Timber-in-Town – current examples for residential buildings in CLT and tasks for the future

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Summary

Solid timber construction (STC) with Cross Laminated Timber (CLT), which was presented for the first time to an international audience of specialists in the context of the concluding conference of the COST Action E5 "Timber frame building systems" in September 2000 [10], can be definitely regarded as one of the most significant innovations in timber engineering within recent decades. Worldwide sales figures of about 500,000 m3 and a wide area of application, which includes not only modern one-family houses, multi-storey buildings, but also office- and administration buildings, hall systems and bridge structures, prove this statement. However, the motto "everything is possible", which goes along with this rapid development, and the legitimate concentration on the feasibility in static-constructive terms (ULS, SLS, fire, earthquake, etc.) lead to the problem that interdisciplinary issues are considered insufficiently; this is in the context of multi-storey buildings with questions concerning qualitative building services adapted to this type of construction.

Therefore, the aim of this report can be seen in dealing with these interdisciplinary problems. In concrete terms this means facing them and offering possible solutions in the context of solid timber construction out of Cross Laminated Timber. Due to the local processes on the subject of using Cross Laminated Timber, this report is based on a number of selected and partly completed projects in the Graz (AT) conurbation.

1. Introduction

"Is timber coming to town?" This question, asked at the 8th International sawmilling Congress in 2013, can definitely be answered in the affirmative. Timber has always been an essential building material in construction and probably one of the first and most important building materials in structural engineering. Due to fire disasters it was banned from the cities and replaced by reinforced concrete at the end of the nineteenth century.

Series events ("timber to town"), completions ("timber construction in the city"), research and development projects ("Low Carbon Future Cities", "Timber in Town"), as well as marketing projects ("Wood Growing Cities"), have contributed to the fact that timber returns to the front line in the cities as for example Vienna (6F), Zurich (6F), London (8F, 9F), Oslo (8F), Växjö

(8F), Bad Aibling (8F), Milan (9F) and Melbourne (10F). Forerunner for this development has been the 25 years existence of Cross Laminated Timber and its associated solid timber construction techniques.

Fig. 1 project "Wohnbau Wagramerstraße", Vienna, AT (left) [18]
project "Murray Grove", London, UK (middle) [19]
project "Via Cenni" / „Legno in Citta", Mailan, IT (top right) [20]
project "Bridport House", London, UK (down right) [21]

Despite the understandable enthusiasm for multi-storey residential buildings constructed of Cross Laminated Timber, it should not be forgotten that other fields of application in urban space are of significant importance as well. Such fields of application are, for instance, the possibility not only of adding further storeys and construction extensions but also the use of timber, in particular of Cross Laminated Timber, for the construction of office and education buildings in urban space. Several projects under the UK government "Building Schools for the Future" programme pioneered the concept of "education builds on wood". In this context numerous kindergarten and schools have been built in UK using the solid timber construction technique, many of them in urban space. Approaches to this concept can also be found in Austria, however based and implemented on the initiative of some individuals.

Fig. 2 project „Open Academy", Norwich, UK (left) [8]
project "Bautechnikzentrum TU Graz", Graz, AT (middle)
project "Kinderkrippe Schönbrunngasse", Graz, AT (right), (Foto: Paul Ott)´

Returning to multi-storey residential buildings, it cannot be ignored that, especially in this category, the human being desires nowadays to get 'always wider, longer and higher'[14]. But for the construction of multi-storey residential buildings in timber, it is also valid that, before thinking of comparative and superlative, the basics have to be known. The competition to maximize dimensions (heights) should not be the centre of attention when building with timber (and in particular when it concerns multi-storey residential buildings) but rather an integral way to reach optimization, combined with aspects like

- wider in application
- longer in period of use and
- higher in quality.

After all, the point is to create living space in a way that saves resources on the one hand and complies with minimum requirements, remains affordable and meets the criterion of sustainability on the other hand. This is a challenge that every method of construction has to respond to. And it is not an easy one when prices of land, building costs and rents rise continuously. M. Linz describes in his publication “Neither lack nor excess”[17] the “three steps to sustainability” and calls them

- efficiency (small input of material and energy per product or service),
- consistency (ecologically harmless technologies; compatibility between nature and technique) and
- sufficiency (low consumption of recourses by reduction of demand).

What does this have to do with solid timber construction technique in Cross Laminated Timber? Over the last two decades the solid timber construction technique has succeeded in gaining such a level that it can be offered to architects and engineers as a safe, robust and reliable building method. However the response after the first use was quite often that it is interesting but too expensive for the customer. S. Smith and T. Wallwork address this topic in their contribution “CLT – **C**ross **L**aminated **T**imber or **C**onsumes **L**ots of **T**imber”[16] and make a comparison with steel and concrete. Their contribution deals with efficiency-raising measures around the product Cross Laminated Timber and results in the conclusion that the “CLT product needs to evolve”. This proclaimed improvement in efficiency can only be achieved by research and development. The necessity of such measures is beyond question. Examples of this are:

- Use of the diversity of wood species combined with deploying regional wood resources
- Reduction of the demand on the wood resource by cross-section optimization
- Effort to standardize according the slogan
  “one system – one element – one product”
- Improved production process and coordinated machinery use
- Design and planning principles combined with standardized verification methods

All the above-mentioned measures can be assigned to the aspect ‘efficiency’. Measures of this type are indispensable for a continuous development of the solid timber construction technique. The second aspect ‘consistency’, which in this context refers to appropriateness, is already inherent in the material, wood, due to it being a renewable resource that has potential for recycling combined with many low emission products. To act according the slogan ‘reduce – reuse – recycle’ comprises the three aspects ‘efficiency’, ‘consistency’ and ‘sufficiency’ and – applied to constructions in Cross Laminated Timber - is able to lead to improved and optimized construction systems (e.g. housing).

The next parts of this paper present examples of structural engineering with solid timber construction technique in Cross Laminated Timber, built in recent years or are actually planned in and around the City of Graz. The reader's attention should be turned to the implementation of the measures listed above in improving the efficiency of building activities with CLT. The aim is not only to contribute to a further spreading of this building method but also to show constructive principles to guarantee a high quality and durability of buildings in the solid timber construction technique. These principles, underlying quotations of Professor H. Gamerith [3] (Emeritus at the Institute of Building Construction at Graz University of Technology), should emphasize the necessity of interdisciplinary thinking and acting within the framework of planning a realisation of multi-storey building constructions.

2. Completed or planned construction projects with solid timber construction technique in Cross Laminated Timber in Greater Graz

2.1 Project „social housing Wittenbauerstraße“, Graz

Fig. 3 Top view building 1 (left picture); building 2 (right picture)

2.1.1 Project description

This construction project, completed in autumn 2012, consists of 22 housing units in total (between 60 and 90 m² of living space) that are split up into two buildings (see Fig. 5). In these units, the main structure is constructed in solid timber construction technique with Cross Laminated Timber. They are arranged as separate three-storey structures and made with access via a central situated staircase made of reinforced concrete. In order to enable largely green space underground parking was planned for its inhabitants. The total of the obstructed surface is 2600 m² out of which 1600 m² (approx. 60 %) can be identified as living area.

