BEAM AND POST SYSTEM FOR NON-RESIDENTIAL MULTI-STOREY TIMBER BUILDINGS – CONCEPTUAL FRAMEWORK AND KEY ISSUES

Gabriela Tlustochowicz[1], Abdy Kermani[2], Helena Johnsson[3]

ABSTRACT: In Sweden, there has been a long tradition of using timber in the construction of housing and in recent years, timber structural systems are increasingly used in multi-storey and large span buildings. The main focus of the majority of timber construction industries has been the development and utilisation of components, systems and construction techniques for the large market of residential buildings. Moelven Töreboda AB, a Scandinavian glulam manufacturer, has developed a beam and post system named "*trä8*" with the intention of filling the gap in the market for non-residential multi-storey buildings in timber. The developed timber beam and post system offers many advantages over other construction systems as well as being an attractive and versatile system for meeting clients' and users' expectations. This paper examines and provides guidelines on key issues in the development of the timber beam and post system for multi-storey non-residential buildings and deals with its structural system, assembly method and weather protection.

KEYWORDS: Beam and post system, Multi-storey timber buildings, Building assembly, Weather protection

1 INTRODUCTION

The beam and post system is an old and well established building system which has been extensively used in steel and concrete structures and to a lesser extent in timber structures. Most probably, it is one of the oldest building systems [1] initially utilising the natural anatomy of trees: trunks as the main bearing elements and branches for the secondary members. Along with the increasing requirements from the developing housing industry after the war, timber lost its prime position as a viable structural material for this system. Instead, it has evolved into simple systems albeit based on similar principles; examples include Skeletal Frameworks, Balloon Frames and Platform Timber Frames which are derivatives of balloon framing.

Currently, when flexibility of the construction shape is often requested and environmentally friendly materials for construction are highly valued, the beam and post system utilising engineered wood products, which permit large spans, architectural freedom, simplicity and flexibility of the construction, finds its place on the market.

The use of engineered wood products makes the beam and post system a feasible option for multi-storey buildings in timber. The system is based on the rectangular modules, with maximum spans of 8 metres (hence the name trä8=timber8), which offers flexibility, variety and simplicity of building design, Figure 1.

The system is suitable for most types of non-residential buildings, filling at the same time the gap in the niche Swedish timber construction market. The system offers an economically advantageous and ecological alternative to concrete or steel based systems. Moreover, the positive economical aspect is increased by the fact that the system is standardised and optimised, which lowers the average design time for each individual project utilising the system.

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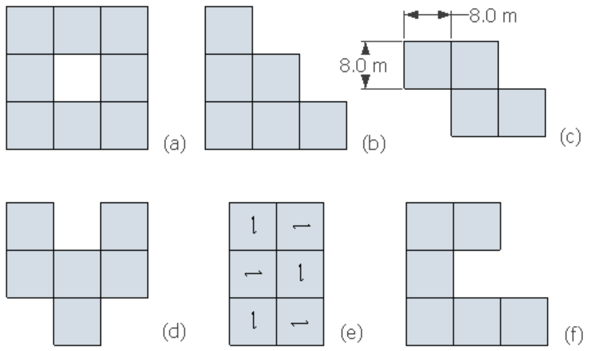

Figure 1: *Examples of possible building shapes*

2 STRUCTURAL CHARACTERISTICS

Since the system *trä8* is in the development phase, the possibilities for its areas of application are not yet fully explored. The developed technologies and system solutions have placed *trä8* in a prime position for use in multi-storey buildings up to four storeys high – classified as medium-rise buildings. The ambition is to utilise the system for much taller and longer-span structures; and at present a number of special solutions required is the subject of development.

2.1 SYSTEM COMPONENTS AND CONCEPT

The timber beam and post system *trä8* comprises a range of products involving elements of the main structural load-bearing system, such as continuous columns, beams, prefabricated stabilising elements (composite walls), prefabricated floor cassettes and roof elements, Figure 2. These are produced off-site by the systems' manufacturer to be delivered to the building site just before assembly. The floor elements are to be placed in a 'zigzag' configuration, so that the working direction of floor elements of two neighbouring modules are perpendicular, Figure 1e.

