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GLUED TIMBER TRUSSES

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ABSTRACT: Current timber trusses are mainly made using steel fasteners, nail plates, or dowels with slotted plates. Glued timber trusses are applied commercially by two companies: German PERI produces trussed joists for concrete casting and Canadian Barret Structural makes trussed joists for residential floors. These trusses are based on finger joints made using a cursor. Recently, a Finnish company Teeri-Kolmio Oy started manufacturing glued trusses for residential floors with the joint processed using a saw blade. The such joint enables deep chord routings up to through the chord, long fingers, large web-chord glue areas, minimal timber splitting, and high resistance and reliability. There are further special characteristics. Top chord support is possible without hangers. The truss can be manufactured as a long billet, stored at lumberyards, and cut for actual needs. The truss can be manufactured without open routings and water pockets. The truss is strong and reliable and can be applied for the roofs of commercial buildings up to about 30 m spans. Our study shows that the trussed roof is more cost-effective than the glulam roof which opens a promising new business possibility.

KEYWORDS: Glue, Truss, Joist, Billet, Trimming, Visual joint

1 INTRODUCTION

The glue is the cheapest, stiffest, and often the strongest timber fastener. The truss is the most effective structural model in horizontal structures with the least material and the best flexibility. Timber is a renewable structural material.

Prefabrication and automation are demands for effective construction. It means that the horizontal structures are made of joists with uniform height. The glued timber truss is the most cost-effective and ecological horizontal joist with uniform height.

Timber trusses are mainly applied for floors and roofs. The floor trusses are always parallel chord trusses with uniform height. Roof trusses are normally pitched. The authors believe that the parallel chord trusses gain market in the roofs, too, as such trusses are well suited to off-site construction and prefabrication and further suit well for attic roofs.

Currently, timber trusses are not applied to roofs. In this article, calculations are presented which show that glued timber trusses have potential in roofs, especially in long-span commercial roofs, with spans normally 15-25 m but up to about 30 m. Our study shows that the trussed roof is more cost-effective than the glulam roof which opens a promising new business possibility.

Consequently, the glued timber truss has potential.

This article focuses on timber trusses with uniform height made of timber and glue only. Timber trusses with steel connectors are touched as a comparison only [1-5].

1.1 LIGHT TIMBER TRUSSES

Light trusses are made of small timber members like sawn wood. Current light timber trusses are mainly made of nail plates. The global market exceeds €10 bill. The glued trusses play a minor role, apparently less than €0.2 bill.

The glued joint has some advantages over the nail plate joint:

- In a glued joint the web chord load path has only one shear joint, but two shear joints are needed in the nail plate joint. Thus, the glued joint is more cost-effective in this regard.
- The glued joint has a lower slip due to a more rigid joint and a lower number of shear joints.
- The glue cost per share area is only about 5 % of the nail plate but the effective shear resistance of the glued joint is about 50 % less. Further, excess timber is needed in the glued joint due to web fingers. The overall glued joint cost is less than the nail plate joint cost.
- In a nail plate joint the web width must be the same as the chord width, which normally is not optimum regarding the web resistance. Especially, in the parallel chord nail plate trusses, the web width, about 100 mm, is defined due to the joint resulting in about a twice bigger web volume and cost than needed for the web resistance. The glued truss lacks this deficiency.
- Glued trusses are mainly used concealed. The glued joint does not require the precise timber cross-section and the planing is not needed,

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while needed in the nail plate trusses. For this reason, the glued timber truss has a 5…10 % timber cost advantage.
- The fire resistance of the nail plate truss is defined by the negligible fire resistance of the nail plate. The fire resistance of the glued truss is defined by the wood charring.
- The nail plate truss has poor resistance in the open air. The glued truss can be used in the open air, the resistance is normally defined by the wood, not the joint.

On the other hand, the nail plate joint has advantages over the glued joint:
- The glued joint needs finger routing in the web and in the chord with excess cost. However, this cost is negligible in automatic manufacturing.
- The finger routings in chords weaken a little the chord resistance. This issue is negligible as the chord routings make only local defects in timber analogous to knots. The primary design criteria in trusses with uniform height are deflection and joint resistance, and the chord resistance is secondary.
- It is difficult to implement the glued joint in complicated cases like pitched trusses. On the other hand, the nail plate joint is flexible and can easily be implemented in complicated pitched trusses and frames.

