New Applications in Timber Constructions

Yves WEINAND
Prof. Dr. Engineer EPFL, Architect ISA
Bureau d'Etudes Weinand
Liège, Belgium
(Johannes Natterer, dipl. ing. EPFL)

Summary

The Bureau d'Etudes Weinand worked on several innovative timber structures over the past three years. Those buildings apply cross laminated timber panels in an architecturally and structural innovative and creative manner. This presentation will point out the structural, constructive and architectural aspects of three of those projects. The geometry of the first project, a restaurant in Fumay, is composed of a spatial polygon-mesh made out of prefabricated triangular elements. The problem of the knot, occurring frequently with traditional timber construction, is not of relevance here. In the second project, the Museum of Photography in Charleroi, three cantilevering cross laminated timber panels span over 11.00 m clearance. Finally, the crematorium in Welkenreadt features a folded, approximately 7200m2 large roof made out of cross laminated timber panels, reaching a maximum span of 21.00m. This roof is structurally innovative and its geometry defines high quality interior spaces.

1. The Restaurant in Fumay – an Extraordinary Form and Construction [1]

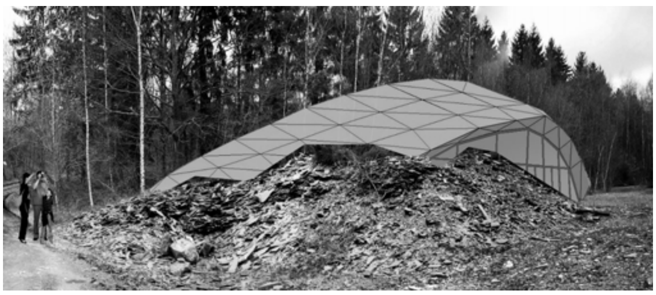


Fig. 1 Simulation of the construction

The nature reserve Givet-Fumay located in the French Ardennen shall be better developed touristically. The Bureau d'Etudes Weinand conceived jointly with the architects ESCAUT Architecture a restaurant and a reception building, from where walkers can discover the amazing natural landscape.

2. Abolishment of the Node in Timber Construction?

Constructions are often based on a connection of linear and prismatic elements. Subsequently a certain number of research studies were conducted on the details and connections of these elements. By the way, numerous scientific papers discuss the question of the node, especially in the domain of spatial structures.

Surprisingly the node principle has very rarely been challenged by civil engineers. It is interesting to observe, that the node has been precisely catalogued in the history of metal structures as constructive engineering expression. Thereby it is assumed as an element on which bars of a grid can be fixed for example. Traditionally it is a flange or web plate, but it can also have the form of a sphere or a clamp. But ultimately it always results in a physical element representing a node. These nodes have always played an important but problematic role, as they often correspond to a weak part of the concerned section. Therefore it is worthwhile searching for a conception, which simply avoids the use of such nodes. In Fumay simple triangles were joined. The starting point is a triangle (or several triangles) and not an element. In places the material is not continuous at the nodes, as it is made up of a multitude of independent triangles. Therefore the material at the traditional node is avoided, opting for a planar structure. This procedure points out the question about structural logic: should prismatic elements (and their connections) be used, or should rather surface elements be joined.

3. Construction Principle

The difficulty of this construction lies in the new way to use plywood boards as structurally active elements. The new way of force transmission takes place through the legs of the triangles and not through the nodes or the node elements, which would be placed at the triangles' corners. The verification of this construction takes place in three modelling steps, concerning both the state of structural safety (stability, stress peaks) and serviceability (deformations, deflexions):

- Space truss
- Spatial sandwich construction made of surface elements

4. Description of the Construction

The basic shape of the restaurant is double curved, which creates a vaulted effect. This form – a three-dimensional polyhedron – constitutes the restaurant's bearing structure. It is composed of numerous rigid triangles. The edges of each triangle are made of gluelam GL24, manufactured in order to fit the different corners. The triangle's external and internal surfaces are cladded with 30 mm plywood board. The membrane forces are routed along the edges. This way the concentration of the forces at the nodes can be avoided. The whole construction is supported by a linear concrete base.

4.1 Attachment of the Triangles among each other

The triangles are attached to each other by offset hex-head screws on both sides (see Fig. 2 Model of the web plates A special detail is about the fixation of the arch to the base, which transfers considerable shearing loads through this point.

