Source: Haneca K, Verheyden A, Beekmann H, Gärtner H, Helle G, Schleser G (eds.) (2007) TRACE - Tree Rings in Archaeology, Climatology and Ecology, Vol. 5: Proceedings of the DENDROSYMPOSIUM 2006, April 20th – 22nd 2006, Tervuren, Belgium. Schriften des Forschungszentrums Jülich, Reihe Umwelt Vol. 74, p. 21 - 27.

The evolution of roofing in Northern France and Belgium from the 11th to the 18th century as revealed by dendrochronology

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Henri Deneux (1874-1969), brilliant architect-restorer of monuments in Reims after World War I, devoted most of his life to the study of the roof frameworks in northern France (Deneux 1927). Given his interest in new techniques, dendrochronology would probably have been more quickly applied to the monuments of early Europe if this architect of historic monuments had met the astronomer Andrew-Ellicott Douglass, pioneer in the analysis of tree-rings (Webb 1983). In any case, dendrochronology was applied for the first time in France only at the end of the 1960s. At present, the gathering of results of laboratory analyses, both public and private, has permitted the establishment of a database supporting an accurate and precise chronology which allows the work of Deneux to be viewed in a new light. For the first time in France and Belgium, a substantial effort was dedicated to the collection of a maximum of dendrochronological analyses in the aim of creating a synthesis of the history of architecture (Hoffsummer *et al.* 2002). We have profited both from the experience obtained from the studies of the monuments in Laon (Hoffsummer & Plouvier 1995) and the methodology developed as a result of the analysis of roof construction in Wallonie (Hoffsummer 1989, 1999).

This undertaking does not break new ground only with the use of dendrochronology. The approach is multidisciplinary, despite the inherent difficulties involved in the work of a team uniting historians, architects, art historians and scientists. In total, the corpus includes around 300 roofs of which a third have been analysed by dendrochronology. Deneux had observed around 500, but only a small proportion was described and illustrated in his article. Benefiting from our previous research, we were able to extend Deneux's territory to include a part of Belgium. There were two reasons for this: rural architecture was more often studied in Wallonie and the Escaut and middle Meuse basins and this territory covers, like the Lower Rhine, a transition zone between the Latin and Germanic worlds. Religious examples chiefly contributed to the collection for the period studied, from the 11th to 19th centuries, *in situ* roof frameworks of rural or common medieval architecture being more difficult to study. Archaeological excavations sometimes compensate for these lacunae by providing some data, at least in reference to the general organisation of wood construction and the disposition of load-bearing structures (Bans 1995).

The domain of carpentry is obviously not limited to ridge roofs. Other aspects are also explored, including half-timber construction, belfries, spires. The importance of carpentry is also underestimated in the construction of workplace or war machinery, scaffolding, arches. We are aware of such aspects but we consider that the systematic study of roofs has created a general canvas whose broad characteristics can be applied to the analysis of other carpentry works.

The synthesis of dendrochronological analyses of a hundred or so roofs has permitted the development of an original database concerning the growth of oak during the last millennium (Lambert *et al.* 1996, Lambert & Lavier 1991). Certain dates on wood remain difficult, if not impossible. It would be mistaken to conceal these difficulties at the risk of discrediting the method. The tree is a living thing whose growth is affected by different factors, more or less striking. Among them, climate induces a characteristic signal which permits the correlations which can lead to a date. If the signal is cloudy, or completely dominated by the environment, the correlations become more sensitive. The action of man on the forest, either via clearing or massive deforestation, also has an impact which is more or less detectable in the sequence of tree rings (Lambert 1996, 1998). Of the hundred studies presented here, several present a substantial percentage of undated wood and three did not succeed at all. In most cases, a higher number of samples collected from a homogeneous structure increases the performance of results by widening the possibility of comparison between trees. There must be a substantial number of beams from which to take samples, which is not always available in small roofs. The "user" of dendrochronological dates must be aware of these limits.

On the other hand, the notion of "frame of reference" develops as a result of new computer advances by which an increasing number of comparisons between samples can be compared more rapidly. Little by little, it is becoming possible to create more coherent tree groups, independent of the traditional frames of reference for the Bourgogne, eastern France, the Paris or Meuse Basins, to cite only the most useful in the region studied. While these standard curves remain valuable for dating, new correlations of their components will lead to other research possibilities, in particular for study of the climate (Lambert 2002).