Project duration was about three years divided into a planning phase of 20 months and a construction phase of 16 months (one of those was the assembly of CLT-elements). Timber construction (specification 'carpentry') , at a cost of €0.7 million, represents a small proportion (20%) of the total project cost of €3.3 million. For cost estimation, therefore, this amounts to approximately €2000 per m² of living area.

After consultation with the constructor and the sponsors of this social housing (the City of Graz and the province of Styria), it was possible, within the framework of the project, to construct the bearing walls of one of the units with CLT made of birch. Because the use of hardwood as a basic material is very innovative in multi-storey building construction, special attention was paid, by the Institute of Timber Engineering and Wood Technology, to production, assembly and the use of these elements in their form of finished wall structure.

This was achieved by issuing an "approval on an individual basis"; within this framework, material tests of the basic material, as well as tests of the finished products, were conducted at Graz University of Technology [15]. For further quality control, spot core samples were taken from completed wall elements (see Fig. 4). The samples were subsequently tested for delamination according to EN 391:2001 [11].

Fig. 4 test configuration for bending test birch-CLT (top left) [15]
taking of core samples on the spot for delamination tests (down left)
wall of birch-CLT – visual quality (right)

To evaluate the building physics behaviour of the walls, the Institute of Timber Engineering and Wood Technology of Graz University of Technology scheduled two control cross-sections (one in birch and a one meter wall strip in spruce-CLT for reference); these were used to monitor and record, by means of installed sensor technology, the change of the relative humidity (thus wood moisture) and temperature across the entire cross-section of the wall. First results are published [9] and a more detailed investigation will be presented at the "RILEM International Symposium on Materials and Joints in Timber Structures" taking place in October 2013.

The aim of using birch wood for the production of CLT was to demonstrate the potential of wood species that are available locally and/or in abundance to become new resources for the production of CLT.

2.1.2 Principle of the structural system

As already mentioned in chapter 2.1.1, CLT elements were mainly used for the load transfer beside the components made of reinforced concrete (foundation and staircases). Because these elements, used for walls and floors, are able to carry both horizontal and vertical loads into the foundation and the floor plan and elevation of the separate units fulfil all principles of stability, the three-storey buildings, are paced around cores but form independent load bearing structures. The central core serves only for access to the units and as the position for "cellar" storage for the units. Using this, it was possible to de-couple the units from each other and from the unheated staircase, acoustically and thermally. Movement joints between the CLT frame and the concrete core are used where necessary to allow differential horizontal movement.

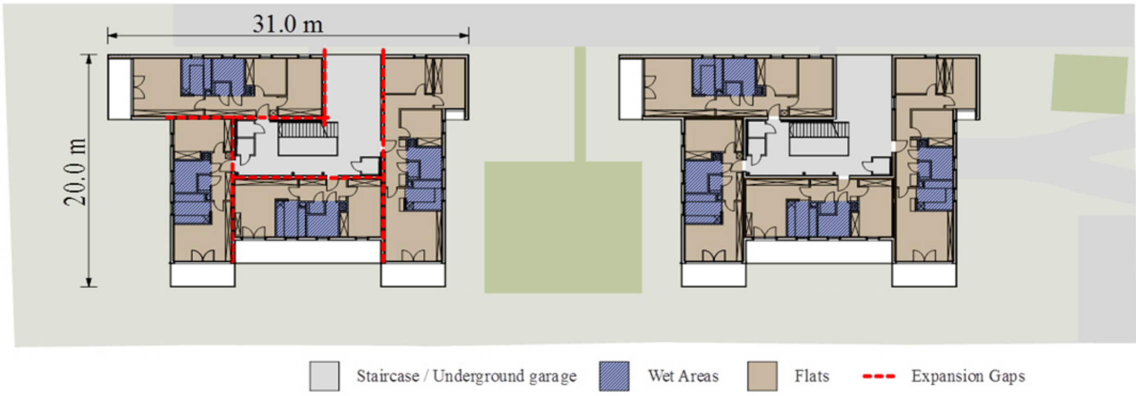

Fig. 5 floor plan of the plot with function sharing in different colours

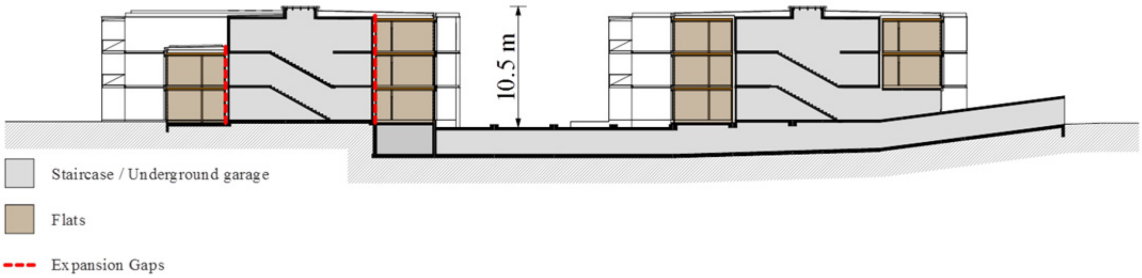

Fig. 6 cross section of both buildings

A one-span system with a width of about 5 m for all units considerably simplified the structural design, as well as the construction (see Fig. 7). The verification of vibrations at serviceability limit state (SLS) was the decisive factor for dimensioning the necessary thickness of elements (5-layered, 198 mm, l/h ~ 26). With a calculated eigenfrequency of $f_1 = 6.1$ Hz, according to ÖNORM B 1995-1-1/NA:2009-07, verification for the chosen element was not fulfilled and, as the maximum depth for 5-layered elements is 200mm, the problem had to be investigated more in detail (7-layered elements should have been avoided). An initial new calculation according to the Hamm/Richter method [7] gave a result of $f_1 = 7.2$ Hz. The main reason for the difference, between the two first eigenfrequencies, is that the active vibrating mass is ascertained for both methods in a different way (ÖNORM B 1995-1-1/NA:2009-07: gravity loads incl. quasi-permanent parts of imposed loads; Hamm/Richter: gravity loads only). Because the newly calculated eigenfrequency was between "normal" (6 Hz) and "high requirement" (8 Hz) [7], the next step was to make an agreement with the building owner to carry out vibration tests during and at the end of the construction progress, in order to verify the calculated eigenfrequency in situ. This was made within the scope of a master thesis at Graz University of Technology [6]. In the master thesis vibration characteristics of CLT-floors were examined on the basis of this construction project. The lowest (measured in different parts of the bearing structure in the building), and therefore essential first eigenfrequency, resulted to 12.9 Hz and exceeded, by more than twice, the 6.1 Hz according to ÖNORM B 1995-1-1/NA:2009-07. This indicates the discrepancy between calculation-verification and measurement and points to the need to continue to research on the vibration behaviour of CLT-floors, especially when taking into consideration the clamping effect caused by wall loads.

