WCTE 2016
World Conference on Timber Engineering
August 22-25, 2016 | Vienna, Austria

EXECUTION OF TIMBER STRUCTURES AND FIRE

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ABSTRACT: Fire safety is one of the six essential performance requirements to consider when building timber structures. Fire safety has to be proven for the whole building process and the end use of the building. On the building site during the execution there might be an increased risk for fire spread because of large amounts of unprotected timber and relatively open structures. Work processes dealing with high temperatures, smoking, vandalism or other reasons can lead to ignition of timber and end up with serious damages. Fire safety on the building site should be handled from the very beginning to the final stage of execution. During the execution the designed solutions have to be checked and followed. This paper gives the background and principles that should be considered in a new Nordic standard for execution of timber structures in terms of fire safety.

KEYWORDS: Execution - Timber structures - Fire resistance

1 INTRODUCTION

Timber is a combustible material. Execution of timber buildings involve a risk for fire. The fire safety on the building site and in the factory has to be assured by proper plan and measures.
The fire safety requirements according to the Construction Products Regulation (CPR) are that structures must be designed and built such that:

- load-bearing capacity can be assumed to be maintained for a specific period of time
- the generation and spread of fire and smoke is limited
- the spread of fire to neighbouring structures is limited
- occupants can leave the building or be rescued by other means
- the safety of rescue teams is taken into consideration

Fire safety of timber building has to be assured throughout the execution and end use of building. Assuring the latter involves appropriate installation and control of fire barriers and fire protection. Proper functioning of fire safety measures for the end use could only be checked during the construction time.

Several performance properties of wooden structures in fire can be determined from EN-standards, so that results can be transferred between countries (if the test conditions are relevant – i.e. similar construction type).

Fire requirements has three major aims:

- To allow occupant to escape in the case of fire
- To prevent the fire from spreading to other parts of the building (EI)
- To maintain sufficient load-carrying capacity for a defined period of time (R)

Requirements are given in national regulations with reference to EN-standards. In many cases there are also national methods. The building owner will usually not require a higher level than prescribed. The requirements are usually specified as:

- Reaction to fire class
- Fire protection ability (K-class)
- Protection time (Integrity and Insulation, EI)
- Structural failure time (Resistance, R)

Substitution by design is harmonised through the relevant Eurocode parts on fire (EN 1991-1-2 and EN 1995-1-2) and further developed in the technical guidelines Fire Safety in Timber Buildings [2] or in Brandsäkra Trähus 3 **Error! Reference source not found.** which comprises guidelines for the Nordic and Baltic countries. However, the Eurocodes require national choices in National Annexes, some of which influence the performance, especially for natural fires. Further, alternative methods are given in the National Annexes in some cases. Requirements are different among the countries.

Building fires consist of an ignition phase, flashover, fully developed phase and cooling phase (see Figure 1). The potential occurrence and the duration of the different phases are dependent on the ignition source, type and

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quantity of the fire load (combustibles), ventilation conditions, among other aspects. Therefore, appropriate management of combustible materials, ignition sources and early compartmentation (to limit ventilation) can minimise the fire damage and risks. Furthermore, active fire protection such as sprinklers and manual fire extinguishers, can avoid flashover. In relation to the phases of a building fire, the approach taken for the new Nordic standard to limit potential fire damage and risks involves:

1. Limit risks of ignition
2. Limit risks of flashover after ignition
3. Limit the spread and intensity of fully developed fires in case flashover occurs.

A fire needs (1) an ignition source (2) fuel and (3) oxygen. Therefore an effective way to limit the risk of flashover after ignition is to store combustible materials as much as possible outside of the building and away from possible ignition sources. Early compartmentation limits the flow of oxygen, the intensity and spread of the fire.