The glued joint is most suitable for standardized applications like parallel chord trusses with uniform height. Implementing a glued joint to pitched trusses is challenging.

1.2 ROBUST TIMBER TRUSSES

Robust timber trusses are made of robust timber members like glulam. The authors made a study to obtain a robust timber truss using only glue in the joint, patent US2008092988. The joint needed sophisticated CNC processing and did not reach the commercial market.
There are research studies for robust timber truss joints made of glue and steel rods or plates. However, such trusses have not gained a significant commercial market.
The current robust timber trusses are made of dowels with slotted steel plates. Such joint has high material and labor costs and therefore the commercial competitiveness is not good regarding other alternatives like steel trusses.
Current primary girders are placed normally 4…6 m apart from each other where a secondary structure is needed. An alternative concept is explained here: the trusses are about 0.5 m apart from each other. A secondary structure is not needed. This article explains that this glued timber truss roof concept offers a profitable business potential as it seems to be more cost-effective than the glulam roof.

1.3 RISK REVIEW

Glued timber trusses are applied commercially little though the high potential. This is apparently due to the perception of the unreliability of the glued joint. The resistance of the glued joint is prone to timber defects like knots and inclined fiber and the resistance of the glued shear joint. The glue must be spread reliably, and the glue must not be decayed. One inproper joint may be fatal for the overall resistance of the truss. Thus, the glued joint must be subjected to strict quality routines analogously to welded joints in steel trusses.
The current manufacturers of glued trusses for the structural market have secured quality issues by proof-loading each commercial glued truss to 1.5…1.8 times the allowable i.e., characteristic load. This quality routine makes a more reliable outcome with a proper proof load than in the code-based design, but it makes considerable excess cost and is difficult in trusses made as a billet and in long-span roof trusses.
The authors believe that proof-loading is not necessary when careful quality measures are taken:
- The basic principle of a glued timber joint is that the failure should not occur in the glue line. It is possible to fulfill this requirement in the glued truss joint.
- The timber quality on webs and especially on the web fingers is critical. Therefore, the webs should be appropriately graded to avoid critical defects, especially big knots.
- The chords should be graded too analogously to the grading of the flanges of I-joists.
- In the glued joint the glue must be spread all over the joint and the glue must not be decayed. The glue cost in the truss is negligible and therefore it is feasible to overdesign the glue joint in critical cases for example by limiting allowable mean glue shear stress to a low value, e.g., about 0.3 N/mm^2 for the characteristic load. The glue cost in the glued truss is little and the overall effect is negligible.
- It is beneficial to make the joint and the fingers big when small knots in the timber are allowed as they play a negligible role.
- The glue should be spread using a robot to exclude human errors and further, an automatic camera checking should be applied to secure the outcome.
- In critical points like truss ends, multiple adjacent webs may be applied to reduce stresses and increase reliability. The web cost in a glued truss is negligible and therefore multiple webs make only a minor excess cost.

1.4 WOOD MATERIAL

Any sawn wood with minor defects especially minor knots like spruce is suitable for glued trusses. Glulam, LVL, and other glued products are feasible, too.

2 EARLIER GLUED TIMBER TRUSSES

There were three glued truss concepts on the market, one based on finger joints and two based on lap joints.

2.1 DSB

DSB, patent US2780842, is the first commercial glued timber truss manufactured in Germany for floors and roofs in multiple plants from about 1950' through 1970'.

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The production was terminated apparently due to quality assurance issues.

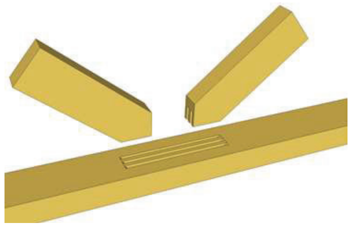
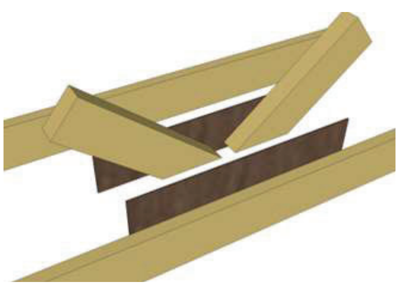