With a trace of bark, the dendrochronological date can be precise to the year or half-year. The use of green wood in architecture has been amply demonstrated, by both historians and dendrochronologists (Mille 1993). The dating of wood by tree rings thus has significance for the history of architecture. These analyses must be integrated into a global approach to analysis of a building and not sampled randomly. The archaeological study of the roof is crucial. The re-use, underpinnings and repairs often complicate the interpretation (Hoffsummer 2002, 2003). This is the case for the cathedral of Beauvais. To interpret the results correctly, the systematic reading of assembly marks is fundamental to verify the coherence of a structure. Fairly rudimentary or even non-existent in the roofs of the 12th century, assembly marks become more systematically used around 1220 and the use of simplified Roman numerals became widespread. Other traces of woodworking are related to transport, when it was floated: special signs identifying the cargo or the destination, perforations for the ties connecting the logs into rafts. We foresee the possibility of weaving the links between these "field" observations and the history of transport or commercial flow.

The modern forest is quite different from that of the Middle Ages. The pressure of man increased considerably beginning in the 16th century, as much to collect wood for architecture as for naval construction, which had different needs. The forest was also plundered for all kinds of uses: kindling, industrial wood, wood for heat. Historians still have much work to do to help us penetrate this forest "reservoir" although the subject has been approached by several recent studies. These illustrate the difficulty of using accounting or judicial documents to answer only apparently simple questions, such as the development of French forest cover or the commerce of wood for construction. Dendrochronologists, perhaps, for the moment, have more answers, by showing certain displacements of wood over long distances.

The difficulty of procuring wood in the 16th century is a reality that the simple typological examination of roofs demonstrates. Obviously, roofs built by the most rich were not limited by this constraint. The great roofs of modern times at Reims, Paris or Troyes are always equipped with rafter-truss couples, which are lacking in the majority of other roofs of the same period.

The typological classification of roofs is a method which appears heavy and thankless. Nevertheless, at the first stage, it creates homogeneous groups. The simple visual comparison of samples at a constant scale is quite productive. We realise the great diversity in solutions to building a simple pitched roof. Among 300 examples, we can identify around 50 different types of structures. Each is an entity in itself that belongs to a very hierarchical corpus. Aided by dendrochronological analyses, and the chronology in general, we can observe these entities and place them in the more general context of the history of architecture. The evolution of roofs, under the form of working hypotheses, changes as a function of changing techniques or the effects of economic constraints.

The oldest roofs are relatively simple and low, with a fairly shallow incline (30-40°) resting on a series of rafter couples attached to close tie beams. Others, but very rare in the region studied, have trusses and purlins beginning in the 12th century. The first king posts do not appear before the end of the 12th century. Half timbered joint is more often used than tenon-mortise joints.

Intense times then mark the evolution of roof frameworks. From the end of the 12th century to 1220, certain joints were perfected, the incline of the roof became steeper (45-50°) and the carpenters launched the first frames divided in bays by the alternation between the tie beam trusses and trusses with sole pieces. These frames covered the first intersecting ribs whose extrados passes the top of the walls. In certain churches at the beginning of the 13th century, the reduction in the number of tie beams favoured another form of covering, lighter than the stone vault and more elegant than the simple ceiling: the wooden vault or "wainscot vaulted ceiling". This method was applied in all "Gothic" edifices from the 13th to 16th century. Other churches, like Saint Peter's of Montmartre, and especially those of the Rhine-Meuse region, however, remained loyal to the ceiling system. The period 1180-1220 was also marked by the use of oblique reinforcements – scarves and struts – in addition to traditional posts and collar beams. Could this have been part of a general current of thought in northern Europe? We find scarves in churches of Norwegian wood in the 12th century as well as in English roofs during the 12th-13th centuries (Ahrens 1981). The heightening of the choir of Notre Dame in Paris, around 1220, marks the apogee of this period of new ideas with a roof which overhangs vaults as high as the walls.