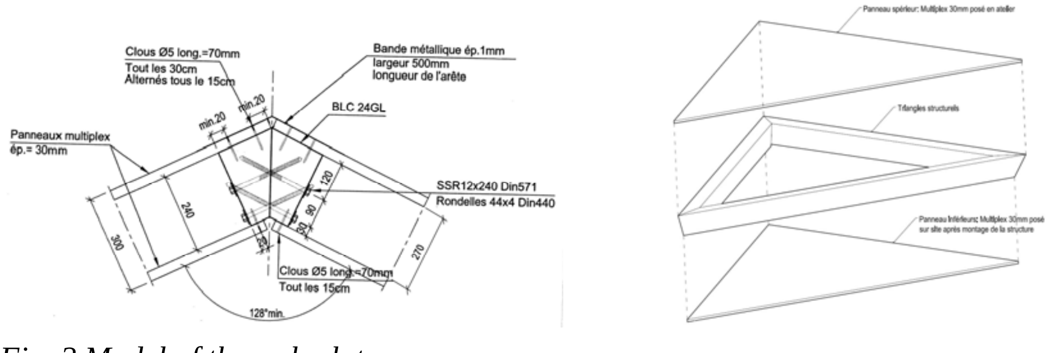


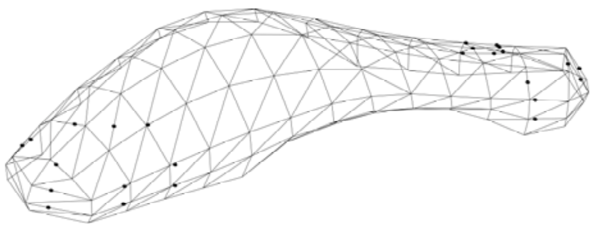
Fig. 2 Model of the web plates

4.2 Execution of the Construction Work

The space-enclosing structure is projected on the floor of the reception building. Subsequently each node gets its height dimension assigned, to accurately position the structure in space. The triangles are prefabricated at the factory, the edges are manufactured to match the different angles and the holes for the hex-head screws have been planned in advance. The triangles are open on their inside. The bottom panel of every triangle is delivered separately. The assembly operation progresses in layers transversally across the vault. The nodes are positioned in space by means of a scaffold. The triangles are distributed in space and fixed to each other, according to the corresponding construction detail drawing. The steel straps are bolted to the exterior. The interior panels are bolted down from the inside. After completion of the structure, thermal insulation is injected into each panel.

5. Spatial Framework

To begin with, the construction described above was simplified to the “space truss“ mathematical model. The actual surfaces of the triangles were neglected and replaced by linear elements (spatial beams as FE-elements) with prismatic profile (double-T-profile). Only the profile of the gluelam truss along the side pieces, as well as the contributing width of the multilayer boards lying above and underneath, were considered in terms of profile and moment of inertia.



This model is globally on the safe side, as the rigidity of the surface elements is completely neglected.

Fig. 3 Model of the space truss

6. Spatial Sandwich Construction with Surface Elements

The following modelling is done in two steps, with surface elements of 30 mm thickness each. The material characteristics are taken from the “Handbuch über Finnisches Sperrholz“ (literally: “Handbook about Finnish plywood”) For the modelling of the longitudinal elements, another surface element of 60 mm thickness was used. To avoid the extremities to transfer forces, fully flexible linear joints are admitted at the junctions (displacement and rotation).

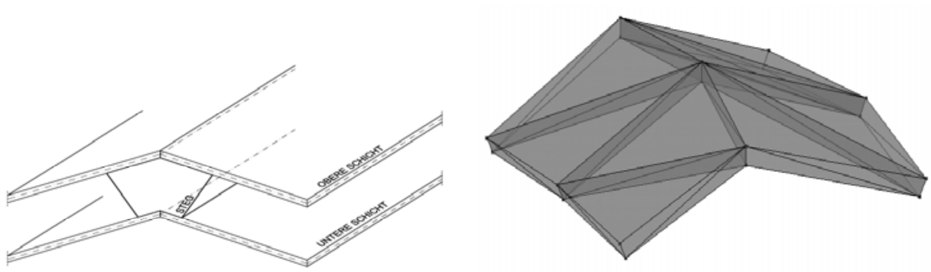


Fig. 4 Model of the space truss

6.1 Results

The construction presents a good load bearing behaviour, the maximal deformation is 44 mm including creep factor, which is less than the admissible deformation at a span of 22.5 m.