Figure 1: *DSB joint, the fingers are not tapering and the webs are not connected to each other.*

2.2 IU-TRUSS

Finnish inventor Pertti Purontakanen filed a patent FI54008 in 1979, for a glued timber truss where the chords are double planks, webs are planks and are inserted between the chord planks, and 3 mm plywood is between the chord plank and the web plank. The purpose of the plywood is to avoid stress peaks in the glue joist and to simplify the glue application as the glue is spread on the plywood. A batch of trusses was stacked on top of each other and pressed together using a hose and air pressure. IU-truss was on the Finnish market for about a decade. The production terminated due to stability issues of the upper chords and webs causing a roof collapse at least in one case. In the IU-truss, both upper chord planks must be nailed to the battens to avoid lateral buckling.



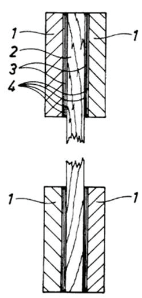


Figure 2: *IU-joint*

Fig. 3

2.3 A-TRUSS

Finnish inventor Arvo Hyvärinen developed A-truss which is like a nail plate truss, but the nail plates are replaced with birch plywood glued to chords and webs. The assembly of the A-truss is the same as in the IU-truss. Although the A-truss is more expensive than the nail plate truss, the A-truss was on the market for two decades. The A-truss fabricator specialized in complicated cases which the connector truss fabricators opted not to do. One may think that the resistance of the A-truss is doubtful, but the authors do not know of one failure with these trusses.

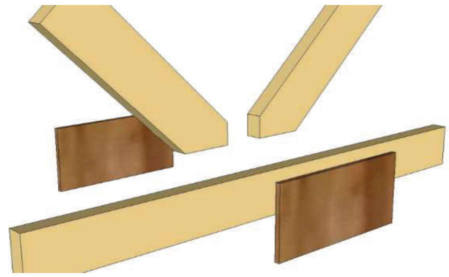


Figure 3: *A-joint*

3 CURRENT TIMBER TRUSSES

Nakashima et al [4], patent JP2014055406A, developed an interesting joist which is a combination of truss and I-joist.

Figure 4: *Nagashima's joist*

There are three glued timber trusses on the market, all based on finger joints.

3.1 PERI

The PERI truss, patent CH306573, is like the DSB-truss, but the webs in the joint are connected to each other by a finger joint with tapering fingers. The PERI-joint has high resistance which is due to deep chord routing and high chord thickness, about 60 mm. The PERI-truss is used as a joist for concrete casting. The PERI-truss is currently exploited extensively on the market.

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Figure 5: *PERI-truss and joint*

3.2 TRIFORCE

A more improved product with a tapering finger joint in the web-chord joint and in the web-web joint was developed in Canada some 30 years ago, patent CA2335684, https://www.openjoisttriforce.com/. The web cross-section is rectangular 38*38 mm^2, and the chord routing is shallow, 16 mm. This joist has established a solid position in the residential floor market in the US and Canada. It is produced in standard lengths with an option for 600 mm trimming on one end.

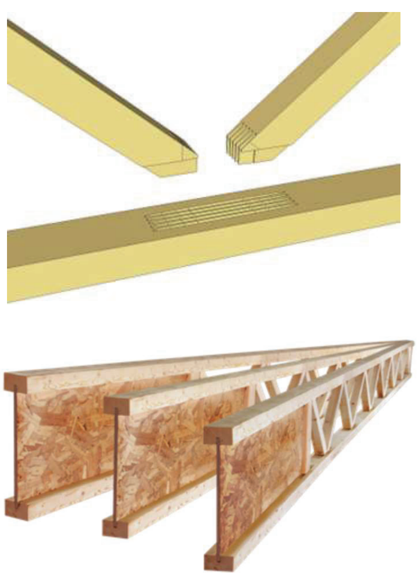

Figure 6: *Triforce joint and truss*

3.3 G-TRUSS

G-truss is the latest glued timber truss on the market explained in more detail in the next paragraph, www.gjoist.com, www.tk-palkki.fi

4 G-TRUSS

The authors started the glued truss development more than 20 years ago. In the beginning, the focus was to develop a joint suitable for light and robust trusses without open routings [1, 2]. A patent US7975736 was granted to a joint where routings were processed using a cursor moving in the axial direction. This embodiment did not reach the commercial market.

