Research in sustainable design and construction systems: multi-storey residential timber buildings in Europe

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ABSTRACT: Advancing construction systems is a way to enhance the environmental sustainability performance of buildings. The growing need to increase density in cities and to rethink construction methods for residential buildings has recently led to a series of innovative approaches for multi-storey timber construction systems in Europe. Hereby, applied research in new materials and interdisciplinary collaboration between architects and manufacturers of building components drive innovation and the development of new structural systems. The paper presents ongoing research, focusing in the first part on technical aspects of such multi-storey timber constructions. In the second part, the paper presents a series of recent case studies of urban timber buildings. The close collaboration between architect and system manufacturer has enabled the development of prefabricated panel construction systems; even in what appears to be a simple project, there is a high complexity in the developed system, systemisation, detailing of components and realisation. The author sees this as a relevant topic within the context of the environmental debate and the need to use sustainable materials and prefabricated systems to ensure affordability in environmentally driven projects. The paper discusses the lessons that can be learnt from the case studies and their use of timber as multi-frame, for multi-level residential buildings. The main objectives of the presented projects are:

- Prototype design of large-scale prefabricated timber elements to improve the construction process and the energy-efficiency of building envelopes;
- Modular design for transformation and disassembly: Systems not designed for transformation lead frequently to user dissatisfaction, adaptability at high cost, and more demolition waste;
- Closing cycles through integrated life cycle design methodologies: Optimization of a frictionless 'digital chain' for the entire process, from design, to production, to assembly.

The conclusion suggests that these prefabricated timber systems allow for high-performance construction methods adequate for multi-storey residential buildings, even in an urban context.

Keywords: Light-weight structural systems; prototypes/demonstration projects; prefabricated building components; timber constructions in urban environments.

1. INTRODUCTION

What will buildings have to be like to achieve the target of CO2 emissions' reduction? What are the new ways to build for inner-city living in denser city centres? Building 'green' is not something to be bolted on once the design is completed – it needs to be integrated in the conceptual phase from the very beginning. Material questions in regard to the construction system are therefore crucial from the early stage of design: Conventional construction methods frequently result in materially inefficient structures that rely on the consumption of natural resources. For instance, building with brick and masonry often limits the building's height and leads to heavy, material-intensive construction; using concrete is increasingly regarded as problematic in terms of its ecological footprint, embodied energy and limited possibilities for disassembly; structural steel has advantages in dematerialisation, but is expensive and still problematic when it comes to the reuse of structural elements. For a long time, timber buildings have therefore been praised for their affordability and potential for easy reuse of building elements, even as a pool of material resources for new constructions. The light-weight characteristic of timber means smaller foundations, as the weight is only around half that of a similar building made of concrete. In addition, timber has regained even more appreciation since the building codes have changed and now allow for multi-storey (more than 3) timber

construction systems. Affordability is of prime importance when discussing housing. Numerous recent studies have shown that energy-optimized buildings can achieve a payback of their sustainability measures in less than 8 to 10 years (e.g. Kats, G. et al: *The Costs and Financial Benefits of Green Building*, 2003). Long-term savings in energy consumption, operation and maintenance - life-cycle costs - are today more important than (slightly higher) construction costs at the time of the building's erection. If harvested from sustainable grown forests, timber is recognised as a modern material that offers great opportunities for sustainable design. Furthermore, the many advantages of prefabrication (reduced time and storage space on site, easier site logistics, less construction waste, life-cycle advantages such as recyclable and dismountable buildings, 'cradle-to-cradle' material cycle with less embodied energy, less damage to site) render prefabricated timber systems as an innovative and sustainable way to build. Today, we see large-scale production of timber components which utilizes new structural panel materials and CNC-carpentry. The data flow from planning to prefabrication, to the assembly on site, benefits from a high extent of automation, systemisation of workflow and frictionless production chains; the forest-based value chain is hereby particularly beneficial for small and medium carpenters. Wood has an excellent insulation value (despite its lack of thermal mass) and can present a sustainable alternative to the commonly used composite thermal insulation systems (most insulation systems are based on mineral fibre or polystyrene foam at the expense of a high amount of primary energy, combined with high levels of volatile organic compounds). The important criterion for sustainable timber is environmentally-responsible forest management practices, in regard to how the timber was planted, managed and harvested. The 'FSC Certified Timber' certification specifies such qualities for sustainable timber products.

