Machine Frames Made of Wood

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Abstract. At present, wood is barely used in lifts at all. However, as the number of high-rise buildings made of wood continues to increase, it seems only logical to consider using wood for lift construction as well. This article provides information on the special characteristics of wood as a building material and describes some extraordinary opportunities for reducing energy consumption and environmental impact – and thus producing better lifts.

In particular, this article describes how wood can be used efficiently as the machine frame, which supports the motor and pulley in the machine room and maintains the distances specified for the rope from the car and counterweight, while achieving the best possible angle of wrap for the rope around the traction sheave. Apart from this example, the author describes generally how wood should be used to a greater extent in lift construction, not only to improve aspects such as noise insulation within the building, but also as a means of reducing costs and increasing sustainability.

1 INTRODUCTION

The idea originated from Mr Fredrick von Maltzahn, the owner of CTV S.L. Málaga, who came from a timber-producing family in Mecklenburg (northern Germany). He also financed the two initial sample machine frames and provided the attached photographs.

At present, an increasing number of high-rise buildings around the world are being constructed of wood. Among them, there are two types of such buildings. The first of them is a wooden construction built around a concrete core. A typical example of this is the eight-storey-high LifeCycle Tower, which was constructed in Dornbirn (Austria) in the year 2012 – see Fig. 1.

Figure 1: LifeCycle Tower in Dornbirn (Austria)

Purists prefer buildings constructed completely of wood, such as Mjøstårnet, which is 85.4 m high, has 18 storeys and was completed in Brumunddal (Norway in March 2019). It is officially the world's tallest timber building (see Fig. 2).

Figure 2: Mjøstårnet in Brumunddal (Norway)

Ambitions extend even further. Researchers at the University of Cambridge together with PLP Architects are planning the Oakwood Timber Tower with a height of almost 300 m in the centre of London (see the computer rendering in Fig. 3).

Figure 3: The Oakwood Timber Tower planned for the centre of London

It is therefore only logical that the components for the lifts in this building should also be made of wood to the greatest possible extent. The machine frame made of wood in the following is an example of this.

2 WOOD – MATERIAL CHARACTERISTICS AND DESIGN EXAMPLES

2.1 Materials for wooden buildings

EN 1995-1-1 [1] is decisive for the dimensioning and design of timber structures. This standard distinguishes between the various timber materials by strength classes, with the rated value of the class corresponding to the permitted bending strength, which like the other calculated values increases with bulk density of the material (see the attached table from EN 1995-1-1 – Fig. 4)

Strength Classes – solid timber (EN 338)

Table 1 — Strength classes - Characteristic values

		Poplar and softwood species												Hardwood species					
		C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50	D30	D35	D40	D50	D60	D70
Strength properties (in N/mm²)																			
Bending	$f_{m,k}$	14	16	18	20	22	24	27	30	35	40	45	50	30	35	40	50	60	70
Tension parallel	$f_{t,0,k}$	8	10	11	12	13	14	16	18	21	24	27	30	18	21	24	30	36	42
Tension perpendicular	$f_{t,90,k}$	0,4	0,5	0,5	0,5	0,5	0,5	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
Compression parallel	$f_{c,0,k}$	16	17	18	19	20	21	22	23	25	26	27	29	23	25	26	29	32	34
Compression perpendicular	$f_{c,90,k}$	2,0	2,2	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9	3,1	3,2	8,0	8,4	8,8	9,7	10,5	13,5
Shear	$f_{v,k}$	1,7	1,8	2,0	2,2	2,4	2,5	2,8	3,0	3,4	3,8	3,8	3,8	3,0	3,4	3,8	4,6	5,3	6,0
Stiffness properties (in kN/mm²)																			
Mean modulus of elasticity parallel	$E_{0,mean}$	7	8	9	9,5	10	11	11,5	12	13	14	15	16	10	10	11	14	17	20
5% modulus of elasticity parallel	$E_{0,05}$	4,7	5,4	6,0	6,4	6,7	7,4	7,7	8,0	8,7	9,4	10,0	10,7	8,0	8,7	9,4	11,8	14,3	16,8
Mean modulus of elasticity perpendicular	$E_{90,mean}$	0,23	0,27	0,30	0,32	0,33	0,37	0,38	0,40	0,43	0,47	0,50	0,53	0,64	0,69	0,75	0,93	1,13	1,33
Mean shear modulus	G_{mean}	0,44	0,5	0,56	0,59	0,63	0,69	0,72	0,75	0,81	0,88	0,94	1,00	0,60	0,65	0,70	0,88	1,06	1,25