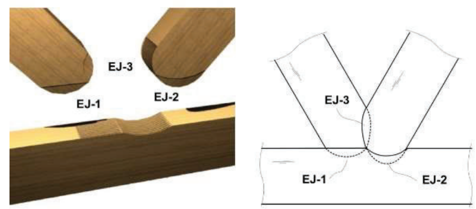

Figure 7: *Glued truss joint, US7975736, suitable for light and robust trusses.*

In 2014-2017 the authors realized a development project where more than 10 joint models and more than 300 full-scale trusses were tested [3]. Innovations were made and three patents were granted EP3620588, US11162262, and US11220821. The new truss was named "G" glued truss and glued joist.
The G-truss consists of some new features:

4.1 Simplicity

All webs in the G-truss are similar and there are no verticals. There are only three different timber member types in each truss. Upper chord, lower chord, and web. All mortise routings in the chords are similar and all tenon fingers on the web ends are similar, too. Thus, the timber members are easy to make and assemble.
The simplicity applies to the structural design, too. As the web pattern is the same along the truss, the resistance also is the same along the truss. The G-truss can be turned upside down. These features are significant in a truss manufactured as a billet.

4.2 Saw blade routing

The fingers in the joint, the tenon web fingers, and the mortise chord fingers are processed using a saw blade. The fingers are tapering and therefore the processing is made in two steps in two saw inclinations, as shown in Figure 8. The saw blade makes a good surface for gluing and a small knot in the finger does not make any timber splitting.

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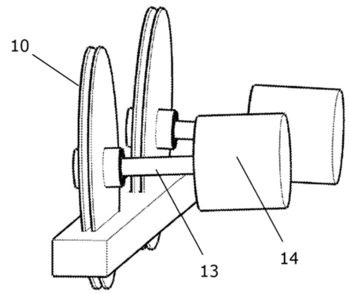

Figure 8: The saw blade routing is processed in two steps to obtain the tapering fingers.

4.3 Trough routing

The web finger punches the chord, which results in a big joint. The joint size is the maximum possible i.e., the whole overlapping area of the web and the chord. In such a joint, a small knot is not critical. The web-chord glue area is large meaning small shear stress in the glued shear joint. The mean glue shear stress for the characteristic load is about 0.3…0.5 N/mm^2

4.4 Only one or two fingers per web

In the glued timber truss joint the resistance of one web finger decreases when the number of fingers per web increases on the web. The G-web has only one or two fingers per web and therefore the web finger is effective.

4.5 Upper chord support

The upper chord support is possible without a hanger as the web finger is long and reaches above the support. This feature makes about a 20 % cost advantage in cases when the hanger can be avoided.

Figure 9: The G-web finger punches the chord.

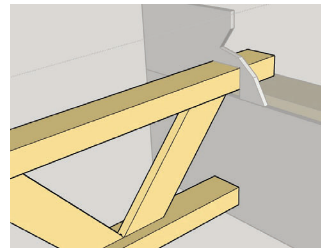

Figure 10: The upper support is possible without a hanger.

4.6 Free web layout

The webs in the G-truss may be connected to each other as is normal in a truss, but the webs may be apart from each other. This enables two features missing in a normal truss where the web pattern and the node points normally are fixed:

- The node points within the truss can be fixed to match the extra support along the truss and thus the reinforcement of the truss is not needed in the support. The extra support may be on the bottom chord or on the top chord.
- The crosswise opening which may be excessively big can be fixed arbitrarily. It is possible to fix a continuous crosswise opening along adjacent trusses for MEP or to assemble a crosswise girder inside the adjacent trusses.

The web layout normally means that the webs make an X-pattern. In this embodiment, the supports and the openings in a truss may be fixed to fully match the actual situation in the building. Figure 11 shows a truss with a special web layout.

In a normal truss, the webs and the chords have no or negligible moment stresses. When the webs are fixed apart from each other in the chord joint, excess and harmful moment stresses are induced, in the joints, webs, and chords. These excess stresses set some demands on the joint and the truss.

- The joint must be reliable and strong.
- Normally at least one extra web is needed in critical cases to shear the excess stresses to multiple webs and joints.

