Timber-Frame Buildings in Scandinavia: High Deformation Prevent the System from Collapse

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Introduction

The timber-frame buildings are well known as one of the most efficient structural systems in order to resist to the seismic events. We know that the use of timber elements connected to the masonry was very frequent, often applied in the ancient buildings not just to prevent the seismic risk, but also to improve the structure's behaviour under its own load.

In fact, the peculiar features of wood let the builders to use timber elements to reinforce masonry buildings in many different situations, that we can sum up in two main categories: timber elements inside the walls' width (or foundations) in order to connect stones or bricks in a better way; as a tie-beam, often between walls or columns to help them in supporting the horizontal loadings. Of course, lots of examples of using timber can take place in these two main categories, from a single piece of wood enclosed in a masonry wall, to a whole building made of timber-frame with infill masonry. In this paper some aspects of this last example will be analyzed, focusing the attention on some ancient buildings in Scandinavian countries.

Origins and diffusion of the timber-frame buildings

One of the most ancient examples of timber-frame buildings is one of the surviving houses of the archaeological site of Herculaneum: it hands down to us the well-known technique called *opus craticium* by Vitruvius and is a formidable evidence of the diffusion of the timber-frame during the Roman period. The *opus craticium*, as other building techniques, was largely diffused in the Roman Provinces, and later developed in different ways in a large number of Mediterranean and European areas. In fact, the timber-frame was a very common technique, obviously in countries with a great availability of wood, for its constructive and structural features: it was a "simple" way of building for the little dimensions of timber elements, that could be easily moved from a place to another, as – for example – the bricks were; the skill of carpenters, in areas where timber was always used, let the builders to rise up houses in a very short time; the small dimensions of timber elements let also a very easy replacement in case of failures or damages, as the fire-events were so common; finally, the frame itself was able to support both static and dynamic loads better than other constructive systems.

Of course, the last feature of the timber-frame was very important in areas where seismic events were common: we know that since VIII century it was present in Turkey (GÜLHAN 2000) and it was largely used in Greece during the Byzantine era (TOULIATOS 2005). Moreover, the well-known events linked to the earthquake in Lisbon (1755) could explain how the timber-frame has been significant in seismic areas: the commission led by Manuel de Maia in Portugal recognized the so-called *gaiola* (cage) as the best way of building a seismic-resistant structure, especially for little or medium buildings (FRANCA 1972). A similar commission of engineers, after a terrible earthquake in Calabria, Italy

(1783), inspired by the recent Portuguese events, published the "Royal Building Instructions", where the timber-frame (*casa baraccata*) was suggested as seismic-resistant (BARUCCI 1990, RUGGIERI 2005).

We can recognize a lot of local expressions of the timber frame with infill masonry developed from the *opus craticium*, called *colombage* in France, *fachwerkbau* in Germany, *half-timber* in Britain, *telar de medianería* in Spain, *himiş* and *bağdadi* in Turkey, *quincha* in Peru, *bahareque* or *taquezal* in Central America, *dhajji-dewari* in Kashmir, *gaiola* or *pombalino* in Portugal and *casa baraccata* in Calabria, as reminded before (LANGENBACH 2007).

We cannot explain the large diffusion of the timber-frame with infill masonry just considering its seismic-resistant nature: of course, it's because we can find infill-frame constructions also in areas where is no earthquakes-risk, and also their features in terms of economy and strength can support this assertion.

Furthermore, other features, typical of the timber-frame, can be added to the three mentioned above (seismic-resistance, economy, strength): the first one is the good aptitude in absorbing different kind of "building faults", as the use of deformed elements or smaller than requested ones, or some unfit connections; the second feature is the way of responding to several failures during building's life, related to foundations, posts or floors; finally, we cannot forget that builders could easily replace damaged elements with new ones. We could resume these qualities identifying the timber-frame as "adaptable", and maybe it's just this adaptability the main reason of the success of this constructive method in so many different countries and centuries.

In this paper we'll see a small catalogue of some Scandinavian timber-frame houses, from XVI to XIX century, where the "adaptations" mentioned above are evident.

Scandinavian traditional houses

Since remote times, in northern European countries like Denmark, Sweden and Norway, because of the plenty of wood, timber was used to rise up composite buildings like the "long houses" (*langhus*, from 700 BC; BREKKE 2003). The traditional houses were made of trunks (*lafteverk*), but during Early Middle Ages, maybe IX-X century, some timber-frame houses (*bindingverk*) are documented in Norway (CHRISTIE 1974), and probably some time before in Denmark and Sweden.

In some areas of Scandinavia the timber-frame with infill masonry was the most common way of rising buildings, both private and public, especially in areas where bricks could be easily supplied. This happened, for example, in Denmark and Sweden more than in Norway or Finland, inside towns or villages more than in the countryside.

The most interesting expressions of Scandinavian timber-frame structures were built since XVI century, when the carpenters get a formidable skill in rising frames, characterized by strength and beauty because of some improvements like the standard use of carved wood elements, or the great variety in posing bricks, that makes the houses' surfaces like a series of different fabric panels. These two features are not just decorative ones, but they take part in the whole constructive system, with a specific role. In fact, the wooden pieces posed next to the first floor's posts often give their surfaces for decorative carvings as flowers or suns (figure 1), but they also provide rigidity to the structure, connecting the right angle formed by horizontal and vertical elements. The infill-bricks, sometimes laid in several ways in the same building (figure 2), seem to help the loads in being supported by the timber system with their different positions, as many are the directions of the loadings and – as a consequence – the connections involved in supporting them.