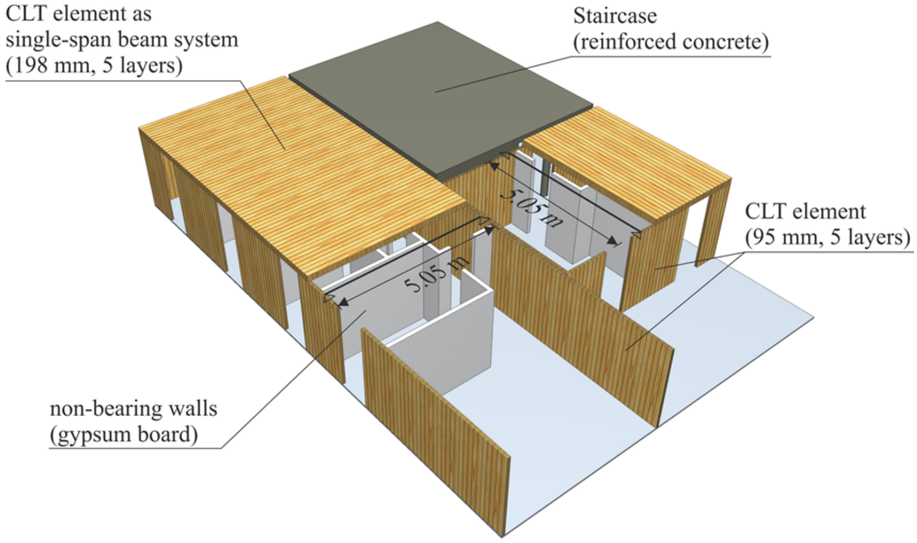

Fig. 7 floor plan with span proportions

In considering the load, g_k , for the floor assembly shown in Fig. 11, a traffic load of $q_k = 3.00$ kN/m² (incl. gravity loads of removable separating walls) and is used in the Hamm/Richter method ("normal requirement") for the calculation of vibration for CLT assumed to be single-span beam systems, with the ratio of span to thickness is generally $l/h = 25$ to 30**.** The range of validity for this ratio is limited to spans of around 6.50 m, which should be sufficient for spans in housing.

In addition to floor and roof systems, the construction of all bearing walls (according Fig. 7 only external walls are bearing) was made with CLT. Because of the advantages, with air tightness and fire behaviour, the choice was taken to use a five-layered CLT-element. The smallest possible thickness of element with 95 mm (5 x 19 mm) from the producer was decisive, not the ULS or fire (REI 60) behaviour.

In view of raising efficiency when building with CLT, when positioning of the load-bearing walls at the planning stage, two essential principles were obeyed. All wall elements should be designed without large openings of full storey height, with the effect that the offcut during production could be reduced to a minimum (see Fig. 8). Positioning of the walls on top of each should ensure that horizontal loads (wind, earthquakes) are transmitted directly to the foundations, thus significantly reducing the loads on fastening the elements, and easing their design.

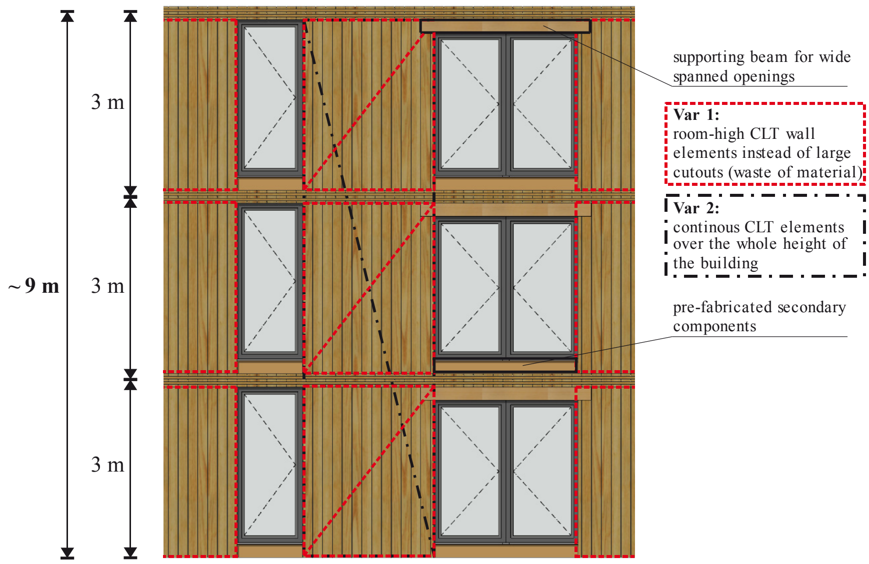

Fig. 8 positioning of wall elements in elevation

As shown in Fig. 3 and Fig. 5, a balcony or a terrace was planned for each unit. In contrast to the widespread use of cantilever floors serving to support balconies, for this project it was decided to make all extensions in form of secondary constructions (in this case made of steel). On the one hand, this was for reasons of building physics (to avoid thermal bridges respectively moisture and air transfer into the structure), and on the other hand it was for structural reasons (due to different life cycles of balcony/floor allowing the possibility of replacement and having no requirement for height compensation because of the assembly of the floor). Or with the words of H. Gamerith [3]:

„The faster a part erodes, is used up or can be damaged the easier it should be reachable to repair or replace "

Fig. 9 gives an overview of the balcony system. It's a prefabricated element and connected selectively with self-tapping screws to the primary supporting structure, entirely in line with the idea to mount and demount quickly.