In the G-truss, the webs may be fixed apart from each other as the joint is strong and an extra web may be fixed anywhere along the truss.

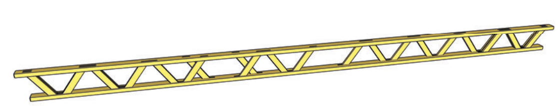

Figure 11: A truss with a special web layout.

4.7 Billet manufacturing

Current trusses are manufactured for fixed length (with eventual trimming option at ends) with supports at bottom chord ends. G-truss can be manufactured as a long billet like I-joist and solid joist and cut arbitrarily to make multiple working trusses. Each joist can be supported at the bottom chord, top chord, between chords, or along the truss.

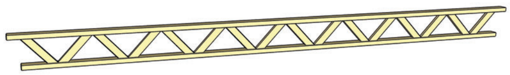

Figure 12: *A billet truss that can be cut for multiple working trusses.*

If the support does not match a node point reinforcement is needed at the support. Figure 13 shows a reinforcement when the support is in the upper chord at the joist end. OSB panels and steel U-rail are nailed on the chord edges.

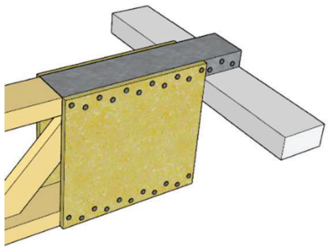

Figure 13: *The billet truss can be cut arbitrarily, if the cutting point does not match a node point a reinforcement is needed. The upper support reinforcement is realized by fixing OSB-paned and steel U-rail.*

5 FLOOR TRUSSES AND JOISTS

The global timber floor joist market is about €5 bill. The I-joist is the market leader with a 50 % market share due to low material cost, simple manufacture, and the option for billet manufacturing.
The floor sets many special demands for the joists. The current joists match differently these demands.

5.1 Horizontal openings

The residential floor often includes MEP installation. The space between the joists can be utilized for MEP. Often the installation across the joists is needed, too when crosswise openings are useful. A truss has crosswise openings without extra cost. Such openings are not possible in the solid joist and I-joist perforation is limited and causing extra cost.

5.2 Support

Floor joists are mostly supported at the lower edge. However, the hanging support suits better, especially for the supporting beam and normally for the wall structure, too. The truss can be supported at the upper chord which allows the advantages of the hanging support. A hanger corresponding to about 20 % excess cost is needed in the I-joist and in the solid joist.
Hanging support is an increased trend in construction. It is especially useful in off-site construction and in prefabrication. G-truss can be supported at the top chords without a hanger.

5.3 Cross bracing

Walking on the floor makes impact loads which should be distributed to multiple joists to avoid harmful local deflection and vibration. Therefore, there should be a cross-bracing "strong back" like a 50*150 mm^2 board across the joist which shares the impact load with multiple joists. Such cross bracing is impossible in the I-joist and in the solid joist and therefore these joists need some greater height to compensate for the missing cross bracing inducing excess cost.

5.4 Billet manufacturing

I-joist and solid joist are manufactured as a billet, kept in stock, and cut to actual need which is effective regarding logistics and the overall economy. G-truss is the only truss that can be manufactured as a billet which is due to the high joint resistance.

5.5 Vertical openings

The residential floor virtually always has a vertical opening like a staircase or chimney where joists hitting the opening are cut and excess joists are fixed by side of the opening. Cross beams are needed to support the cut joists. Currently, the cross beams are fixed at the perimeter of the opening and fixed by the faces of the excess joists. G-truss has three characteristics that enable a simple and flexible structure:

- The cross beams can be fixed inside the G-trusses i.e. they need not be by side of the opening. For this reason, the cut beams may run beyond the cross beams to make overhangs. Cutting of the overhangs is arbitrary and therefore the form of the opening is arbitrary, for example, a circle. Currently, the form of the opening can be rectangular only.
- The cross beams are not supported at the faces of the excess joists, but inside them, which denote simple joints e.g. hangers are not normally needed.
- The crossbeam may be excessively long to be supported by multiple joists and thus sometimes extra joists are not needed.

Figure 14 shows the principle of the new structure.