Numerous innovations can now be seen in multi-storey timber buildings all across Europe. Increasing ecological awareness, rising expectations with regard to the health and comfort of home environments, and interesting new products from the timber construction industry, provide a basis for innovative designs even in the urban context. These recent demonstration projects for multi-storey residential buildings using timber construction systems, offer a series of systemic and environmental advantages, such as:

- Prototype design of large-scale prefabricated timber elements to improve the construction process and the energy-efficiency of building structures and envelopes;
- Modular design for transformation and disassembly: Systems not designed for transformation frequently lead to user dissatisfaction, adaptability at high cost, more demolition waste and an increase in the material consumption.
- Closing cycles through integrated life cycle design methodologies: Optimization of a frictionless 'digital chain' of the entire process, from design, to production, to assembly.

1.1 Timber - a sustainable urban material for the 21st century city

The quality of a building can be measured by its potential to be transformed from a spatial to a material concept without negatively impacting on the environment. For a long time, timber buildings have been praised for their healthy indoor environments, even for inner-city living in denser city centres. If we take a holistic look at energy consumption and the material cycle in the building industry, we find that wood offers many advantages: Excellent insulation characteristics, ideal values of embodied energy, relatively easy to recycle and insulation qualities that are superior to either metal or concrete. The use of sustainable harvested timber can help to keep the embodied energy content and use of material resources low. It also 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. It is therefore suggested that more buildings could be built in timber to achieve the target of CO2 emissions reduction. High-performance timber products, which are now becoming available, offer increased stability, good acoustic insulation and high fire rating (e.g. large-scale, structurally highly stable, cross-laminated panels, such as produced by Lignotrend, Kerto, Renggli – just to name a few). These engineered wood products have a series of additional advantages:

- Low formaldehyde emission levels,
- Facilitating design for disassembly (structural framing, façade systems, entire GLT wall elements, etc.) and easier recycling, further minimising resources associated with demolition.

Forests in central Europe have been increasing in size every year due to more wood being grown than is used. During its growth phase, wood binds carbon dioxide and retains it for many years, even when the wood has become a building material, thus preventing CO2 from re-entering the atmosphere. (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". 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 2.3 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). 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. All this is accompanied with interesting changes in the building code: New building regulations will in the future allow building timber constructions of up to five storeys or more (e.g. the Building Regulation for Prototypes, a Performance-based Code, 11/2002 in Germany, and similar developments in other countries; e.g. changes 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). Load-bearing components of Building Category 4 (floor of top storey <13m) must be highly resistant to fire, i.e. they must be able to withstand fire for a minimum of 60 minutes (Dehne and Krueger, 2006).

As a consequence, building with wood is gaining again in popularity. (The increasing popularity is also visible in education: there is a new interest in urban timber buildings, with several universities now offering postgraduate programmes (for instance, at the universities in Munich, Vienna, Dresden, Innsbruck, ETH Lausanne and Helsinki University). This paper takes a closer look to evaluate some recent case studies.

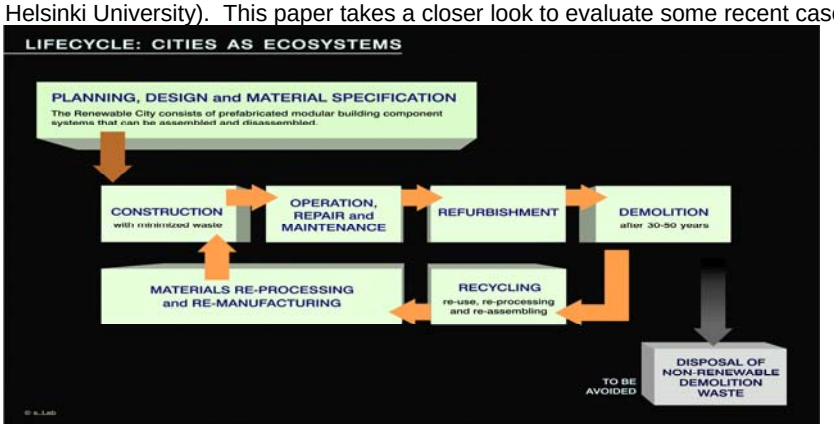

Diagram 1: Life-cycle of buildings and cities (diagram by the author, 2008)