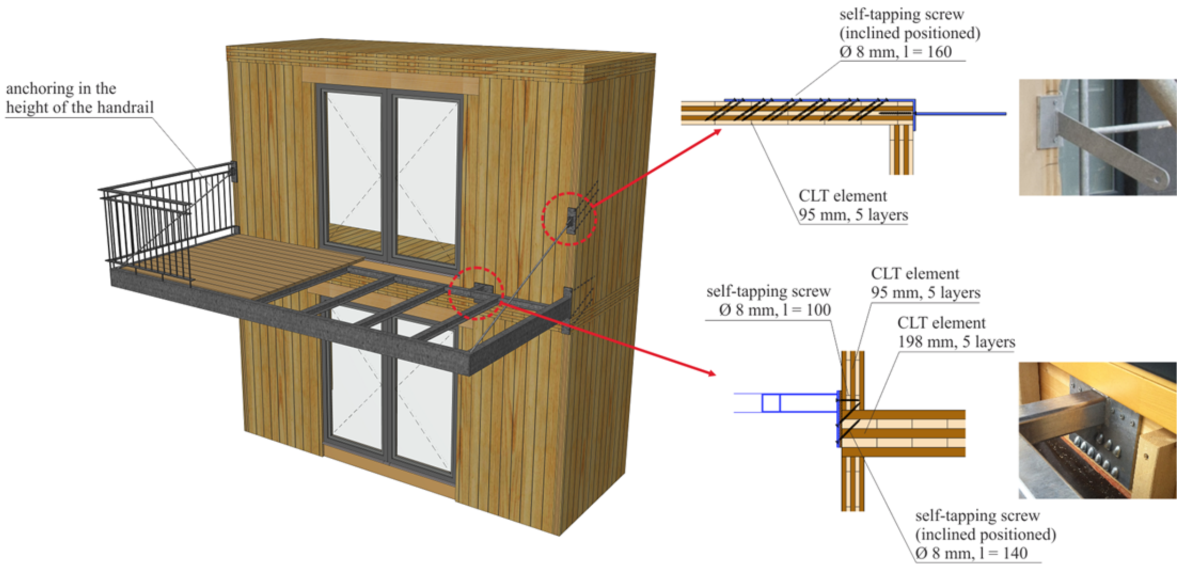

Fig. 9 schematic illustration of the balcony

The on-site installation of linear timber products is quite cumbersome compared to the assembly of large-sized CLT elements and can be avoided by means of precise planning right from the start. Only the lintels for big wall openings (double window elements) and the supporting members where the floor span direction changes in one of the four unit types, had to be carried out in form of laminated timber beams. But even these lintel beams could have been avoided by taking into consideration the two-dimensional structural behaviour of CLT and by dividing the elements in a suitable way (perpend joint not in the window area) (see [4]). After all the whole timber volume consists of only one percent of linear bearing components.

Because of the relatively low height of the structure, its position in a not earthquake prone area and the already mentioned positive design of elevation, conventional joints have been used for the connection of wall and floor elements:

- Connection wall:underside-of-floor or wall:top-of-floor:
  Angle brackets in general and hold-downs in horizontal highly stressed bearing walls, situated at the ends of the wall
- Connection floor:wall, wall:wall (butt joint) and floor:floor (stepped fold):
  fully threaded self-tapping screws (inclined arrangement)

In view of the different requirements of solid timber construction, the use of more expensive hold-downs instead of angle joints for the transfer of uplift forces at the end of walls, a principle taken from timber frame construction, should be reconsidered. Within the framework of a research project at the Institute of Timber Engineering and Wood Technology, project comparative experiments of horizontally stressed CLT shear walls with different joining techniques for the connection joint have been carried out (see [5]). These experiments form the basis of the following statement: The difference in load bearing of walls with hold-downs at the end of walls compared to those using angle brackets justify in no way the additional costs in joining technique.

As already mentioned earlier in the paper, movement joints have been devised to allow for differential horizontal movements between parts of the structure. They are presented in the next figures.

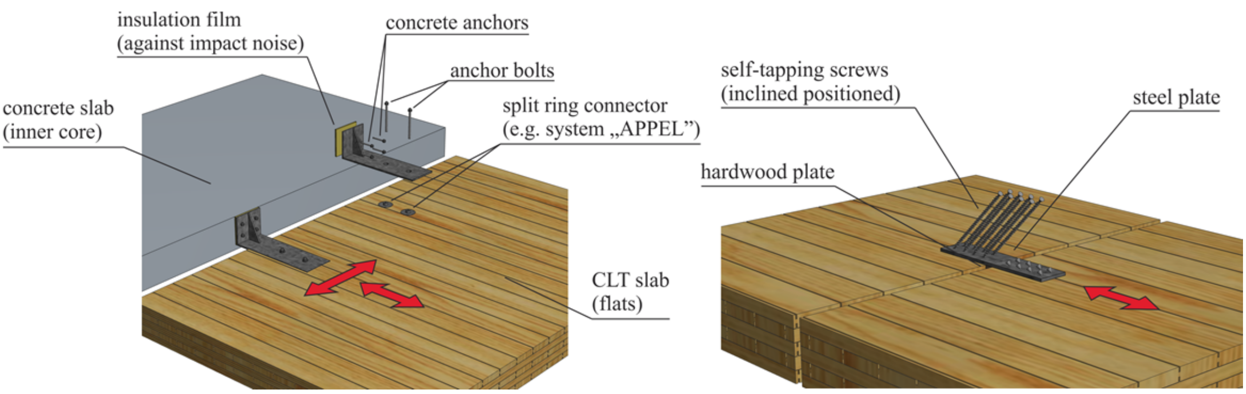

Fig. 10 left: connection of CLT floors to the inner core (each storey)
right: connection of CLT to CLT (at roof level)

In conclusion Fig. 11 summarizes the design principle of the building in solid timber construction, applied and explained in this chapter.

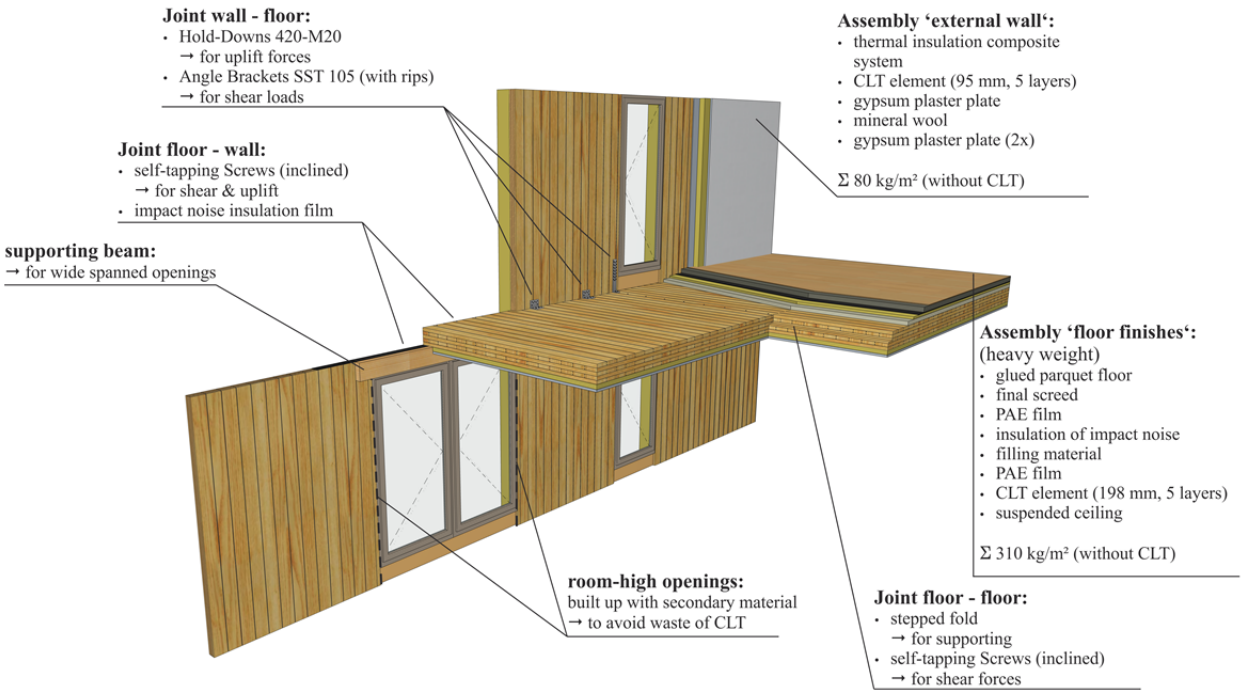

Fig. 11 illustration of CLT supporting structure for this project

2.1.3 Essential constructive aspects

As already briefly discussed in chapter 1, if multi-storey buildings in solid timber construction technique with CLT to be built it is essential to guarantee the quality of the construction over the whole lifetime cycle of the structure. This corresponds to the basic requirements of durability according to EN 1990:2002.