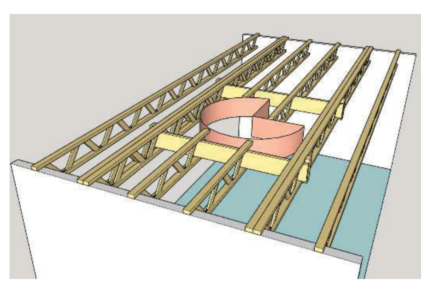

Figure 14: *the principle of the new opening structure.*

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5.6 Costs

The special features explained above have cost effects different for each joist.
Figure 15 shows approximate costs for a typical 6 m residential floor.
G-truss has the least material cost and has no excess costs regarding the special features.
In this Figure, the factory price of the G-truss is €7/m. The high price is due to patent royalties and good profit for the licensee manufacturer.
In the long run, the factory price of the G-truss and the I-joist should be about the same.
Approximate CO2 emissions are given, too, the G-truss is the most effective in this regard.

	G-joist	I-joist	Metal web joist	Plated joist	Wood joist
Material	3.2	3.5	5.0	5.5	9.0
Manufacturing	2.3[1]	1.0	2.0	2.5	-
Overhead costs	1.5	1.5	1.5	1.5	-
Factory price	**7.0**	**6.0**	**8.5**	**9.5**	**9.0**
1.Perforation	-	0.5	-	-	0.5
2.Support	-	1.0	≈0.5	≈0.5	1.0
3.Cross bracing	-	0.5	-	-	0.5
4.Billet opt	-	-	1.0	1.0	-
5.Openings	-	0.5	0.5	0.5	0.5
Reference price	**7.0**	**≈8.0**	**≈9.5**	**≈10.5**	**≈11.0**
CO2ekg/m	**0.3**	**0.6**	**2**	**2**	**3**
Current market		**2 500 M€**	**2 500 M€**		

Figure 15: *Approximate floor joist costs, €/m at 6 m span.*

6 ROOF TRUSSES

The global roof demand is huge. Currently, timber is competitive in residential roofs mainly via the nail plate truss. Steel and concrete dominate the commercial roof market.

6.1 RESIDENTIAL ROOFS

The nail plate timber truss dominates the residential roof market due to its low cost and flexibility to accommodate multiple geometric and structural forms. However, the nail plate truss has some deficiencies:

- The nail plate truss needs height which means that the prefabrication of the roof is not feasible. The roof must be constructed on-site from prefabricated trusses.
- The nail plate truss is not effective for a house with an attic, either the truss will be very expensive, or the attic space is limited.
- A roof opening in a nail plate truss roof is complicated and expensive.

Glued timber trusses are not currently applied in residential roofs. Joists with uniform height, I-joists, solid joists, or nail plate trusses are sometimes applied for residential roofs. The glued joist would be more cost-effective.
Off-site construction and prefabrication are strong drivers and trends in construction. Therefore, the authors believe that the joisted roofs gain market.
The mono-pitch residential roof is the most cost-effective for the glued truss as it suits the offsite manufacturing of panel components. A double-pitched roof can be prefabricated effectively too if the joists can be fixed parallel to the ridge. Ridge beam plus joists along pitches are feasible, too.

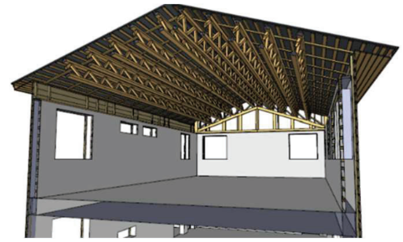

Figure 17: *Pitched roof can be constructed effectively using joists by fixing the joist parallel to the ridge.*

6.2 COMMERCIAL ROOFS

The nail plate truss can be applied for commercial roofs up to about 30 m spans. The truss cost is low, but the roof can't be prefabricated. The expensive on-site construction work deteriorates the overall economy.
The glued truss enables roof prefabrication and automation and is feasible in long-span commercial roofs where strict deflection and dynamics demands are missing. The feasible height of the glued truss is about span over 25. The reliability without proof loading is obtained using the measures explained above. The overall economy is good and there is commercial competitiveness even with proof loading.
Next, two commercial buildings are compared regarding roofs, one building has a G-roof, and the other has a consistent glulam roof [5]. The walls and roof of both buildings are rigid diaphragms to resist horizontal forces. The columns in the glulam building resist the vertical forces only.
The snow load is 2.2 kN/m^2. The net inner height is 5.2 m, and the width is 18 m. In both cases, the roof consists of 2.4 wide and 18 m long prefabricated elements. The measures of the glulam girder is 1164 mm…1440 mm*190 mm, GL30c, c/c 6 m.
The 18 m long G-truss has a height 780 mm, chords are 60*195, and webs are 45*73 doubled at the ends.