2. NEW CONSTRUCTION SYSTEMS AND INTERDISCIPLINARITY

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 in multi-storey residential projects, which has recently developed in a sophisticated way. Modern approaches to timber construction in central Europe have undergone innovative changes. Traditional approaches, such as block and half-timbered constructions, or the balloon-frame and platform-frame constructions seen in North America, have given way to today's prefabricated 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 (Kolb, 2007). These constructions are characterised by the method of assembly of prefabricated structural elements and the structure of the envelope. When working with prefabricated timber elements, it requires the designer's close collaboration with the manufacturer of those components to enable real innovation and the development of new prefabricated construction systems. Architecture has – of course – always been the outcome of a manifold of complex understanding and a multidisciplinary domain of knowledge and practice. However, we now witness the fast development of technological possibilities, and a shift to interdisciplinarity appears to be an increasingly necessary condition.

2.1 Aspects of planing with timber: construction systems

Generally, building systems consist of similar wall and ceiling elements, though these elements can also be used in combination to form the 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. clad post and beam structure
  - Solid wall panels: i.e. stacked board elements, glue-laminated elements

- Solid wall plates: i.e. cross laminated boards, veneer laminated plates.

- **Ceiling (horizontal structural element)**
  - conventional beam structures
  - combined timber elements: hollow box girder; combined concrete timber elements
  - solid ceiling elements: stacked board elements or cross laminated plates.

2.2 Industrial elements

Examples of the variety of industrial elements built from wood and other materials are described in the following chapter., with some examples of industrially manufactured timber construction elements that offer interesting opportunities for application, which are now widely available in Europe:

Figure 2.2.1 (left): Assembly of prefabricated floor and wall panels on site (photo: FGH)
Figure 2.2.2 (middle): Image of the hollow box girder elements, filled with insulation (photo: FGH)
Figure 2.2.3: Combined timber-concrete ceiling elements (photo: Lignotrend)

- **Stacked board elements**

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, for ceilings, walls
Overall height x width: up to 240mm x up to 2.5m

- **Solid cross-laminated timber boards**

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

Overall height x width: up to around 280mm x up to 4.8m

- **Hollow box girder elements**

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**

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.

2.3 Construction physics – efficient protection necessary

Regarding ecological issues and rising energy costs, the challenge lies in the design of energy-efficient buildings, combined with an appropriate climate-responsive concept. (Hausladen, G. et al, 2004). 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 a timber building requires a larger amount of careful detailing and precise planning. 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 is causing wet rot inside the walls. This is sometimes hard to detect and may not be noticed until mould growth or rotting of material actually occurs. Consequently there is a need for a 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. 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 of gaps and hollow spaces.

3. CASE STUDIES: TIMBER STRUCTURES IN THE CITY

The results of a recent architecture competition illustrated well, that timber is meeting with a positive reception, even in a city context: A total of forty projects were submitted for Vienna's first competition for wooden constructions, and most of them were in the 'residential buildings' category. For instance, Austria'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 (2008). A total of 400 multi-family developments are being erected either entirely from timber or mixed timber/concrete systems. Wood is beginning to establish itself again as a completely 'normal' building material 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. For instance, the new community centre in the town of Ludesch, Austria (2006) is a perfect example of an innovative and cost-effective ecological building. As well as creating a passive building, the objective was to half the specific primary energy consumption, 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%.

3.1 Demonstration Projects

Some recent European examples of multi-storey, residential timber buildings illustrate the application of timber in architecture. The following four international case studies (from four countries) are all low impact buildings with a small ecological footprint.

3.1.1 Project 1: Svartlamoen multi-apartment building in Trondheim, Norway, 2005 (Architects: Brendeland & Kristoffersen Arkitekter, Trondheim)

Figure 3.1: View of the five-storey residential building in Norway (photo: J. Musch)