EN 1995-1-1 Design of Timber Structures

Figure 4: Strength classes of solid wood

Strength classes are higher for wood species with a greater bulk density. The native softwood species (fir, spruce, pine) with bulk densities of approx. 410 – 520 kg/m³ lie in the range between C35 and C50, while the hardwood species (beech and oak) with bulk densities between approx. 740 and 870 kg/m³ lie in the upper range of the table. This means that only hardwood species come into consideration for the buildings with more stringent requirements on strength.

When solid timber is employed, the dependence of load on the grain of the wood has to be taken into consideration. Furthermore, the strength of the material decreases as moisture content rises (see Fig. 5), with an increase in moisture content of the material from 12 to 20% reducing strength by 26%.

Furthermore, the dimensions change as well. This is why, more than 150 years ago, plywood was invented, which involves several layers of wood each with the grain rotated by 90° being glued together. This leads to higher strength values and the swelling and shrinkage of the individual wood layers is homogenized.

Over the course of the years, further timber materials have been introduced, which in principle are based on the technology of and experienced gained with plywood. Examples include:

- Laminated timber made of softwood or poplar (glulam) in accordance with EN 14080, with the boards having the grain in the same direction when glued together – glulam from hardwood is currently used together with cross-laminated timber, CLT, (which is made of boards glued together with the grain arranged perpendicularly) for high-rise timber buildings

- Laminated veneer lumber from softwood species (LVL) in accordance with EN 14279 and 14374, in which veneer layers with parallel grains are largely glued together with phenol formaldehyde resins to produce beams or boards

- In the early 1990s, Germany and Austria then saw the development of laminated veneer lumber types, in which the individual veneer layers were glued together with the grain pattern normally rotated through 90° (in a similar way to CLT, which uses boards instead of veneer). By using hardwoods, these components then achieve strength values that enable steel structures to be replaced.

  The design of the machine frame used such a laminated veneer lumber made of beech for load-bearing purposes – boards of BauBuche Q (henceforth called “special beech LVL”) produced by Pollmeier, a company from Creuzberg in the German state of Thuringia. Design and calculation were then conducted in accordance with the BauBuche manual for structural calculation [3].

2.2 Special aspects to consider when designing with timber

The influence of grain is reduced by crosswise gluing of the veneer layers but does have to be considered in the calculation. The maximum load-bearing capacity is achieved when the grain is in the longitudinal direction of a support.

The large influence of *moisture content* in wooden structures has already been mentioned above and this is depicted once again in the following graph (Fig. 5).