The three different models demonstrate that no substantial difference can be detected in the load bearing behaviour. The dimensioning of the elements shows a homogeneous stress in the surface elements of about 4.0 N/mm2. The deformations of the three models are almost identical and suggest the same result, despite considerably different assumptions. This approach however was necessary to ensure that no serious mistakes would occur at modelling. Furthermore the last system is the most complex to model and should therefore only be employed, when less complex models fail or don't suffice.

7. Museum for Photography [2]

Fig. 5 Museum for photography

7.1 About the Design

An extension of the museum for photography in Charleroi (Belgium) became necessary to accommodate the permanent exhibition of about 1200 m². An ambitious building was achieved from an architectural and constructive point of view, in close collaboration between the architects *ESCAUT Architecture* and the *Bureau d'Etudes Weinand.*

7.2 Problem of Upright Mounted Massive Slabs of Wood

Normally massive slabs of wood are used as horizontally positioned bottom plates or as vertically positioned wall units. Initially they were used in domestic construction. The homologations consequently stipulate their application exclusively in the described situations, especially in Austria and Germany. The experiments aiming to consider the load bearing behaviour of these slabs in view of the forces acting in their plane, are relatively novel. Especially upright positioned slabs need to transfer shearing forces from one layer to the next. The boards composing the slabs are glued together at 90° respectively to each other. Therefore such boards are also solicited perpendicularly to their fibres and need to transfer shearing forces as well. As generally known, in this case the resistance values are very low and need to be considered precisely. This stress mode is presented schematically in the following illustration.

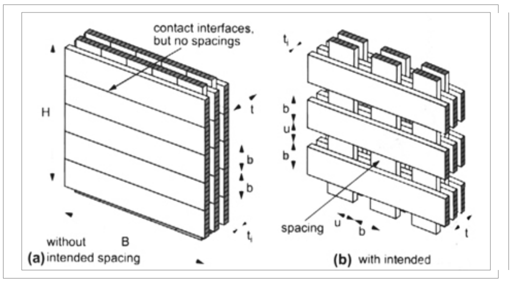
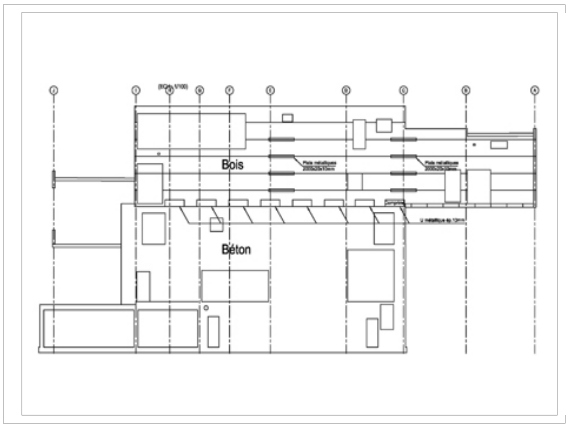


Fig. 6 Terminology and definitions for CLT plate elements, (a) standard configuration U = 0, not glued at the narrow faces, (b) non-standard configuration U > 0 Cross-Laminated Timber Wall Segments under homogeneous shear with and without Openings, WCTE, 2006, Portland. Thomas Moosbugger, Werner Guggenberger, Thomas Bogensperger

7.3 Execution

At first, the static plans were drawn, already showing the segmentation of the elements. General details were already calculated and drafted for the bid invitation. Following the project assignment and the revision by the executing company, all details were finalized. The drafting of the element plans allowed for a recheck of all dimensions of the slabs as well as of their connections.

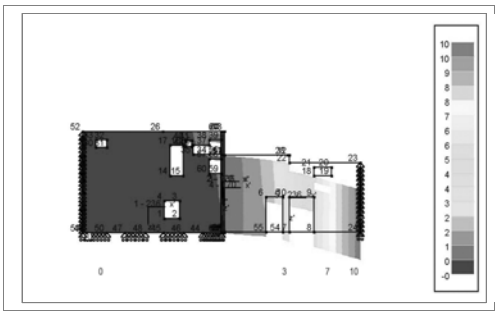


Each element is specified by a file and a corresponding plan. This plan contains the six elevations including the dimensions of every edging and incision. The file can be exported as a three-dimensional model and be read by a CNC-controlled cutting machine.