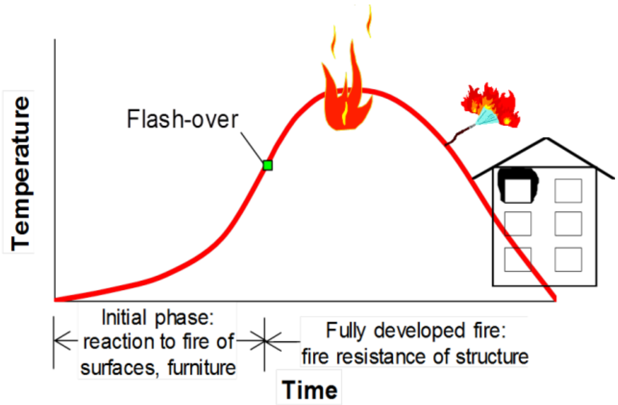

Figure 1: *Phases of a building fire.*

2 FIRE SAFETY IN THE DESIGN AND EXECUTION PHASES

During the execution of timber buildings there are periods when there can be large amounts of unprotected timber might be exposed. This temporary situation may contain high risk for fire spread that is not taken into account with design. The fire safety has to be followed during the entire execution phase and all the risks to fire spread have to be minimized.

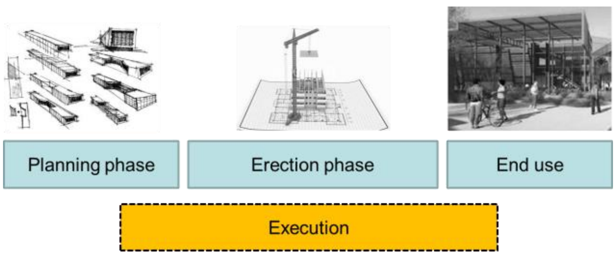

Figure 2: *Execution is affected by planning and affects the end use.*

Execution includes all activities carried out for the physical completion of the work, i.e. procurement, manufacturing, gluing, mechanical fixing, transport, site assembly, surface treatment, inspection and documentation [6].

During the execution of timber structures the main topics to regulate are moisture content, fire safety and tolerances of the structural elements and details (See Table 1).

Table 1: *Topics to consider according to the new Nordic execution standard*

Requirement	Requirement purpose (time) Assembling	End-use
Stability	✓	✓
Fitting of elements	✓	
Fire safety	✓	✓
Moisture safety		✓
Acoustics		✓

There are three aspects of fire safety and execution that has to be followed:

- proper execution of the designed solutions to fulfil the assumptions made during the design
- fire safety of the constructions during the execution phase
- fire safety of the building site in general.

Fire safety concept of the buildings will be created and planned in the design phase of the building process.

The concept should consider fire resistance of load-bearing structures, evacuation routes, fire alarms and extinguishing devices.

Design is based on assumptions that the execution will be done following the needed quality level. For example proper mounting of fire protection layers and systems is important to make the solutions perform properly. Not properly fixed protections do not provide the performance of the construction that has been designed. Another example is that fire resistance of the load-bearing timber frame assemblies is generally based on the assumption that insulation protects the timber member from the sides. In the case of non-correct placement of the insulation the latter can fall down during a fire so that the timber member is not protected as it was designed. After covering the insulated cavities with claddings the placing of insulation cannot be checked anymore. These examples clarify that there are subjects that have to be controlled and verified during the execution phase.

Figure 3: *Execution of glulam roof trusses.*

4. FIRE SAFETY ON BUILDING SITE

Fires during building construction and refurbishment have happened from time to time. The reasons for a fire occurring are varied, ranging from arson to accident, some are related to the work processes on site.

There have many serious fires occurring in the UK during the execution of large timber buildings. This led to relevant statistical studies of fires during construction. During construction approximately one-tenth of 141.075 reported fires in England, between October 2009 and December 2011, involved timber frame construction. In comparison, 1 in 57 fires of fully constructed buildings occurred involved timber frame construction. The statistics, therefore, indicate that fire hazard is significantly larger during the construction phase. The statistics showed, furthermore, that the damaged area after a fire during construction is typically larger for timber frame construction than for other types of construction. This indicates that the fire spread should be considered as a concern during construction of timber framed buildings.

A severe example of a fire that occurred during construction is the building site fire in Colindale in the UK (see Figure 4). In July 2006 a construction fire occurred on a timber frame building site at Beaufort Park. The houses consisted of blocks with 5 and 6 stories. The damage sustained on the building site was extensive. The fire had grown to such a large size that the collapse of one block of the housing occurred 9 minutes after the fire alarm started [4].