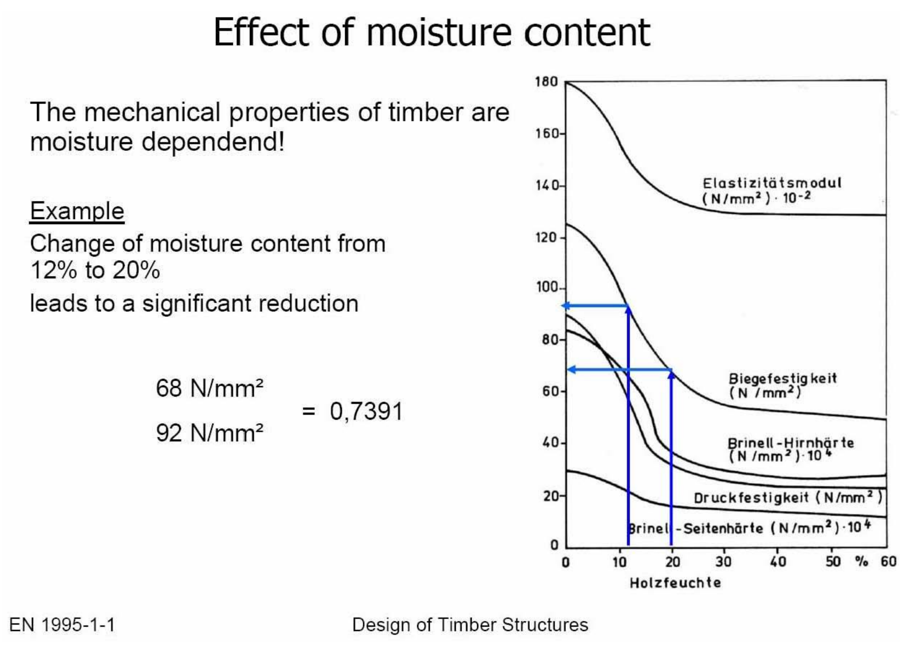

Figure 5: Influence of moisture content on the strength of wood

Biegefestigkeit = Bending Strength [N/mm²]

In order to take account of moisture content, service classes have been defined which then have to be considered in the calculations.

Wood deforms more markedly than steel, and, under constant load, the deformation is no longer reversible. The calculation therefore needs to take account of the *load-duration classes*, from permanent load to instantaneous loads.

Wooden materials naturally contain *formaldehyde*. In laminated timber this content is further increased by the use of adhesives to join the individual layers. As formaldehyde is a substance harmful to health, it is important that the maximum values of Class E1 (=0.1 ppm) quoted in the Declaration of Performance for the special beech LVL is observed.

The *fire behaviour* of wood is also considerably more favourable than would appear at first glance. Admittedly, wood as a material is flammable and is indeed classified by the German standard as normally flammable. Nevertheless, wood withstands a fire for a surprisingly long time. In the process, a carbonized layer forms on the surface of wood which has a heat-insulating effect and thus maintains the temperature on the inside at a low level [4]. The design of the structural framework for exposure to fire has to be compliant with EN 1995-1-2 [2]. Table 1 in this reference specifies a charring rate of 0.65 or 0.7 mm/min for laminated veneer lumber with a bulk density of ≥ 480 kg/m³. These values are also guaranteed for the special beech LVL. As there are also fire doors made of wood [5], it also has to be possible to produce lift doors from wood.

Wood has to be protected against *pests* (fungi, insects, bacteria). The most important protection involves keeping the wood dry as then no chemical wood protection is necessary in such cases. In hoistways, special attention is required to ensure that no condensation can arise due to temperature differences.

2.3 Examples of components made of wood in lift construction

<u>Beams on 2 supports</u>

The benefits of a timber construction made of laminated veneer lumber can best be shown with the aid of a simple example. Fig. 6, for instance, shows a bending beam on 2 supports, with a load and dimensions typical for the beam in the headroom of a lift with a capacity of 630 kg and a machine in the well.