It is known from experience, that if the drainage of surface water is not carried out properly, due to damage in waterproofing and the uncontrollable increase of moisture content in the load bearing construction, the result can have very negative effects on the life cycle of the supporting structure. Particularly affected are horizontal surfaces, such as floors and of course flat roofs. To avoid this possible structural damage, particular attention should be paid to the construction of such components. At this point it is worth to taking a closer look at the flat roof construction because there are, according the opinion of the authors, some positive problem-solving approaches available.

As Fig. 12 shows, the roofing system is in principle a back-ventilated and green flat-roof construction with a bearing layer of CLT (186 mm, 5-layered). The back-ventilation is the core aspect of the system and fulfils two essential functions. Due to the permanent air change in this zone, it provides, on the one hand, a certain degree of protection against overheating of the top floors during summertime, and ensures, on the other hand, that, in case of unexpected moisture of the wooden under roof, construction can dry out. Surface water is normally collected in the highest layer (layer of vegetation), with external gutters (and downspouts) draining into the soil. A second protection layer, situated behind the back-ventilated level, serves as additional protection layer against moisture for the supporting structure, in case of damage.

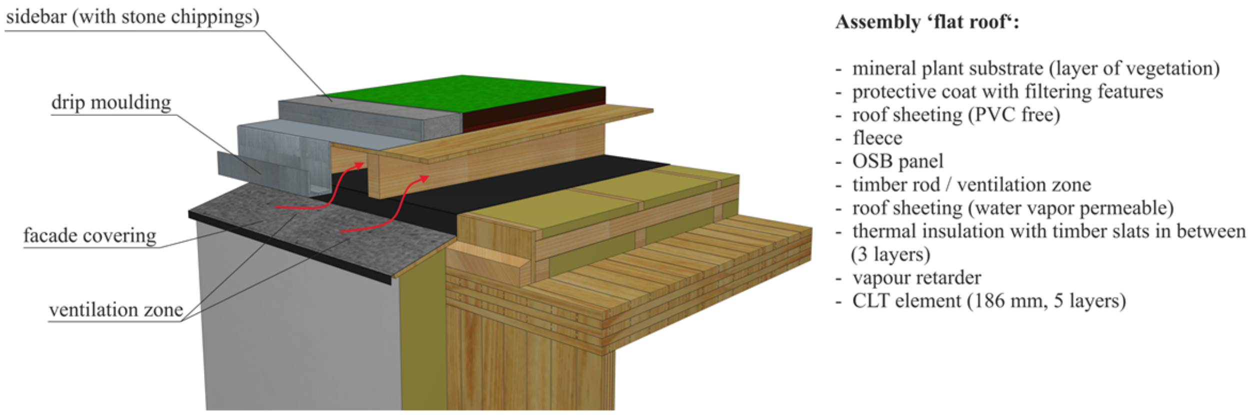

Fig. 12 Assembly of the flat roof construction in CLT

For future construction projects, it would make sense to construct back-ventilation inclined and at accessible height. This method would increase the cross section of ventilation and thus the air renewal rate, and enables a permanent control of the drainage levels in a non-destructive way. According H. Gamerith [3] it should be considered that:

"Constructions should be drafted in a way that they are easy to maintain, to control if they are fully functional and easy to repair in case of necessity (e.g. fastening technology, flat roof construction, installation technology etc.)"

As the major part of the exterior walls is equipped with an external thermal insulation composite system (ETICS) the combination of such a system and CLT elements as load-bearing structure should be enlarged upon at this point. As already included in the designation, these are system solutions that offer an economical alternative to back-ventilated construction. Because of the lack of a normative standard, they are regulated by European Technical Approvals (ETA), which indicates, besides the components "surface coating", "reinforcement", "insulating material" and "fastening" also suitable base coat (if mineral then brick or concrete wall; if organic then wood-based panel material). When studying these approvals it can be seen that many thermal insulation composite systems, especially those with synthetic isolating material such as EPS, are decidedly not approved for structures consisting of plate-shaped wooden composites.

Other systems, which were especially designated for timber base coats (commonly with mineral or organic insulation products), limit them to certain specified products, so that CLT elements are only allowed in a few cases. These cases, found in the frame of investigations concerning this topic (without making claim to be complete), are systems using fibreboards as insulation product. In contrast to that, external wall assemblies in CLT, combined with ETICS, using mineral wool panels are commonly used in present and – according to the opinion of the authors – proven to be suitable. The grey area in law, caused by the missing approval, should be kept clearly in mind however. To summarise the following cite by H. Gamerith [3] is appropriate:

"Reliable detail systems are safer than unreflected in-house developments."

2.2 Project "Wohnen am Fluss (Living on the river)", Graz

Fig. 13 image of the project (preliminary draft) [1]

Fig. 14 image of the project (preliminary draft) [1]

2.2.1 Project description

In contrast to the already finished construction described in section 2.1, this project is being planned in present. The developing process is based on a pre-investment study [1], which was performed by three architects, in cooperation with three industrial firms, under the coordination of the Institute of Timber Engineering and Wood Technology at Graz University of Technology in the year of 2012.

As shown in Fig. 14, seventeen buildings, with five to eight storeys and containing approximately 400 flats, are designated to be erected in solid timber construction with CLT. This would lead to a living space of roughly 30,000 m², with overall costs of €60million (internal assumption). As a consequence of this high value the investor plans to erect the buildings in three phases of construction, which will last the whole decade 2010-2020.

2.2.2 Principles of structural design

Besides extensive investigations concerning the architectural feasibility with a special focus on urban requirements, alternate structural designs were part of the pre-investment study mentioned above. The following sections will demonstrate these results, on the basis of a representative building type.