Figure 4: *Fire in timber frame building occurred during the execution. Colindale. July 2006. Photo: Wei Yecheng*

In order to prevent or limit fires it is important to prevent or limit the following:

- oxygen
- fuel
- ignition

The flow of oxygen in traditional construction of light timber frame buildings was not limited by the
In traditional construction, as performed in Colindale, the structure was open allowing a large amount of oxygen to intensify the fire. Furthermore, the lack of closed compartment dividing members, such as closed walls, doors and windows, led to a large and very rapid fire spread. Therefore, it is for fire safe construction very important to close compartments as soon as possible. This can be done by for example building with closed timber frames, which have all plates and insulation assembled on the frame before their placement in the building, instead of open timber frame assemblies, which have no plates assembled on the frames. Furthermore the early placement of doors and windows (Figure 5) will make the building much less vulnerable for intensive fires involving a large fire spread.

As mentioned before, fire needs fuel. Diminishing the amount of available fuel effectively reduces the risk of flashover. Fuel includes all unprotected combustible materials. These could be, among others, waste materials, storage and stored gases. It should be noted that exposed timber that is part of the building also contributes to the fuel load. During the execution phase of the timber building there are often large surfaces of unprotected timber that can cause a risk for ignition and fire spread (Figure 6). The amount of exposed timber surfaces during construction is often higher than that after construction. This causes a larger fire hazard during construction that during the end use of the building.

Figure 5: *Timber buildings with early compartmentation limit the intensity of fires and fire spread*

Risk of ignition can be limited by limiting potential ignition sources, by for example prohibiting smoking on site. Further, management of ignition A plan should be documented which defines safety distances between identified ignition sources and fire loads, such as waste, fire hazardous fuels, self-igniting materials (such as linseed oil) and exposed wood based materials.

Figure 6: *Timber buildings with large amounts of unprotected timber at the execution phase can be sensitive for the fire risk***.**

Figure 7: *A compartment for a modular building*.

Figure 8: *Execution of module houses***.**

An advanced way to build timber houses is the module building technology. Three dimensional modules are built in the factory. See Figure 6 and 7. A significant advantage of this construction method is the compartmentation of modules prior to their arrival on the building site. As the modules arrive as fire safe compartments, the risk for highly ventilated, intensive fires that can spread rapidly is diminished. The method also allows performing major part of the execution in the well-controlled conditions. The moisture content of the structural elements as well as fire safety in the building process can be followed by means of factory equipment.

Using modular building only the final phase of the execution – the mounting of the modules - will be provided on the building site. Fire safety measures have to be taken into account, both, in the factory and on the building site. The factory conditions form a stable working environment that makes the fire safety concepts easier to follow. Modular building was for example used partly for building the world's tallest timber building Treet in Bergen.

Following the new Nordic Standard, a fire safety plan during construction shall include measures to limit the probability of ignition and to limit the impact of a fire. One member of staff should be appointed as responsible for the management of fire safety during construction.

Hot-work should only be done by personnel with relevant permits and experience. A safety distance of at least two meters from the nearest combustible material is required. In cases that this cannot be achieved, fire protection must be used to prevent ignition.

After any hot-work, temporary protected surfaces within two meters should be checked for smoldering or glowing combustion. In case any type of combustion is identified, it should be extinguished using fire-extinguishers or water and any hot-working activities should be postponed until an improved fire safety plan is documented. Preventing/controlling heat sources is implemented for example by banning smoking on site. The regime of hot-working permits for close monitoring of activities such as welding and hot gas procedures is to be followed.

A plan to mitigate fire spread should be documented and should include:

- Early compartmentation including the early placement of doors and windows
- Regularly scheduled checking for obstructions of doors
- The installation and location of fire extinguishers or other fire suppressing equipment.

There has to be a plan for fire extinguishing devices on the building site for the entire execution phase of the building. Fire extinguishers should be located:

- Within 5 meters from any hot-working activities
- At a minimum walking distance of 12m from any point on the building site

The management of building site waste has to be handled. Unhandled waste management can lead to potential fire risks.

5. REQUIREMENTS FOR EXECUTION WITH RESPECT TO END USE

Fire safety of timber building as any other building should be solved by design. There have to be different fire safety concepts included in the design to guarantee the fulfilling of basic fire safety requirements. Reaction-to-fire requirements have to be fulfilled. Fire resistance requirements have to be proven by calculations or by full-scale fire testing.