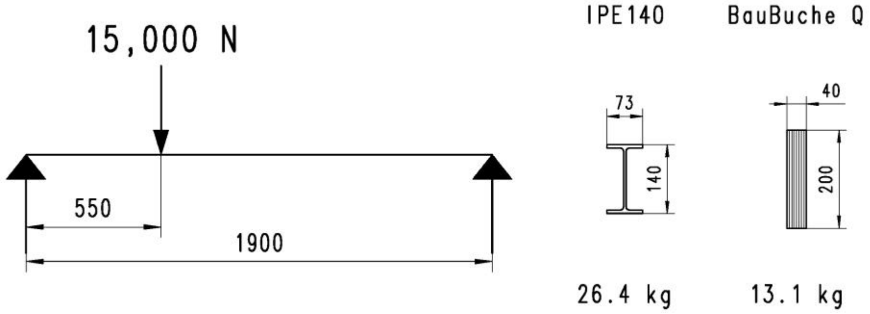

Fig. 6: Example of a simple bending made of wood compared with steel

Owing to this load, a steel beam IPE 140 is required and the maximum bending of this beam that results is approx. 1.5 mm (less than 1/1000 of the span). To achieve the same deflection, a wooden beam of 40 mm of special beech LVL would have to have a height of 300 mm and would be approx. 26% lighter. As EN 1995-1-1 permits deflections of up to 1/300 of the span, it would even be sufficient to have an overall height of only 200 mm for the wooden beam. Verification of the bending stress shows that we are then also far below the permissible limit of bending stress for the special beech LVL with this value. In this case the wooden beam would then weigh only 13.1 kg and would thus be only half as heavy as the steel beam.

Machine frame made completely of wood using the special beech LVL

The first machine frame that was designed, consisted entirely of wood. In this design, all steel components were systematically avoided (see Fig. 7).

Figure 7: Machine frame made entirely of wood

Machine frame made of the special beech LVL using steel parts

As a second version, a design was then produced that primarily consists of wood but uses a number of steel parts (see Fig. 8).

Figure 8: Machine frame made primarily of wood

Owing to the existing production options, this second version was preferred. It does also, however, have substantial advantages for the absorption of internal horizontal forces. It is better suited to the creation of a complete production series in left-hand or right-hand design with a simple adaptation to the required rope centre distances, ASL, between car and counterweight. Fig. 9 illustrates how it is possible with a few simple saw cuts to maintain rope centre distances of 650 mm to 1000 mm with an accuracy to the nearest millimetre.