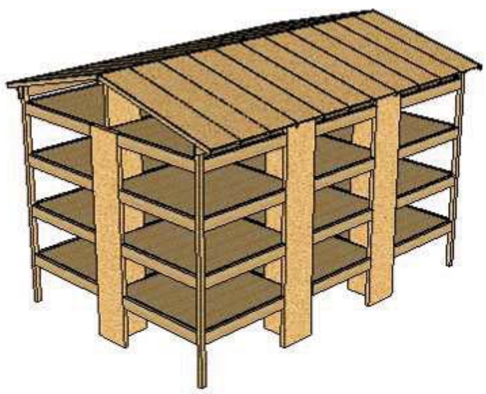

Figure 2: *Illustration of the building system structure*

No load bearing inner or outer walls are included in the system, which adds to the architectural competency of the system. This feature of the system enables the application of large glass areas in the facade and also enables the creation of large open inner spaces, which can be very advantageous e.g. for commercial buildings and for conference halls in office buildings.

2.2 MATERIALS

The newly developed system *trä8* involves the application of two engineered wood products, glued-laminated timber and laminated veneer lumber (LVL), with the commercial name Kerto. The main elements of load-bearing structure (beams and columns) are made of glulam class L40 (according to Swedish designation). The remaining prefabricated elements of the structure such as floor and roof cassettes, and stabilising elements utilise Kerto LVL, produced in two types Kerto-Q and Kerto-S, utilised for different purposes.

3 STABILISATION STRATEGIES

3.1 MULTI-STOREY TIMBER BUILDINGS

Since timber structures are considered to be light-weight in comparison to steel and concrete structures and do not have the mass to provide the necessary stabilising force for the building, structural stability is one of the key issues for these buildings that requires careful attention. Action of horizontal forces such as wind can cause large deformations in timber structures and can be highly inconvenient for the inhabitants. The problem becomes more severe with increasing number of floors.

Conventionally, in low-rise buildings, two main approaches are utilised: diagonal bracing and shear walls. Residential low-rise buildings are often stabilised through shear wall action, where the sheathing (in most cases OSB or plywood) nailed or screwed to the timber frame assures a sufficient horizontal resistance of the building. Often, this method appears to be the most effective and economically advantageous, since it assures relatively ductile performance and no expensive materials or connectors are used. In industrial buildings, where the number of windows are generally less and the aesthetic issues are not as important as in domestic buildings diagonal bracing can be utilised, either being made of timber members or steel chords. However, sometimes it can be an intentional architectural feature to make the stabilising elements of the structure visible (Figure 3). In some cases, mostly in industrial applications, also stiffening in one direction can be realised through frame action (moment resisting connections).

Figure 3: *Application of diagonal bracings combined with steel rods in the office building*

When dealing with taller structures it is necessary to assure the users of higher storeys a good comfort against possible horizontal deformations in the structural system. For these structures, the above solutions must be designed in the serviceability limit state to limit displacements. A few structural solutions can be adjusted to be applied in multi-storey timber buildings to fulfil the high demands put on their stabilising systems [2].

The shear actions in tall buildings are often transferred from roof systems, walls and floor diaphragms onto the foundations via a system of effective connection systems. However, the transfer of loads, in some cases, requires special solutions; for example, multi-layered (cross-laminated) timber panels can be used instead of the more common nailed or screwed sheathing boards to limit excessive horizontal deformation.

Another alternative can be to use the stair cases or elevator shafts, often constructed in concrete, as the stabilising mechanism for the whole building. Unfortunately the presence of the concrete shaft inside a timber building may make it visually as well as environmentally unattractive. Also, such construction methods could introduce problems due to differential settlements in the materials.

In the systems based on volumetric elements, the basic shear wall action is utilised, as volumetric elements are manufactured as light frame systems. The main problem for this system is that the joints between the modules must be robust enough to provide satisfactory transfer of shear forces. In addition, a reliable anchorage to the ground must be provided to prevent the uplift of light structures.

3.2 BEAM AND POST SYSTEM

The structural system introduced in this paper, is based on a modular system of beams and columns connected by theoretical pins requiring a very strong and reliable stabilising system. The argument of building ecological structures is crucial for the system; consequently the possibility of using concrete structure for lift shaft or stair cases is not taken into consideration. Moreover, the system is planned to be used for non-residential buildings, which for example in office buildings, puts a high demand on a stabilising system to enable large openings or glass areas.

The demands put on the system's flexibility and functionality are high, hence the stabilising system should be well-designed, reliable and robust. The concept proposed here is based on the stabilising prefabricated walls built of a glulam skeleton with Kerto-Q boards glued and screwed onto its both sides, cross-section on Figure 4.