The development of the 13th century mirrors that of the carpenters. In 1220-1300, the roofs of grand monuments were richly covered in carefully attached materials which allowed steeper inclines (60°). They were thus high (often 10 to 12 meters) and wide (sometimes 15 meters), due to the increasing mastery of frame construction in spite of considerable wind loading. The nature of the structures joined together many thick rafters, one piece elements reaching 12, 15, 18 meters, linked in groups of ten. Solutions for triangulation and longitudinal bracing are varied; the sides were reinforced with longitudinal braces or purlins. The king post is no longer the only suspension piece of the tie beam: while it was extremely long, it was supported by long post brackets which formed a stirrup at the base. Consoles leaning on the flar walls could complete the plan of these large roofs. The ridge piece was added fairly early to certain monuments of Bourgogne, at Auxerre and Tonnerre.

In-depth studies of the roofs of Beauvais and Amiens shed new light on the history of two prestigious cathedrals. The age of the roof of the choir of Beauvais was unknown. We now know that the original framework, built soon after 1257, suffered in the upper parts of the church during the violent storm in winter 1284-85 but we also know that it held. The underpinnings of pillars, buttresses and stained-glass windows were made under its protection. The roof had been reinforced and slightly modified over time. Some oaks were cut down at this time, in 1284-85, that is, the same year as the trees for the choir roof at Amiens. The coincidence of the date forces comparison between these two edifices, some ten kilometres apart. The roof framework at Amiens is much lighter, as if the accident at Beauvais had incited the master builders to derive some insight from the misfortunes of their neighbours (Murray 1997, Taupin and Hoffsummer 2002). Much knowledge coexisted, besides, at this period. The construction sites open the same year at Soissons and Liège adopted other methods although they still shared the use of close coupling of long rafters. The techniques of bracing and the idea of principal trusses varied from one region to another. Amiens did not have collar ties in the principal trusses; the cathedral at Soissons did but lacked struts. The Sainte-Croix church in Liège belonged to the northern school and used large crossbeams inspired by the crucks.

These regional characters are observed when we compare the sickroom of Tonnerre with that, much further to the north, of the abbey of Bijlok at Gent, both particularly imposing, from 15 to 20 meters wide. The structure of the crossbeams at Gent, which resembles a truncated principal truss, recalls the cruck construction, while the roof at Tonnerre only amplifies the structure of the truss with tie beam and king post. The rural world escapes our analysis, due to lack of evidence. We know only that the carpenters had to demonstrate their abilities in other categories of buildings, such as barns and three-naved covered markets.

Few new ideas emerged during the continuation of the history of carpentry, except for the process of Philibert de L'Orme: his "invention pour bien bâtir à petits bois et à petits frais" (De L'Orme 1561, Perouse de Montclos 1991). Although marginal and imposed before the 19th century, the carpentry of joining reveals the principal concern of architects of modern times: to economise the wood. The majority of inventions of the 13th century were copied during the 15th to 18th centuries but procurement constraints for obtaining suitable wood for construction were strongly felt. Rafters, whose sections were continually reduced, were relegated to the simple role of roofing pieces. In a general manner, the length of the wood diminished, favouring the development of tiered construction, particularly in the northern zone, and mastery of the construction of crossbeams. The reduction in quality of wood also generated solutions for ease of assembly. This is particularly true with respect to the disposition of purlins. In Picardy and the Paris Basin, more rarely in the north, these were simply placed on the cleats attached to the rafters. In the Lower Rhine, the situation was somewhat different, the massive use of resiniferous woods favoured the use of long, regular grained wood. The context is thus different from that of oak regions and this is reflected in the typology. Alsace was also influenced by the construction of crossbeams of Germanic type.

Summarised in a few lines, the development of roof carpentry north of the Loire was particularly rapid in the 13th century (Courtenay 1985, Simpson 1992), building on previous experience gained during the Low Middle Ages, but was then limited by the reduction of resources during modern times and finally cedes its place to metal structures soon after the Industrial Revolution. We can imagine the importance of carpentry knowledge during the 13th century but no text or treatise (Jousse 1627, de la Hire 1702) yields further information to aid in our understanding. The typology and evolution of carpentry are two aspects which allow us to rediscover this knowledge. Mechanics also plays a role. Wood structures pushed by the wind at 50 to 60 m altitude are not rigid and we have to study them according to the closest standards of the behaviour of plane bodies rather than those of reinforced concrete structures. Modern techniques of modelling should yield information not only for the history of architecture but also to aid in choosing the most suitable methods for conservation and restoration. Certain repairs in the framework would be better than the complete replacement of a patrimony record of knowledge of seven centuries, even if it is invisible to the eyes of the typical visitor of a historic monument.

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