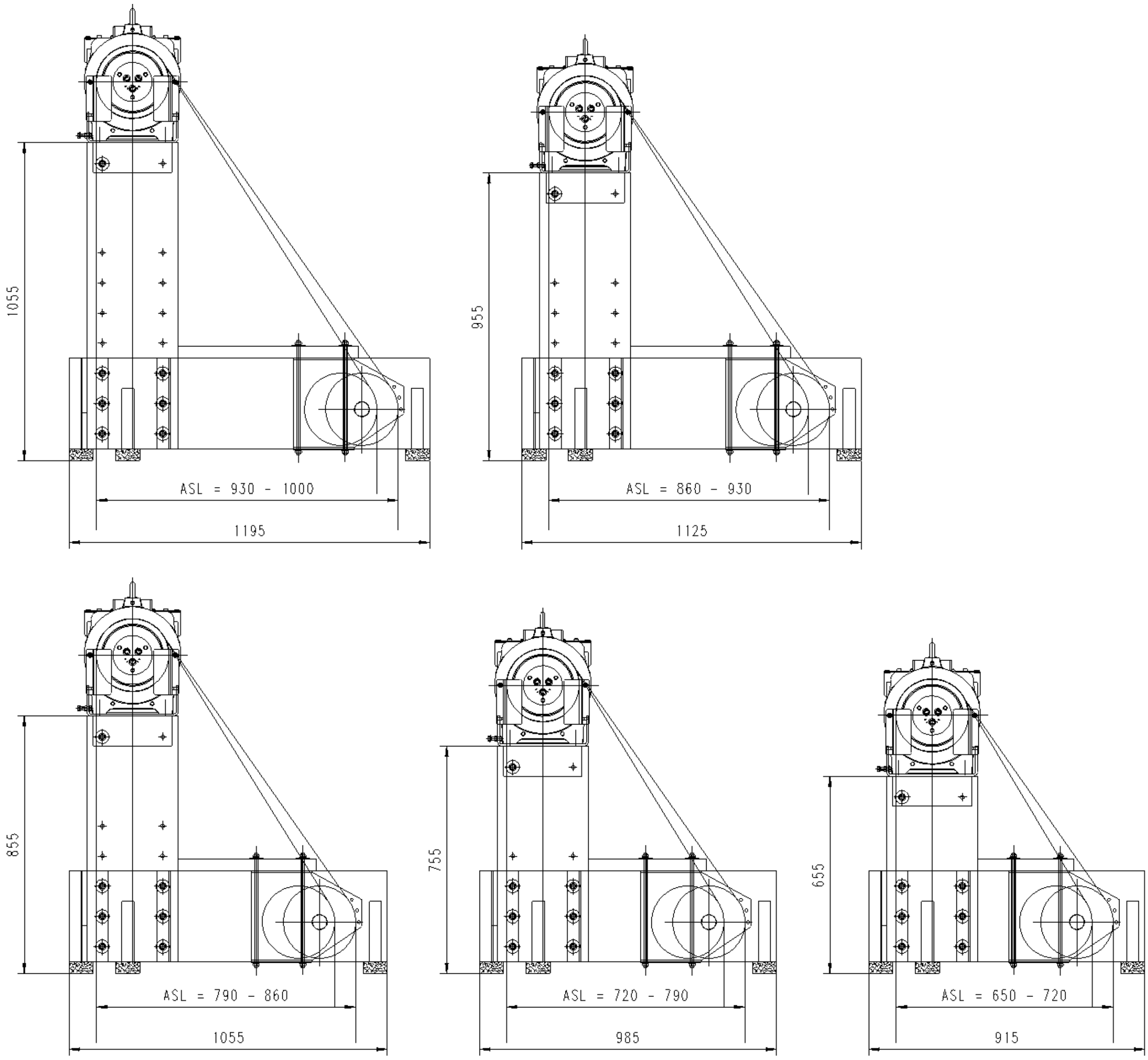

Figure 9: Simple adaptation of the required rope centre distances, ASL

The design displayed has been drafted for a lift with a capacity of 450 kg and a speed of 1.0 m/s, with a direct reeving (1:1) of car and counterweight. The weight of the motor required for this design is approx. 200 kg and the machine frame weighs approx. 100 kg, of which the steel parts including the polyamide pulley accounts for approx. 40 kg - the proportion of wood therefore amounts to approx. 60 kg.

The low weight facilitates transport on the building site and installation. A further advantage is that wood, unlike steel, has a lower tendency to vibrate.

3 USE OF WOOD AS A CONTRIBUTION TOWARDS REDUCING THE ENVIRONMENTAL BURDEN

The greatest advantage of using wood, however, is the contribution that it makes to reducing the burden on the environment. It is sufficient to consider one small aspect at this point: namely the amount of energy required to produce a steel part (e.g. a beam or plate) from iron ore. – The manufacture of wooden materials involves much shorter production routes and much less energy to manufacture the end product. And prior to this, the tree has already been contributing to an improvement of the environment by producing oxygen.

Today, large lift companies advertise with the aid of an Environmental Product Declaration in accordance with ISO 14025 in order to indicate that their product is especially environmentally friendly. It is referred here, for instance, to a declaration such as that for the OTIS Gen2 Stream [6], where it can be clearly seen that the greatest environmental burden occurs in the procurement of the material (U1) and during the operation of the lifts (D4) over a number of years (see the following diagram – Fig. 10 – which has been taken from this EPD).