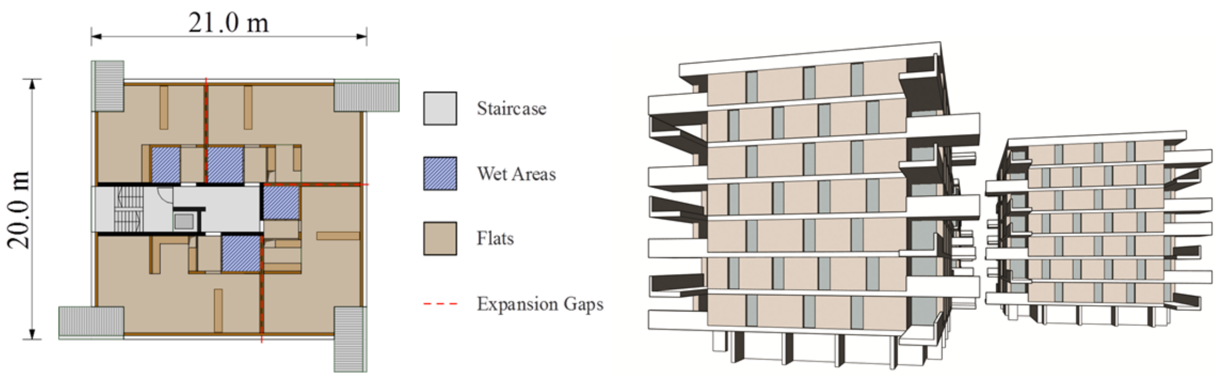

Fig. 15 Floor plan with function sharing in different colours (left)
Impression of the chosen building type (right) [1]

As shown in Fig. 15, many principles to increase the efficiency and building quality, described in section 2.1.2, have already been considered in this preliminary draft version. Thus, two-span systems (160 mm, 5-layered; see Fig. 16), with consistent widths and beams as supporting members are used. Furthermore, there are room-high wall segments, without openings, as well as pre-fabricated balcony systems as secondary structures. In contrast to the project described before, not only external but also internal walls and, especially, separating walls of the flats are designated to be part of the bearing structure. Those internal and separating walls will provide enough horizontal stiffness and will give more freedom for creative design of the external walls. The inner core (again in reinforced concrete because of local fire protection requirements) is in this case also planned to be part of the bearing system against horizontal loads (especially wind loads).

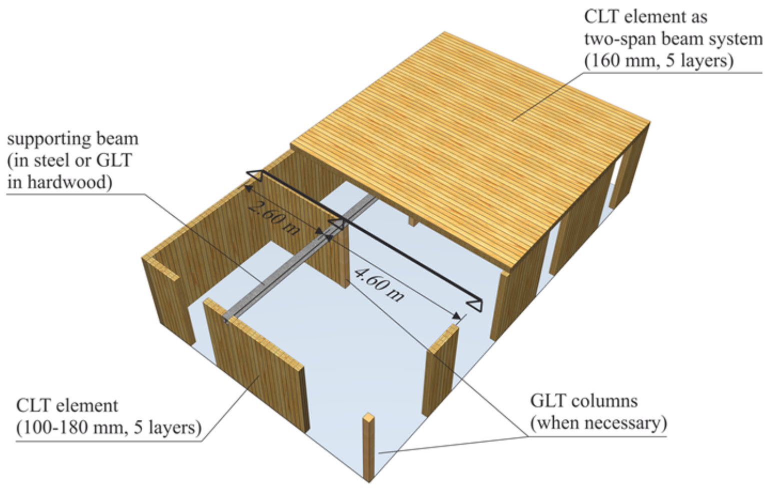

Fig. 16 Floor plan of the floor system of one representative flat

Because of the height of the 10-storey building, high horizontal wind forces have to be considered in the design of connections. The hold-downs and angle brackets used for the project in section 2.1.2 are useless if their number exceeds a certain value per running meter wall joint. Dowel-type connections with local steel plates between the CLT wall elements could be used instead, especially for the joints in the first storeys; see Fig. 17.

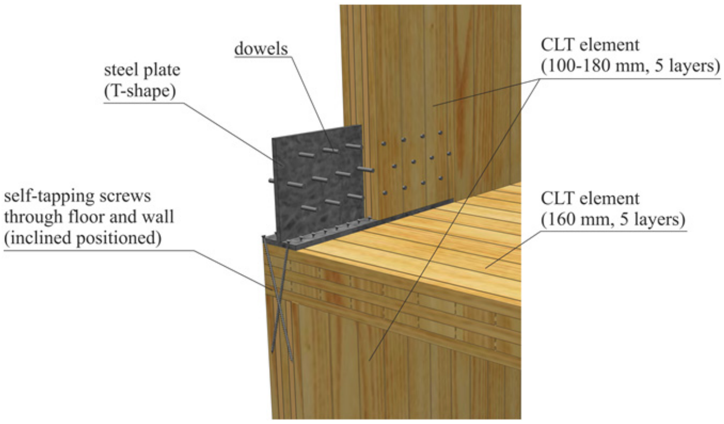

Fig. 17 Dowel-type connection with steel plate in between the wall element for efficient joint design

As shown in Fig. 16 and Fig. 17, the thicknesses of CLT wall elements range from 100 to 180 mm (increasing from the top to the bottom). The reason for these dimensions can be seen not only in the surcharge resulting from floor and roof systems, but also in the criteria for fire protection of R90 (fulfilling a structural capacity during 90 minutes burn-off) given for buildings with building class 5 in Austria, or rather the resulting economical optimisation of the ratio of covering to element thickness.

2.2.3 Essential constructive aspects

Fig. 5 in section 2.1 also gives insight into the arrangement of the wet rooms of the two described buildings. It is obvious that all of them are situated centrally in each flat. Consequently all service pipes containing water run through the timber construction. In case of a defect this situation may lead to unseen and uncontrollable moisture ingress in the bearing structure. Fig. 18 represents this scenario to emphasise the problem.

Fig. 18 Damage of the CLT bearing structure caused by moisture ingress in a wet room

Because of the high costs caused by rehabilitation works, such damage needs to be avoided in multi-storey residential buildings erected in solid timber construction with CLT. In the worst case four flats may be affected by a single damage. Therefore, to provide the durability of the timber construction against moisture ingress, it is important to consider this problem in the course of developing the preliminary draft

This aspect has been considered in the context of the pre-investment study and for the present, resulted in the arrangement of wet rooms around the building core of reinforced concrete. This first approach enables the main lines to be run between the transition zone of reinforced concrete:CLT; see Fig. 19.

By adjustment of channels, with possibilities for observation (or with a simple sensor system) beneath the water pipes, damage may be easily detected and repaired by removing the shell construction. Wet rooms, or other areas with a need of water supply (kitchens, etc.), which are not situated close to the core, may be reached by duct located in the suspended ceiling. Possibilities for observation of the system would be given by providing inspection doors in the ceiling. Furthermore, possible damage that could be noticed easily would only affect the non-bearing part of the lay-up of the ceiling. According to H. Gamerith [3] it can be said:

"Because of different service lives, carcass and extension have to be conceived separately from each other. Especially supply and delivery pipes containing water (added by G. Schickhofer) have to be i) creatively integrated into the building, ii) structurally disintegrated and iii) accessibly organised."