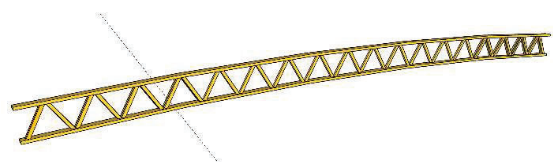

Figure 18: *The 18 m long G-truss*

Figure 19 shows the cross-section of the G-roof element. Soft mineral wool insulation or loose insulation is applied to enable simple application in spite of the inclined webs. Semi-hard insulation panels are at the sides to make a good seam between the elements.
We see that the basic structure is flexible:

- Additional trusses can be fixed in cases when extra resistance is needed e.g., in point loads or in roof openings.

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- A crosswise girder for extra support, crosswise overhang, or point load may be added.
- The G-truss can be supported at the top chord which is beneficial in the beam support.
- The G-roof element can be fixed to the wall or a beam by processing above the element, with no fixing nor sealing below the element needed.
- The sealing between the elements is simple, only the upper membrane must be fixed onsite.
- The seam includes a big assembly tolerance, though it is air and moisture tight.

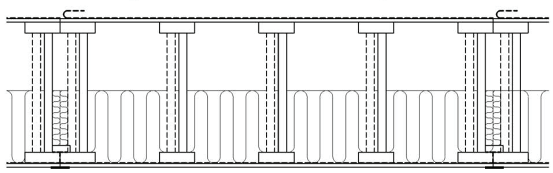

Figure 19: *Cross section of 2.4 m wide roof element of G-roof. The element includes five G-trusses.*

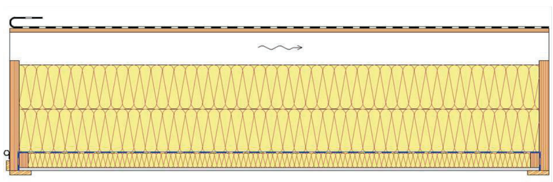

Figure 20: *Cross section of roof element supported on glulam beams, such element is dominantly used in Finland, disclosed in LVL Handbook, Figure 2.39 https://proofer.faktor.fi/epaper/LVLHandbook_2020/#76.*

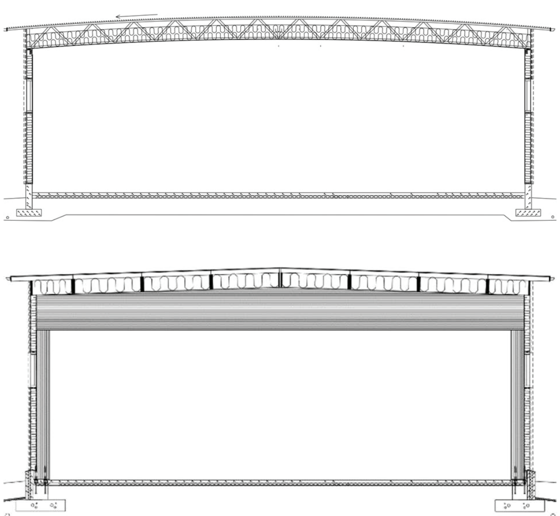

Figure 21: *Cross section of the G-building above and the glulam building below, the net inner height is 5.2 m and the width is 18 m. The wall height of the glulam building is 6864 mm, and 5920 mm in the G-building. The overall roof height in the G-building is about 50 % less. The glulam building has a secondary and normally harmful building volume between the beams, 25 % of the net volume.*

Table 1 includes wood volume, approximate wood cost, and approximate CO2 emission for the G-roof and for the consistent glulam roof in 18, 24, and 32 m spans. The calculation is based on the sawn timber cost €300/m^3, and glulam and LVL cost €600/m^3. The assembly cost of the G-truss is €3/m [5]. The table includes the wood cost only, the lower and the upper cladding and the insulation are the same in both structures and these costs are excluded.