Fig. 7 Elevation of a partition with slab division

7.4 Dimensioning

The geometry of individual partitions was fed into the computer as pane surface elements. This input stipulates to consider the monolithic connection of the surface as a whole. As a single partition is composed of several 1.25 m large (or high) massive wood slabs, the slabs had to be adequately force-fit tied. The next step was to attach the partition as a whole to the existing building made of reinforced concrete. The shear flow from one slab to another is transferred by steel plates or multilayer boards fixed on both sides. All the connections in bearing areas (maximal shearing force over girder depth) had to be reinforced by steel plates. All vertical and horizontal borders were connected by L-profiles, in order to reinforce the cantilever volume as a whole (horizontal wind load). A particular difficulty lied in hiding the connections in the volume of the slabs, in order to allow for a finish adapted to the architecture and the interior space. Furthermore, skirting boards needed to be flush fitted.



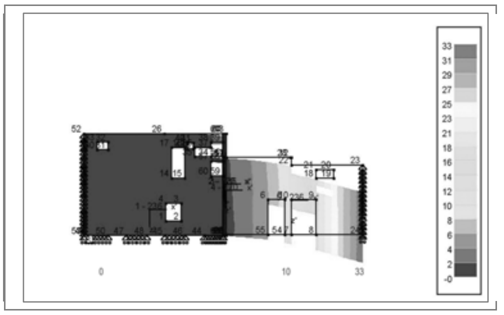


Fig. 8 Diagram deflexion Dz (mm) Min Fig. 9 Diagram deflexion Dz (mm) Max

Fig. 9 shows a maximal deflexion of 33 mm at the determining loading condition combination of the serviceability, which is acceptable.

7.5 The Building Site

The support point was realised by means of U-formed steel plates. A neoprene layer helps to avoid stress peaks in the compression area. Laterally the steel brackets and the slabs were bolted. The actual adjustment of the complete geometry was completed by pouring in the in-situ concrete, on which lay the U-formed steel plates.

The traction support points were executed similarly to the compression support points, but without a neoprene layer.

Originally a traction support had been intended, where threaded bars corresponding to the slab height would have supported traction forces. The executing company however opted for the detail being exposed here.