One of the most remarkable, and probably tallest, timber buildings in Europe can be found in Trondheim. The architects responded in 2002 with a convincing concept that was also cost-effective: Two buildings with an overall area of 1030m². The ground floor of the main five-storey building, which measures 6m x 22m, contains rooms that can be commercially used. On the four upper floors, units of 120m² in size can be used by groups of up to six people. Compact individual rooms lead to attractive community rooms with large windows facing the sun. The auxiliary building turns the ensemble into a protected courtyard with six apartments and a generous patio area. The entire construction was made out of solid cross-laminated timber boards developed and produced by the Austrian company Santner, and clad with Norwegian larch. The untreated timber surfaces of the load-bearing elements are visible inside in all rooms. Ecological and flame-retardant aspects played a crucial role in the choice of the glue-laminated timber (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. With the solid GLT elements defined as firewalls, each floor could be treated as an independent fire zone. The load-bearing panels, which 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 columns. The separating walls made from 96mm thick GLT panels are not part of the structural system. The sandwich structure of the outside wall consists of a 200mm thick layer of mineral wool surrounded by gypsum fibreboard and clad in untreated larch. The weight of the building is only half that of a similar building made from concrete, which simplified the construction of the foundations. The use of pre-fabricated elements reduced the construction time significantly, to 10 months. Through the efficient assembly of the timber elements, four workers managed to erect the main structure in just ten working days.

3.1.2 Project 2: Muehlweg residential development in Vienna, Austria, 2006 (Architects: Hermann & Johannes Kaufmann, with Riess & Untertrifaller, Schwarzach, Vorarlberg Region)

Figure 3.2.a (left): View from the courtyard, facing the buildings (photo: B. Klomfar)
Figure 3.2.b: Detail of the highly insulated wall panel system, a prefabricated element (2.4x2.4m), developed by the architect (photo: H. Kaufmann)
Figure 3.2.c: Image of on site assembly of prefabricated board ceiling elements (photo: KLH Austria)

This building is Vienna's first four-storey timber residential construction and has received awards for its bold design and innovative use of timber. Since 2001, the reformed building code permits 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 authorities, criteria were laid down to ensure such requirements were met. One hundred public housing units were built in wood and hybrid wood/concrete constructions, with an emphasis on the ecological and economic benefits of timber and mixed constructions. The architects of the construction co-operative Hermann & Johannes Kaufmann are both, architects and manufacturers in one. A design and construct process was used. Each project part developed its own urban character: A terraced house and a L-shaped building surround an internal courtyard, offering outdoor space for communal use and two different plans: The north/south-oriented terraced concept, with maisonettes, has a two-storey timber construction on the second floor, erected on top of a podium of reinforced concrete. The timber 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 many floor-to-ceiling French windows provide an eye-catching contrast to the naturally ageing, wooden façade. The project 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 by October 2006. The project was possible because planners and public authorities succeeded in working closely together. In an interview, Kaufmann explains 'the necessity of an early dialogue with the consenting authorities in order to develop solutions for the fire engineering, and to share specific knowledge on timber construction on a competent and open basis. (...) When working with prefabricated timber systems, it requires the architect's close collaboration with the manufacturer to enable genuine innovation.' (Kaufmann, 2005; in: Journal *Zuschnitt*, 2005) The project was designed as *passive energy house*. To reach this objective, the architect chose a highly insulated, air-tight shell as timber frame construction with narrow posts, free of thermal bridges, minimising heat loss. The individually controllable, decentralised ventilation system manages the flow of fresh air while doubling as heating system. The insulated shell encapsulates the compact volume of the building: A skeleton construction featuring wooden pillars and suspended, gravel-filled hollow box girder elements. Standard 2.40m square, pre-fabricated wall elements, insulated with 350mm-thick mineral wool, are mounted in front of the structure to form a friction-free building envelope.

3.1.3 Project 3: Holzhausen multi-family home in Steinhausen, Switzerland, 2006 (Architects: Scheitlin-Syfrig & Partner, Luzern)
This residential project is a model for learning about ecological construction and mode of living, an educational showpiece. 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 multi-unit complex in Steinhausen, designed by the architects 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. Each storey accommodates two spacious apartments, 150m²

or 166m² in area, with the main rooms and large balconies oriented to the south and west. Cedar wood, anthracite coloured windows, fibre cement cladding and corrugated sheet panels on the balconies characterise the building's appearance. The basement and ground floors are solid masonry constructions.

Figure 3.3 (left): View of the six-storey building in Switzerland (photo: Renggli AG, CH)
Figure 3.4: Rendering of the proposed nine-storey building in London's East end;
so far, the tallest wooden housing block worldwide. (photo: W. Thistleton)

Highly insulated, 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; 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 ventilation, so that (with correct usage by the inhabitants) the heat requirement ratio is just 20 kilowatt hours per square metre. 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.