During the execution process the follow-up of design documents has to be checked to avoid the deviations from designed safety concept. However, there are actions during execution that are not covered by design documents but can affect the fire safety of the end-use phase of the building. The execution and quality of those actions can be checked only during the execution phase of the building.

As mentioned before, one staff member has to be responsible for the control of compliance with the design requirements. Additionally, third party control is required in order to check if the design solutions are followed. Deviations from the design require an additional fire safety assessment. Building materials that are used have to be checked during the execution to be in accordance with the design.

Timber buildings can be sensitive to correct detailing in order to prevent fire spread through the cavities. The risk for fire spread in the cavities is one of the main challenges for the fire safety in timber buildings. Proper installation of fire barriers in the cavities has to be checked and documented. In case compressible fire barriers are used, such as stone wool fire barriers, the dimensions of the fire barriers should be suitable to firmly clamp the barrier in the cavity [8].

A student house in Luleå was built with three-dimensional modules of timber. The constructions for the modules were properly designed including fire safety. In August 2013 there was a fire, which originated in a kitchen due to ignited oil in a saucepan. The fire spread through the ventilation shaft and ignited combustible material in the attic. The attic completely burned out after which the visible fire stopped. However, within the cavities the fire spread downward (see Figure 9) and caused re-ignition of the fire in lower floors. After the fire, the building had to be demolished as the fire damage was too high for recovery. The end result can be seen in Figure 9. Fire stops between the modules did not stop the fire spread. That might be due to not proper installing of fire stops. That can happen and can be controlled during the execution phase only. There is also lack of proper test methods to evaluate the performance of fire barriers in the cavities comprising combustible materials [8].

Detailed solutions are important in all types of buildings, but may have greater impact in wooden houses than in other types of constructions when considering fire safety. The detailing is especially important at joints between elements or where installations penetrate the building components. Quality of the penetration can be only checked during the execution phase.

Non-structural requirements for the joints of timber structures are important for the fire safety. Limited gaps and sufficient tightness are crucial to verify during the execution phase.

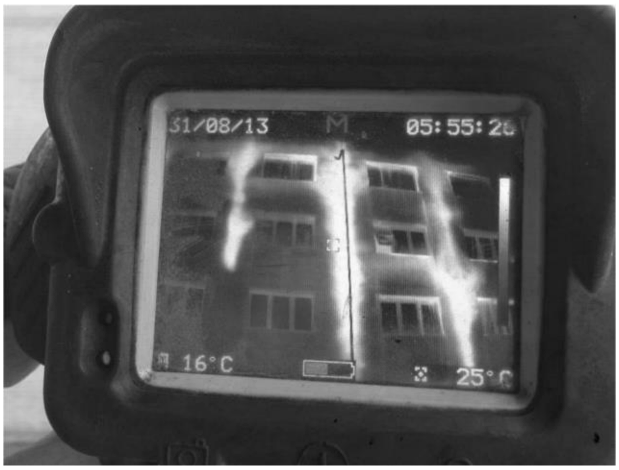

Figure 9: *Fire spread through the cavities between the timber modules. Fire in Luleå 2013.*

Figure 10: *Fire spread through the cavities between the timber modules. Fire in Luleå 2013.*

Protective materials and details that are used to prolong the fire resistance time of the joints, have to be sufficiently fixed to stay in place for the required fire resistance time. Encapsulated timber structures can have fire resistance levels similar to concrete structures, but the encapsulation has to be properly fixed and checked.

Figure 11: *Fire barriers tested in the model scale furnace at SP. Before and after the fire test.*

Air tightness of the timber frame assemblies is important. Air flow through the construction can reduce the protective properties of the mineral wool. Heavy air leakage can cause local decompositions of the materials. Protective properties of the insulation might be decreasing or lost if noticeable air-leakage through the construction occurs.

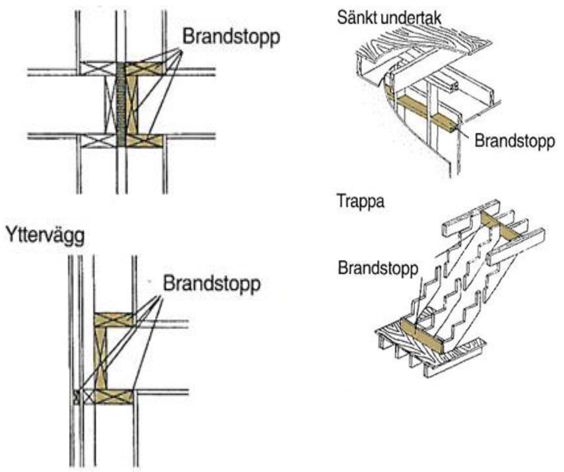

Figure 12: *Detailing of fire stops can be only controlled at the building time [7]*.

