Architects'

Baumschlager Eberle Architects, Vorarlberg Region, Austria: www.baumschlager-eberle.com.

Brendeland Kristoffersen Architects, Trondheim, Norway: www.bkark.no.

Herrmann Kaufmann,Schwarzach, Austria: www.kaufmann.archbuero.com.

Johannes Kaufmann, Dornbirn, Austria, www.jkarch.at.

Thomas Herzog, Munich, Germany: www.herzog-und-partner.de

Mahler Guenster Fuchs, Stuttgart, Germany: www.mgf-architekten.de.

Hubert Riess Architekt, Graz, Austria: www.archinform.net.

Scheitlin-Syfrig + Partner, Luzern, Switzerland: www.scheitlin-syfrig.ch