3.1.4 Project 4: The tallest wooden housing block 'Timber Tower' in London Hackney, UK, 2008/09
(Architects: Waugh Thistleton, London)
This experimental project, a nine-storey residential tower (with 30 units) in an urban context, is a model for the innovative use of new fire-engineered, load-bearing wall panels: Built of cross-laminated 'Jumbo Plywood Panels' (manufactured by Kaufmann's company KLH in Dornbirn, Austria), the entire structure is currently constructed of prefabricated timber panels, including the walls, floor slabs and even the stair and lift cores. According to the architects, the timber structure will save 125 tonnes of CO2 emissions compared to a concrete structure of similar size (equivalent to 21 years of carbon emissions from such a building). The prefabricated panels are up to 9metres in length, with cut-outs for windows and doors; as they arrive on site, they are immediately craned in position. The entire structure is currently built in only 10 weeks (mid 2008). The exterior cladding is made up of 5,000 panels which are to 70 per cent made of recycled waste timber. A similar 7-storey project in Berlin is now in the design stage, using the same technology (architects: Kaden & Klingbeil).

4. LESSONS LEARNT FROM THE CASE STUDIES

The presented case study projects have all in common, that:

- the designs and subsequent commissions were the outcome of architectural design competitions;
- sophisticated timber wall systems for energy-efficiency were especially developed for the projects;
- during the procurement of these projects, productive team integration was achieved by leadership of the architect, leading a collaborative approach with the system manufacturer.

When interviewing the teams of the presented case studies, the importance to uphold the leading role of the architect during the entire project procurement was repeatedly mentioned as important criteria for the success of the projects. The architect was still seen as the discipline member most appropriate to imagine, visualise and coordinate a project until completion (rather than handing-over to a project manager, who has been only marginally involved and not trained to synthesise complex input). This appears to be particularly important for the development and implementation of innovative fire-engineered solutions, on which the successful completion of these timber projects heavily depended. It is also clear from the comments, that in each case a close collaboration with the manufacturer of the timber components was essential: When working with prefabricated timber systems, such collaboration appears to be a basic requirement for making innovation possible. Architects are often strong in synthesising problems, prepared to take and manage risks, and have been professionally trained to co-ordinate complex tasks under tight constraints. They frequently demonstrate a cohesive understanding of the building process and are therefore likely to be leaders of technological change, which can give them a higher degree of design control. The architectural profession is used to guide the full consultant team and other disciplines involved. Kaufmann points out: 'Adapting 'lose-fit' design strategies is necessary to provide for the required flexibility when developing new solutions and construction methods with industry, extending project-based knowledge.' (Kaufmann, 2007)

Over the last twenty years or so, there have been some great examples of collaborative, risk taking architects, innovating in the timber industry: Swiss architects Burkhalter & Sumi and Peter Zumthor; German architects Thomas Herzog and Otto Steidle; Norwegian architect Sverre Fehn; as well as some contemporary Japanese architects (Katsuhiro Ishii, Shigeru Ban), have been forerunners in the rediscovery of timber as a contemporary construction material. They have combined it both with a vernacular, regional approach to design, and with innovative application. New lightweight and high-performance components were developed, minimising waste on the construction site through prefabrication (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).

5. CONCLUSION

In regard to sustainable development, 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)
The environmental dimension has certainly enriched architectural thinking, shifting the attention to a search for long-term sustainable developments. It is very likely that multi-storey timber-framed construction will make an important contribution to the future residential market. Such innovative developments 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 author suggests that wood is a contemporary construction material of the 21st century. Numerous multi-storey commercial and residential buildings throughout Europe (North and South) demonstrate the manifold possibilities 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 specialised consultants to avoid common problems in detailing and surface treatment. Timber appears well-suited 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. The presented urban examples have their own individual appearance. They look elegant, however, these are not only examples of aesthetic refinement; they also demonstrate that timber allows for an energy-efficient architecture that can be adapted to provide the community with healthier buildings and a more sustainable building regime for our cities. The conclusions are therefore:

- Multi-storey timber construction makes an important contribution to the future residential market.
- Architects and system manufacturers are key players in the process of creating sustainable buildings in timber, for affordable inner-city housing.

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