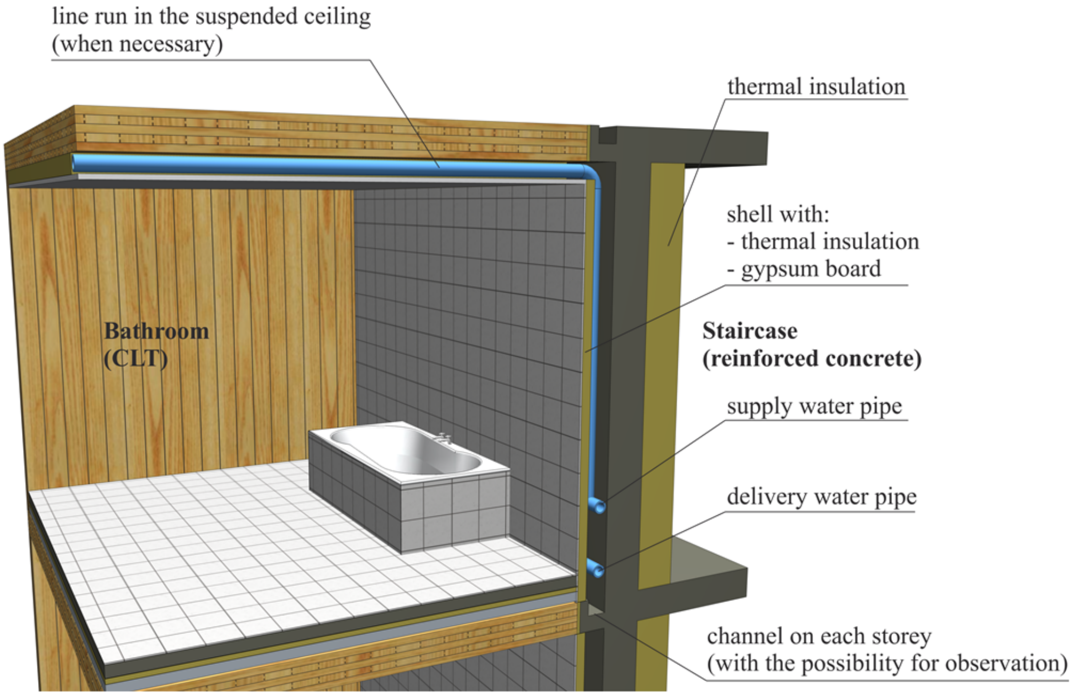

Fig. 19 Possible solutions for line runs in flats of CLT

2.3 Project „bio-impuls centre Styria“, Graz

Fig. 20 image of the project “bio-impuls centre Styria”, preliminary draft [2]

In contrast to the multi-story buildings described in sections 2.1 and 2.2, a commercial building in solid timber construction with CLT is presented here. The main reason for choosing this project is to demonstrate the application of optimised CLT slab-systems to wide spanned floors, which can rarely be found in residential buildings.

2.3.1 Project description

This project includes the erection of an office, administrative and event building and has been started in the second half of the year 2012 by organising an architectural competition. The image presented in Fig. 20 shows the preliminary draft of the winner of this challenge.

According to this design proposal, the building is going to contain two storeys with separate functions. The ground floor will be used for events, including an exhibition and presentation hall, an entrance area and storage rooms. On the first floor, administration offices and meeting rooms have been planned. On the basis of the floor plans and the cross section given in Fig. 21, an open interior design, leading to wide span floor systems of up to 10 m, has been created for both storeys. The systematic solution for this building, which makes use of CLT, is provided in section 2.3.2 for these situations.

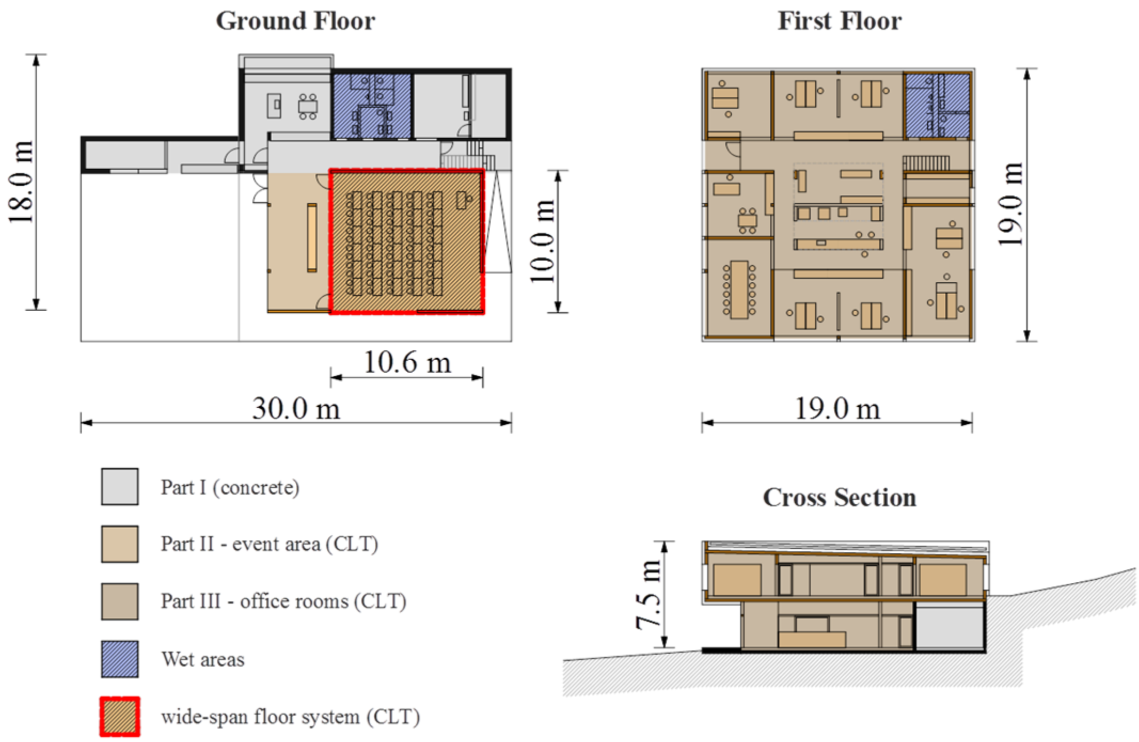

Fig. 21 Floor plans and cross section of the preliminary draft [2]

Based on the results of the architectural competition, the planning team is currently working on the development of the building. Commencement is not earlier than in the beginning of 2014. The overall costs are roughly estimated to be €1.3million.