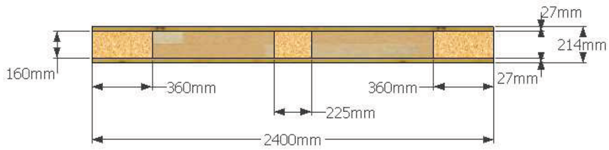

Figure 4: *Cross-section of the stabilising element*

The boards used for sheathing maximises the use of the Kerto production width decreased by 100 mm to comply with Swedish transportation rules, resulting in 2.4 m width. The plane stabilising elements are to be joined into desired configurations, T-, L- or X-shaped, Figure 5. Elements produced in this manner will have large lateral load-bearing capacity and stiffness, and can satisfactorily fulfil the stabilising function in a four storey building. The areas under development are the anchorage system for these elements and connection between elements.

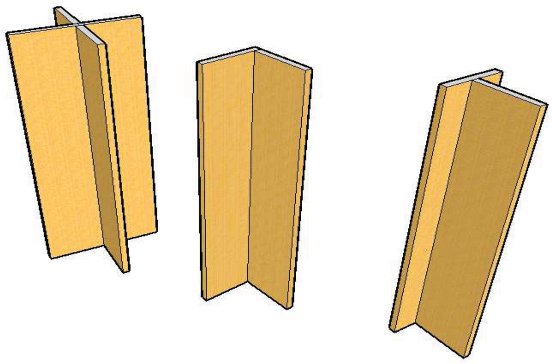

Figure 5: *Possible configurations of the stabilising elements*

4 ASSEMBLY METHOD AND WEATHER PROTECTION

4.1 GENERAL

One of the very important issues related to using wood as a structural material is its sensitivity to moisture and, generally speaking, weather exposure, especially during the assembly phase. Throughout centuries this property has caused a lack of trust in the durability of timber structures and scepticism from the construction industry.

It is important to emphasise that not only timber is sensitive to moisture, but so are other organic materials used in construction such as gypsum or insulation materials. Erection of timber buildings under "open-air" conditions, especially in bad weather conditions, may cause moisture to be encapsulated within layered construction materials to develop during service time into a harmful biological threat. With regard to these facts weather protection of the construction site for timber structures is preferred. Furthermore, a barrier creating a beneficial working environment is desirable.

The problem of moisture sensitivity of wood products can be minimised to some degree by applying appropriate preservatives and ensuring proper detailing (chemical and physical protection). However, this kind of protection can only be efficient up to a certain level of moisture content and or humidity in the air (heavy rains and very humid climates might not be covered)[3].

For smaller houses the weather protection concept leads to an increased degree of prefabrication. Buildings (e.g. villas) can be entirely manufactured off-site and then transported to the destination location and the assembly including the roof can be completed in half to one full working day. In this case, the additional conditions for successful moisture protection of the structure are: a dry concrete plate and protection of the unassembled (waiting/stored temporarily) elements. However, this method does not apply for non-residential buildings or multi-family houses or apartment blocks. For these buildings the erection time as well as the exposure to weather is longer, so the principal protection against weather should be an integral part of the building system design.

For multi-family houses and other larger buildings, there are a number of methods for protecting the erected building from the climate's influence. Again, for multi-storey buildings a very high degree of prefabrication as, for instance, volumetric elements can be a solution to avoid moisture influence problems. Even if the assembly is much faster compared to the conventional construction method, the structure can be still strongly influenced by weather conditions. So the problem of weather protection of the building site occurs again, but in a smaller scale and some additional actions need to be taken.

In Sweden, there are three common ways of protecting taller buildings during construction. The largest problem arise when the construction work goes on without any protection, besides the protective layers of wax or impregnation (sometimes a plastic foil is used although not durable) applied directly on timber members. In this case the bearing structure is erected firstly, not including any moisture sensitive materials like gypsum boards or insulation materials, so the moist structural elements can dry-up before completion of the work. This is the most common method applied for non-residential buildings or halls. The biggest disadvantage of this method is the requirement of the follow-up quality control to assure the correctness of the dry-up.

Another option is a method analogous to that used for small houses. The assembly method is to assure that the roof structure is mounted within one day. This method has some limitations and is usually applicable to a maximum of four-storey buildings and requires a high degree of prefabrication, e.g. volumetric elements.