We see that in all cases the overall wood volume is about the same in all alternatives, but the G-roof is about €20/m^2 cheaper as the G-roof consists of low-cost sawn timber only. The G-roof has lower CO2 emissions.

In the G-buildings, there are further advantages resulting in lowers costs not considered in the figures of Table 1:

- The wall area is less.
- The volume of the building is less requiring lower heating/cooling costs.
- Columns and column foundations are not needed when the roof is supported on walls.
- The secondary structure of the roof costs less. In both cases the assembly of the 2.4 m*18 m roof element is manual. The assembly of the G-element costs less as it has only 8 wood components per element whereas the glulam roof element, FigSure 20, has 75 wood components.
- The construction work is simple including the walls, and the roof only, the building skeleton, columns and girders, and the column foundations are not needed.

The factors listed above make further benefits for the G-building and the overall advantage is about 10 % of the overall cost of a commercial building.

Table 1: *Comparison, G-roof vs glulam roof [5]*

	Span (m)	18	24	32
G-roof	Wood (m^3/m^2)	0.061	0.106	0.195
	Wood (€/m^2)	25.6	37.9	64.8
	CO2 (kg/m^2)	4	5	8
Glu-lam	Wood (m^3/m^2)	0.078	0.104	0.179
	Wood (€/m^2)	43.2	58.0	103.2
	CO2 (kg/m^2)	8	9	14

7 DISCUSSION

The G-trussed joist used in residential floors seems to be more cost-effective than other timber joists. The cost advantage is €1-3/m i.e., €2-6/m^2. The high floor cost is an Achilles heel in timber engineering, especially in long spans. In this regard, the G-truss increases the competitiveness of timber engineering.

The authors believe that the joisted roofs gain market due to prefabrication and automation. The G-truss apparently is the most cost-effective joisted roof structure.

G-truss economically reaches long spans up to about 30 m. There are two prefabricated wood elements that reach long spans, too: LVL box slab https://proofer.faktor.fi/epaper/LVLHandbook_2020/#76 and modified I-joist-box-slab https://www.kielsteg.com/. Both are more expensive than the G-truss, as in these elements the wood plus glue cost is about 100 % higher, and the CO2 emissions are manifold. Further, these slabs have difficulties in thermal insulation, assembly at the

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site, vertical and horizontal openings, supports, crosswise connections, air circulation, crosswise girder, and crosswise overhangs.

The G-truss seems to be sufficiently economical to undercut the costs of the current dominant structural model of commercial buildings: a skeleton arrangement plus a secondary structure. Thus, the G-truss has the potential to change the construction paradigm.

G-truss roof is competitive against steel and concrete roofs, too. Thus, the G-truss increases the competitiveness of timber in construction.

Only floor and roof glued trusses are addressed here. However, glued trusses are feasible in other applications, too like bridges, scaffoldings, railings, joists for concrete casting, and studs.

The truss is a complicated structure; however, the G-truss is simple, and it goes in for prefabrication and onsite automatic construction:

- The G-truss is flexible, therefore residential floors can be built with no excess labor regarding special issues like support, openings, and cross-bridging.
- Residential roofs can be built offsite using automation with negligible onsite labor and enabling effective use of attic space.
- Commercial buildings can be constructed without a skeleton.

Timber structures are more design intensive than concrete and steel. The authors have worked with codes and suggested modified allowable stress design. It simplifies the timber codes and makes considerable material savings when the excess reliability for the loads with low variability is removed [7].

8 CONCLUSIONS

Glued trussed joist is feasible for residential floors due to its low cost and flexibility and seems to be more cost-effective than other timber joists.

The nail plate timber truss dominates the residential roof market mainly due to its flexibility for multiple geometric forms. However, the nail plate truss poorly suits prefabrication and construction automation. If the roof can be constructed using joists with uniform height the glued truss is a feasible option.

Our study shows that the glued truss roof in commercial buildings up to about 30 m spans is more cost-effective with lower CO_2 emission than a consistent glulam commercial building. In this regard, the glued truss may change the current construction paradigm.

The glued timber truss simplifies timber engineering.

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