2.3.2 Structural concept

By considering an estimated weight of 200 kg/m² for the assembly of the floor and traffic loads of 3.00 kN/m², the thickness of this 10 m span, 9-layered CLT element would amount to 360 mm, controlled by SLS-verification. Consequently, this unusual dimension would cause high manufacturing costs and problems with the room height; hence, this system is hard to accomplish. Furthermore, the 1st eigenfrequency of 4.3 Hz, calculated according to the method of Hamm/Richter [7] for this one-dimensional system, is far too low to fulfil the verification of vibrations and, therefore, an optimised bearing system is needed. Fig. 22 and Fig. 23 show two possible solutions for this situation. The spatial trussed structure given in Fig. 22 not only reduces the span length (the point support separates the system into three parts), but also enables two-way spanning structural behaviour of the CLT-element. Thereby an optimised lay-up of the element is assumed. In contrast to that, Fig. 23 demonstrates a GLT-CLT ribbed plate with a strict orientation in one direction. In this way, the CLT-element's dimension is minimised and the rigid bonded GLT members are located in the suspended ceiling.

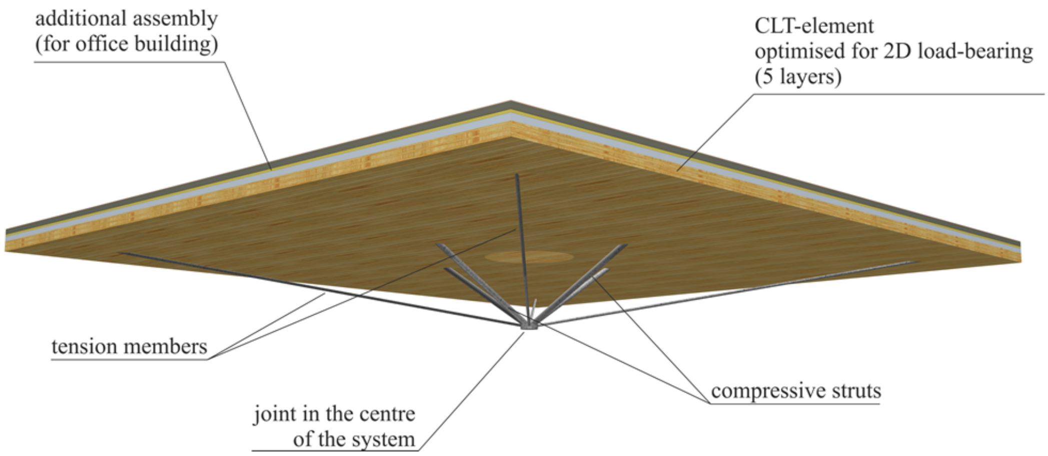

Fig. 22 Spatial trussed CLT floor system

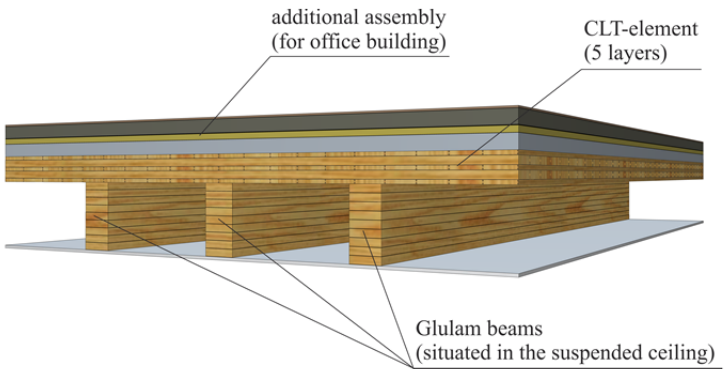

Fig. 23 GLT-CLT ribbed plate

Similar structural solutions are the roof construction of the Centre of Building Technology at Graz University of Technology, which has been erected between 2000 and 2001 [10]; see Fig. 24. If these systems are used for floors (and not for roofs), it is necessary to verify their serviceability, with a special focus on vibrations.

Fig. 24 Special solutions for the centre of Building Technology at Graz University of Technology:
Trussed CLT system as roof construction for the great testing hall (left)
GLT-CLT ribbed plate as roof construction for the offices (right)

2.4 Outlook regarding further projects

In addition to the projects demonstrated in the previous sections, in which the Institute of Timber Engineering and Wood Technology at Graz University of Technology has been involved, the project “Peter Roseggerstraße” will be briefly described in this section. This planned construction contains 12 buildings with three, four and five storeys and is going to be realised to the west of Graz. Three phases of construction are going to include 143 flats overall. Applied concepts of alternative energies are worth mentioning in this context [22].

Fig. 25 image of a five storey residential building of the project “Peter Roseggerstraße“[22]

3. Conclusion, outlook and acknowledgements

As well as in international overview, in the course of describing selected projects, which have been partly completed in Greater Graz, this report also attempts to represent a snap shot of using Cross Laminated Timber as basic material for constructing multi-storey buildings as well as office- and administration buildings Rather than simply presenting the existing opportunities for top quality, state-of-the-art approaches in timber construction, the focus of attention is on demonstrating principles of (conceptual) design in order to increase efficiency and guarantee high levels of performance throughout life. .

To summarise, these principles are presented again without making claim to be complete:

- use of superabundant and/or local wood species to produce Cross Laminated Timber as an opportunity to make effective use of resources;
- conception of uniform structural systems for regular floor plans and elevations (floor spans, continuous stiffening walls) as well as finding special, innovative solutions for specific situations (trussed systems, ribbed plates and box girder cross sections);
- arrangement of almost full-faced floor-to-floor bearing walls in Cross Laminated Timber to avoid cutaways and, hence, material loss;
- concept of adaptability of structure, in terms of secondary load-bearing structures, which are replaceable and weather-proof;
- provision of approved system solutions for the main assemblies “panel” and “floor”;

– interdisciplinary thinking and acting across multiple building phases (carcassing – extension – method) in the course of designing and constructing critical building parts (flat roof, wet rooms);

"Timber is the new concrete", is the slogan used by architect A. de Rijke. Based on his fundamental experience with Cross Laminated Timber, this quotation can be seen as a prophecy of new market segments and field of application. In fact, a nine-storey structure, correctly dimensioned in terms of ULS and SLS and built in timber solid construction with CLT, shares the same characteristics as concrete construction. Panels, floors, roofs and staircases are massive. Wooden floors have no vibration problems, but show similar features compared to floors of reinforced concrete and even have a similar thickness due to their low density. If the wood had the same colour as concrete, one could hardly distinguish between them. However, there are some substantial differences: Wood is a natural product and, consequently, does not share the same strengths and weaknesses with concrete. Wood reacts to high moisture conditions by changing its features. In case of continuously high moisture conditions, wood loses its substance and load-bearing capacity. Therefore, in the context of designing, it is of utmost importance to guarantee a permanently dry wood structure. This also implies the need for building services appropriate to timber construction. To summarise, this means that (a) water-bearing utility- and waste disposal lines need to be separated from the timber construction (b) the details for panels, roofs and floors need to be compatible with building physics. One point cannot be stressed enough: "Timber is **not** the new concrete".

Added to the necessity of finding permanent, efficient and economic system solutions, the focus now shifts to vibration, mentioned in section 2.1.2; to the development of a connection technique related to this type of construction and to a detailed analysis of new structural systems to cope with wide spans in the context of office- and administration buildings (especially with regard to the functional efficiency).

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