In Scandinavia the traditional infill-frame constructions are not so different from the others in the rest of Europe: a timber cage based on the repetition of a little *module* in plan (ca. 80-150 cm width), lied over a masonry foundation (stones sometimes with the insertion of bricks in order to level the horizontal surface); the vertical walls are risen for two or three floors, horizontally marked by the posts posed according to the *module*, while their height in defined by the position of the window, that is located in the upper part of the storey-wall, separated from the lower one by an horizontal joist. The position of the wooden floors in shown over the outer walls' surface by the main beams: the two beams concluding the floor take part in the wall's design, and sometimes the other beams' end is laid out of the wall's external surface, between two beams perpendicular to the main ones (figure 3).

Figure 1. A timber-frame house in Odense (Denmark), where the carved wooden "corners" take a great part in the decorative power of the building.

Figure 2. In this XVIII century house in Lund (Sweden) we can see several way of posing the infill-bricks.

Figure 3. A traditional house in Lund.

Typical failures in timber-frame buildings

The failures we'll see here could be divided into two main groups: the ones related to the constructive process form the first group, the other ones that commonly have effect during building's life belong to the second group.

In some of the houses observed in Scandinavia it's evident that the timber-frame structure can support the imperfections of the single wooden members, like the torsion of a beam or an approximate position of some elements, sometimes due to a natural irregularity of pillars or beams, in other cases because of the morphology of the site, or because of a simple mistake in designing the building (figures 4-5). In these situations, builders well knew that the whole structure could accept similar defects, so today we can see these examples still surviving, thanking the cooperation of all the members of the frame structure.

Although the not great rigidity of the timber-frame houses is a formidable seismic-resistant system, it also make these buildings exposed to the deformations of some structural units, or of the whole frame. One of the traditional multi-storey houses in Aarhus Folk Museum shows a great deformation of its structure (figure 6); in this case the wooden squares that form the frame are not provided of diagonal rods, except for the little ones placed just under the floor levels. Commonly, in the timber-frame houses observed in Scandinavia the diagonal rods are always present near the corners of the building, taking up the final module of the frame, often for the entire height of the floor. This device provides rigidity to the whole structure, even if not all the squares are wind-braced. The great deformation observed in the building shown in figure 6 is caused by the lack of the rods, but maybe it doesn't take the building to collapse because of the brick masonry filling, that confine the deformation in a sustainable range.

Figure 4. Detail of a house in Aarhus (Denmark): the floor beam on right is still in position in spite of its great deformation.

Figure 5. This façade in Aarhus shows clearly a rough design, but the stability of the whole system doesn't seem to be compromised.

Figure 6. In this building in Aarhus Folk Museum the deformation of the frame causes a great slope of the first three floors, that moves horizontally dragging the fourth one that maintain its shape because of the triangular frame.

One of the most common deformations of the infill-frame structures is the sinking of a part of the building, due to a foundation failure, or to a pillar failure, etc. In the building shown in figure 7, where we can notice the diagonal rods placed in each module of the lower part of the floor-wall, the beams related to the two floors are flexed in the same way: the sagging of the lower floor, caused by a foundation failure, drags the rest of the house deforming it in a significant way, but the rigidity of the whole building –

provided by the thickness of the timber elements, by the little dimension of the stitch modules, by the presence of so many rods – prevails despite of the failures.

Figure 7. XVI century house in Aarhus Folk Museum.

The same kind of deformation, caused by little failures of posts or connections, can be found in the two buildings shown in figures 8-10. The effects of deformation over the red house in Odense is very similar to the last one described above, but the origin of the failure is not to be found in the foundations: the flexion is caused by the load over the floor, not enough supported by the pillars. The long timber-frame house in the city centre of Aarhus shown in figures 9-10 is affected by a combination of failures: the sinking of the floor, in three different points, and the inclination of the walls' posts. This kind of situation is often caused by partly inadequate joints, that can't react effectively to excessive thrusts or unexpected saggings.

The loss of the vertical position of a single pillar, or of a group of them, can be due to different failures (approximate location of the members, inadequate connections, excessive load, etc.); in some cases, the entire wall loses its position because of horizontal loads: often it happens at the upper floor, for the push of the roof trusses (figures 12, 13). The roof's beams are connected to the top of the walls' posts; under this joint, a slender tie-beam links the two main walls: the ends of this beam come out of the walls through little holes carved in the posts, and fixed to them by bolts. This kind of connection is not always efficient, and it needs to be replaced (figure 14), or to be reinforced by iron ties (figure 15).

Sometimes the timber members of the frame houses, deformed as we saw above, can be damaged under the great stress caused by loads, thrusts, etc. In order to assure the survival of the building, is often needed to substitute the damaged members with new ones: even if this custom is not conservative, and we cannot approve of such these choices without preliminary analysis and if they are not strictly necessary, we see that the replacement of timber elements is a very common practice in Scandinavia (figure 16).

Figure 8. Significant deformation of the floor in this house in Odense (Denmark).

Figures 9-10. Traditional house in Aarhus city centre.

Figure 11. A timber-frame house in Odense with significant deformations of the floor-beam and of the upper wall.

Figure 12. A typical inclined wall at the upper floor of the house (Lund).
Figure 13. Another case of inclined wall, in Aarhus. The deformation is due to the push of the roof structures.

Figure 14. Wooden tie-beam replaced in a traditional farm-house in Kertinge (Denmark).

Figure 15. Reinforcement of an ancient wooden tie-beam with an iron one in Lund.

Figure 16. Recent replacement of timber elements in a XIX century building in Odense.

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