Figure 6: *Example of usage of tent over the whole building (photograph by Anders Björnfot)*

The most advanced way of isolating the construction works from the weather influence is covering the building site with suitable tents (light bearing structures with fixed tarp), Figure 6.

On the Swedish market, there are a number of solutions available. There are tents covering the whole structure with an opening roof or tents protecting one storey of construction work, successively moving up as the work progresses. This kind of weather protection shows very good results for instance in the case of erecting a multi-storey building in solid wood system. Another large advantage of this kind of protection is that it enables using inside it a travelling crane. However, this method also has some limitations, for example ventilation problems during warmer periods, logistic complications and higher cost in comparison to other methods, [3].

Figure 7: *Weather protection used for volumetric element systems (photograph by Hans-Erik Johansson) [3]*

There are also some less advanced ways of protecting the structures from harmful moisture influence like covering the erected parts with different types of tarpaulins (Figure 7), but this type of protection is not durable and may also cause additional problems for instance with handling the tarpaulins during erection work.

4.2 BEAM AND POST SYSTEM – MOUNTING METHOD

The weather protection systems and products available in Sweden have proven to have a positive impact on the industry. The general evaluation of applying weather protection systems is positive, since they provide a meaningfully improved working environment, which in turn leads to shortened production time, higher level of safety at work and improved final quality [4, 5]. The main criticism regarding these systems is their high cost, which seems to be the argument for their limited use.

Therefore, the goal for the beam and post system is to create an inexpensive system-specific solution for weather protection of the buildings during erection time. The principle is similar to that for small houses, to assemble the roof of the erected section of the building within half to one working day. Such a result is possible due to the primary assembly of self-stable e.g. T-modules (or other configurations, as shown on Figure 3) of robust and rigid prefabricated elements (Figure 8a). The vertical continuous columns of the systems are raised first with pre-mounted steel brackets to support the connecting beams. Thereafter, columns and stabilising elements are connected by a number of beams, (Figure 8b), creating a sufficiently stable structure enabling early mounting of the roof over the erected segment, just after assembly of the floor elements over the top storey, (Figure 8c-d).

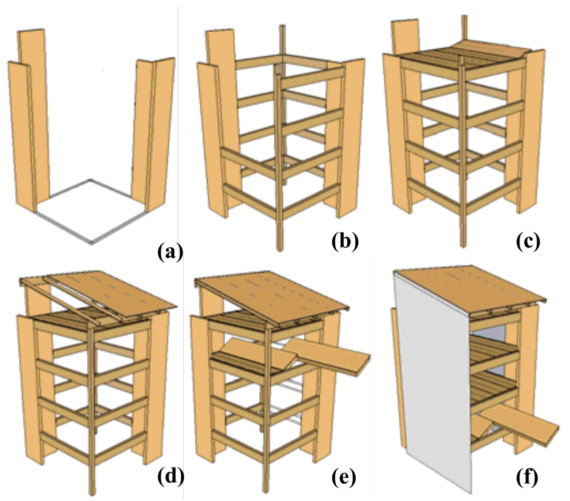

Figure 8: *Assembly method for system trä8*

The modular configuration of the buildings built using beam and post system allows division of the whole structure into smaller sections. Early assembly of the roof reduces the risk for floor elements being damaged or harmed by rain, as well as facilitating the assembly of the vertical façade creating a protected environment inside for the continuation of construction work of the covered part.

The façade tarps, attached to the roof structure (Figure 8 f), are developed with the system, fixed to some sections of the bearing structure and rollable or movable from other sides, enabling assembly of remaining beams and floors. An illustration of the assembly method is presented in Figure 6. Assembly performed in this manner can be applied to arbitrary shapes of the building (ref. to Figure 1).

5 FURTHER RESEARCH CHALLENGES

One of the issues related to the stabilisation of light timber structures is the anchorage of the walls or in the case of the system *trä8*, stabilising walls. This issue together with the acoustic performance is currently the main focus of research.

The racking capacity of the stabilising walls plays an essential role in the performance of the system. The resistance of these walls against the horizontal loads has recently been experimentally investigated and the results are currently evaluated.

The work will continue to concentrate on utilising full racking capacity of these walls and the interaction between the different structural components.

For future use, further improvements of the system would be necessary in order to meet the architects' and clients' expectations with respect to the geometry of the buildings as the system is planned to be used for buildings based on the rectangular modules.

The future development of *trä8* should also take into account the possibility of utilising longer spans and a larger number of storeys to be able to compete with other systems on the market.

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