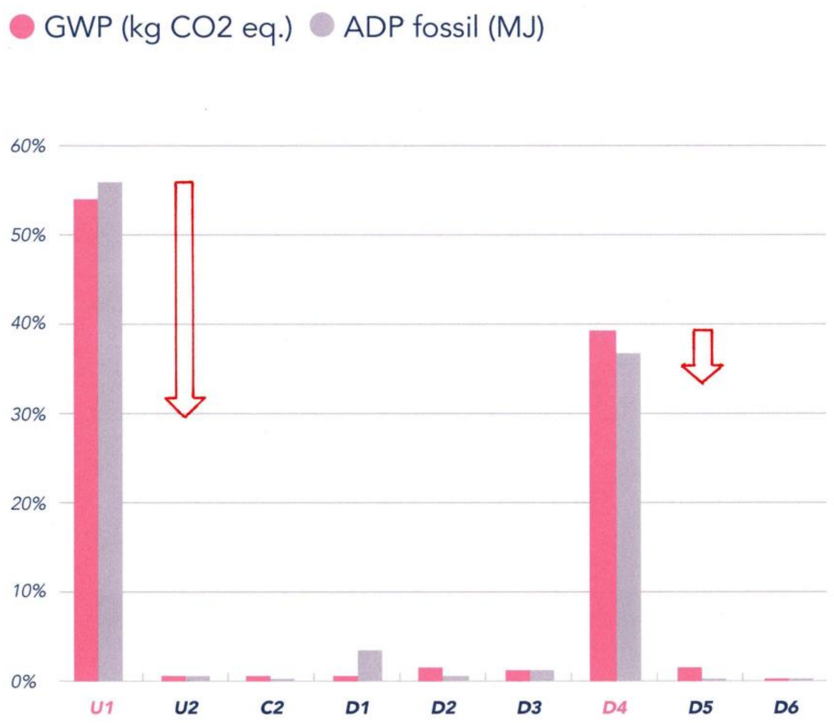

Figure 10: Life Cycle Assessment OTIS Gen2 Stream

GWP – Global Warming Potential [kg CO2 eq.]

ADP – Abiotic Depletion Potential [MJ]

This also clearly sets out how the environmental burden can be effectively reduced. One particularly effective measure lies in the field of material procurement by reducing the steel content:

- By reducing the masses (lightweight construction)
- By eliminating entire components (e.g. the counterweight with its guides in drum lifts)
- By replacing steel with wood – the more components that are replaced (e.g. machine frame, car, landing doors, …), the more effectively the environmental burden can be reduced and very large savings can be achieved in this way.

The savings potential to be achieved in the operating costs is lower:

- Due to the lower mass (e.g. wood instead of steel) that subsequently has to be moved during operation, the frictional losses decrease during the journeys, which means the efficiency within the system improves and, accordingly, the required motor output and power consumption decrease.

- Added to this is the fact that the lower masses lead to a reduction in the start-up and braking currents.

However, this also requires a change in thinking for driving the lifts. In the traction drive, which is the most commonly used system at present, the friction is produced on the traction sheave by the large masses of car and counterweight. If the masses are reduced through the use of wood, the advantage lies with other drives:

- For smaller travel distances (up to 25 m), the winding drum lift (or other drives that function in a similar manner) offers a solution.

- In the case of greater travel distances, traction lifts are conceivable in which suspension ropes and driving ropes are separated and the friction for the drive is produced via weights (or, for example, similarly functioning drives). Such drives have been familiar since the beginning of the last century and have been produced by a number of lift manufacturers up to the present day (see US Patent No. 810 941 dating from 7 May 1903 [7]).

Wood can be used for the following lift parts: beams, machine frame, cabins, car doors and landing doors and hoistway cladding panels. In many cases, timber is already the predominant material for scaffolding and barriers needed during installation as well as for packaging.

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BIOGRAPHICAL DETAILS

Dipl.-Ing. Roland Stawinoga has been involved in the mechanical design of elevators (and escalators) for more than 60 years. He is a member of the IAEE and well-known for his technically authoritative lectures (ELEVCON from 1993 in Vienna till 2001 in Berlin), which have also been published in the most important elevator trade journals (Elevator World, Lift-Report, China Elevator and others).

In 1990, he founded his own engineering office in Hamburg and – since planning and supervising the construction of the lifts for two of the five buildings in the German Bundestag – he has been living in Berlin. He passes on his experience to lift firms by providing them with technical advice and delivering special designs and calculations. In 1997, he was invited by OTIS to conduct further training seminars for their employees and since then has conducted far in excess of 100 seminars with a total of approx. 1,100 participants (among them 470 OTIS employees). A large number of these seminars took place in Rosswein in Saxony, where four seminars are again scheduled at MFM this year. Furthermore, he has also conducted seminars for firms directly on company premises, most of which have been held in English, Spanish and Polish.