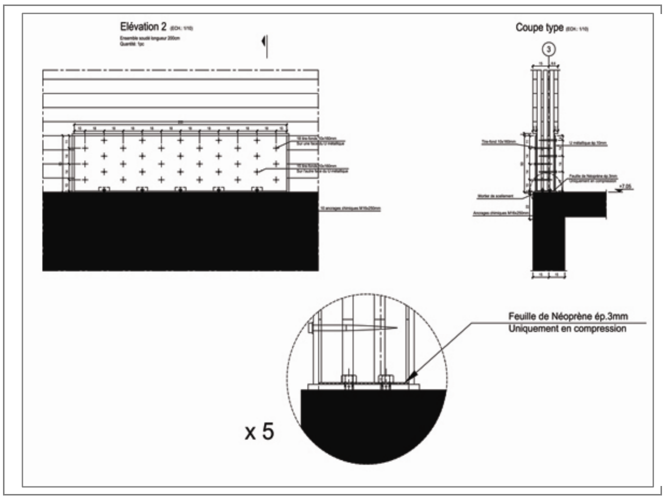


Fig. 10 Timber/concrete bearing

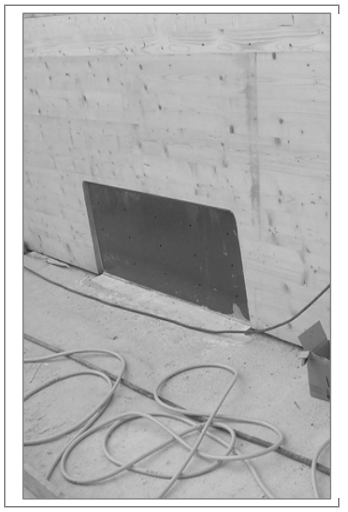


Fig. 11 Execution of 10

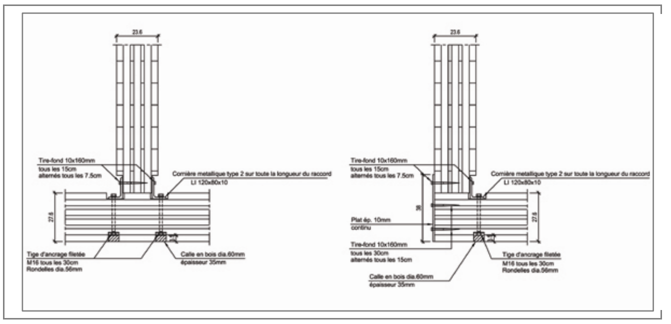


Fig. 12 Slab on floor

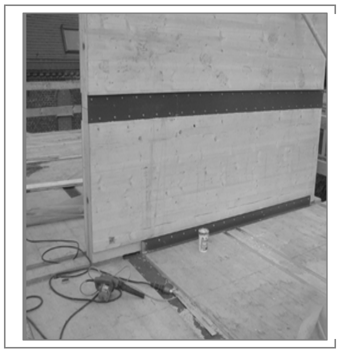


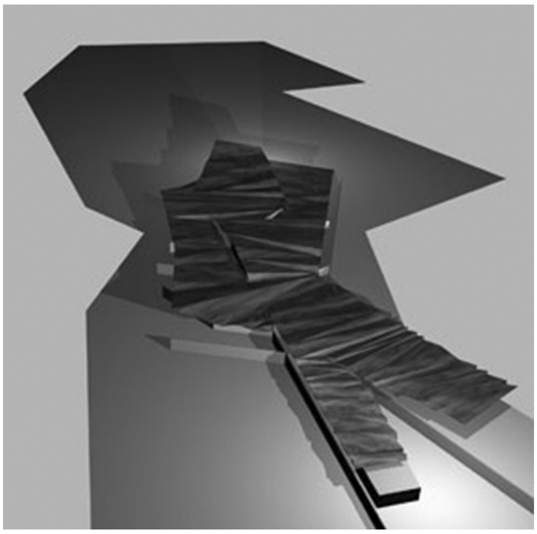
Fig. 13 Execution of 12

The suspension of the floor slabs is carried out according to two different details: In case of continuous bearing possibilities, two L-profiles are installed, bolted to each other by the side, embracing the slab thickness (see Fig. 12). No local bending of these profiles occurs. The profiles are bolted to each other at a distance of 15 cm.

At particular places, where linear bearing is not possible, web plates have to be inserted, which are bolted higher up into the timber part .

Furthermore the connexions between the slabs can be identified, which must be able to bear the shear flow across the whole slab height (Fig. 13). Normally only three-layer slabs are mounted and bolted. In case of increased shear flow, the three-layer slabs are replaced by 6 mm metal plates, but only in particular zones.

8. The Funerary Centre Welkenraedt



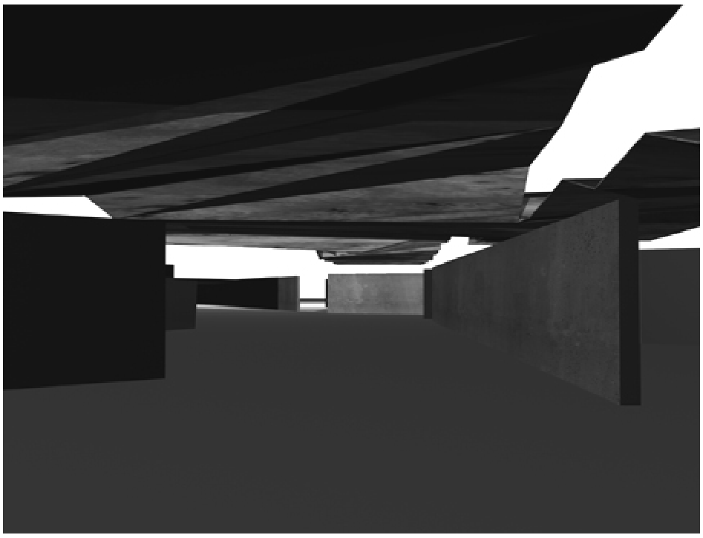


Fig. 14 General view of the building *Fig. 15 Interior view*

The building shall be embedded into a challenging landscape. The border triangle Lüttich-Maastricht-Aachen is considered to be the catchment area of the funerary centre to be built in Welkenraedt (Belgium). In addition to a crematorium, a funerary centre shall be constructed as well, both accessible to different religious denominations.

The provided site is situated in a rural area, beyond the urban zone. The site offers far-reaching views over the surrounding woodland and meadows, which should also be the case from the building. Hence the architects designed an open building, framing views of very different landscapes. Individual load bearing walls structure the interior spaces along the depth of the site, called "longitudinal direction" in the following. The external facades are almost completely glazed. The single storey building is covered by a timber roof. The wooden surface visible from the interior affects the ambiance of the entire interior. The roof is a folded structure, composed by plywood boards cut in triangular shape.