Timber members can have protection by insulation materials during the fire after the fall off of cladding layers. Insulation materials give a contribution to the fire resistance of loadbearing timber frame assemblies by delaying and slowing the charring rate on the sides. Insulation must stay in place when its protection is expected, as was the case for the test shown in Figure 13. Incorrect mounting of insulation by incorrect work or missing of fasteners may lead to faster collapse of timber element in fire due to missing protection on the sides. The fixing of insulation is important to be ensured during the execution phase.

Means of fixing of insulation are:

- Overdimensioning i.e. the width of insulation batt is (5-10 mm) bigger than the width of cavity (see figure 13)
- Fixing the insulation mechanically by fasteners, such as screws, steelbars, etc
- gluing the insulation to the other structural layers on the non-exposed side
- using steel net or battens with sufficient cross-section to hold the insulation in place after the claddings failure

Figure 13: *Mineral wool fixed using over-dimensioning after 60 minutes fire test.*

Figure 14: *Fixing of insulation material by overdimensioning.*

6. FIRE AND SMOKE ALARMS AND FIRE EXTINGUISHERS

Fire alarms and fire extinguishing devices have to function during the entire execution phase.

As mentioned before, during construction, fire extinguishers should be placed within 12 meter walking distance from every point in the building and within 5 meter from every hot-working activity (as can be seen in for example Figure 15).

For placement of fire or smoke alarms the following is recommended:

- Fire or smoke alarms are recommended to be placed at a maximum horizontal distance of 5 meters from timber frame construction (columns and walls), unless the product specifications describe otherwise.
- A fire or smoke alarm is recommended to cover not more the $50m^2$ of area in a single compartment, unless the product specifications describe otherwise.
- Fire or smoke alarms should be mounted at or below a maximum height of 7.5 meters from the corresponding floor level unless specified otherwise by the specifications of the fire alarm.

For the construction of multi-storey timber buildings it is recommended to install temporary sprinklers in stairways and fire hazardous areas. Fire hazardous areas can for example be areas with a lot of combustibles present, areas with a risk for highly ventilated fires, or areas with a high risk of ignition.

Figure 15: *Fire extinguishing devices are required for the works with high temperatures.*

Sprinkler systems that are installed for the end use, should be installed by a certified company and should be tested and approved before the occupation of the building.

7. NORDIC EXECUTION STANDARD FOR TIMBER BUILDINGS

Proposal for Nordic standard on execution of timber buildings is to be developed by a working group consisted of the representative institutions and industries from Finland, Denmark, Sweden and Estonia. The chairman of the group is Tomi Toratti (Finland).

The goal of the work is to propose a model standard for execution of timber structures. The standard will give requirements for construction of timber structures, on-site or off-site, which are used as load-bearing structures and are made completely or partially from wood-based structural materials.

For the purposes of this standard, inspection of execution involves checking the following:

- Previously non-verifiable project design requirements of significance for safety are met,
- The work is carried out in accordance with the relevant specifications, drawings, and other documentation.

Production and execution should be performed in accordance with the relevant documents. Deviations from the production documents should be documented and corrected.

- Moisture control
- Installation of fire safety measures
- Assembly tolerances

Contents of this paper will be background for the fire part of the proposed standard.

8. CONCLUSIONS

The following aspects need to be considered in the execution standard:

- Right materials with sufficient properties
- Proper workmanship regarding fire safe detailing
- Extinguishing systems, alarms, fire safety installations
- Fire safety on the building site, which includes managements of combustibles, early compartmentation, etc.
- Fire safety measures should be taken for the whole period from start to the completion of construction

Fire safety has to be assured on the building site during the entire execution time and for the end use of the building.

ACKNOWLEDGEMENTS

Authors of this paper would like to give acknowledgements to Nordic Innovation Centre, NICe, for sponsoring the work.

The authors would like to acknowledge the COST Action FP1404.

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