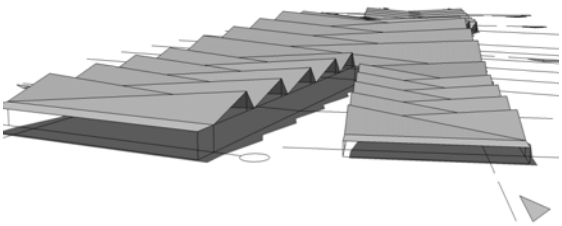


Fig. 16 Roof structure

The ground floor is covered by a roof of 4500 m². The surface is consolidated at first, then divided into two "arms". In the first zone the folded roof spans transversally across 18 m and allows cantilevers of up to 4 m. Beyond the division of the two arms, both main halls are covered by around 12 spanning folded structures each. The truss gets its rigidity from the folding. The plywood boards were modelled as surface elements. According to the first pre-dimensioning, a board thickness of 18 cm is sufficient. Already it becomes clear that using this form, very efficient bearing structures can be created.

The geometry characterized by sloping grooves on both sides enables rainwater evacuation both ways.

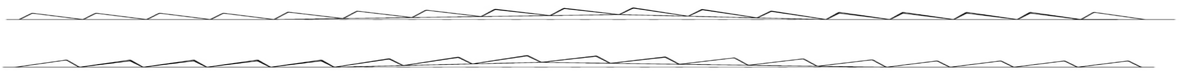
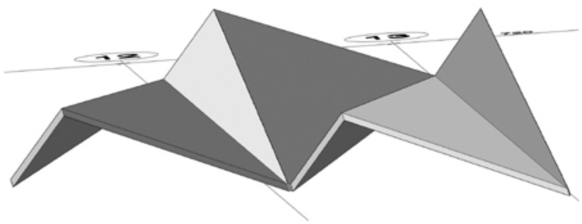


Fig. 17 Longitudinal section across the roof geometry

In the longitudinal direction a geometrical sequence was proposed, also due to spatial considerations, which can be understood by looking at the longitudinal sections. The visitors will “glide” through different spatial ambiances, reinforced as well by the different heights of the roof structure along the longitudinal direction. In order to be able to verify the spatial sequence, a 3D model of the roof construction was specially prepared. This way the roof becomes slightly elevated in the middle section.

These illustrations show that thanks to the nowadays available digital means, the chain from 'presentation pictures' to 'execution planning' is to be considered as one single chain of operations, which are closely related to each other. The digital model serves as the basis for design, dimensioning and execution planning.



-

Fig. 18 Portion of the roof geometry as 3D model

Finally the same 3D model enables most diverse applications. Illustration 18 shows a portion of this model. The low points of the construction are parts of the same horizontal plane. These low points are located on an axis system, which was numbered consecutively covering the whole area. In relation to this axis system all points can be defined in a Cartesian coordinate system. It is particularly interesting to observe specific points of the geometry. Illustration 19 shows the deployment at the support point of the roof. The double-folding almost disappears and both low points are not situated symmetrically to the axis 2, as one would have supposed intuitively in a traditional drawing.

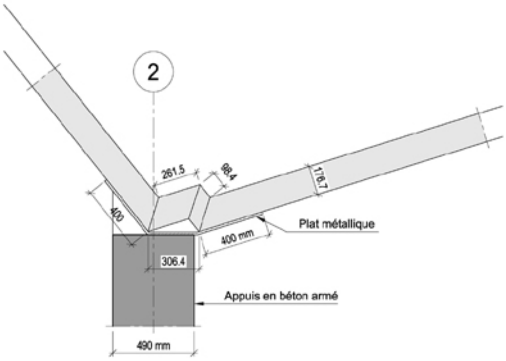


Fig. 19 Principle details of a support point

9. Conclusion

The projects shown materialize a synthesis of structure, space and form. From these briefly presented descriptions emanate, that the synthesis among these three poles can be achieved based on the use of plywood boards. This opens up perspectives for numerous novel applications in architecture and in construction engineering.

10. References

[1] Weinand Y., Natterer J., "Das Restaurant in Fumay", *39. SAH-Tagungsband 2007 Proceedings,* pp. 125 - 134.

[2] Weinand Y., "Museum für Fotografie", *39. SAH-Tagungsband 2007 Proceedings,* pp. 207 – 214.