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C

CLUSTER WOODEN BRIDGES

Centria
AMMATTIKORKEAKOULU

C, Centria tutkimus ja kehitys - forskning och utveckling, 19

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Summary

The purpose of the project:
The overall objective is to improve the competitive advantages of the wood material and products. Strengthen the R&D work in the region and ensure the availability of well-educated engineers in the wooden constructions (bridges) industry in the future, in benefit for the wooden industry in the northern region.

The purpose of this feasibility study is to find out possibilities to establish cooperation between knowledge centres in Finland, and Sweden to ensure the availability of wooden engineers and knowledge regarding wooden bridges. The project is a pre-study and will with big probability lead to new development projects, either internal in companies or joint projects with partial public funding. The source will be dependent on the characteristics of the projects.

The objective for the project was to:
- Identify the opportunities to establish cooperation of knowledge and in development of wooden bridges that can be one of the leading R&D research clusters in Europe regarding wooden bridges in the future.
- Contribute to increase the competitiveness of wooden bridges.
- Deepen the cooperation between R&D-partners and the industry.

The project was divided into three main parts, Market situation, Technology issues and Planning for future actions. Cooperation with other partners as industry and prospective partners in Norway and dissemination was also parts of the project. These two parts are indirect presented in the report.

"Market situation" of the project includes state of the art regarding wooden bridges in Finland, Sweden and some European countries. "Technology issues" present the technical state of art that the partners in the project have common interest in, some of these technical issues are wireless sensors, scanning techniques, LCA and future cooperation can benefit all partners. "Planning for future" include ideas for R&D-work as visual design of timber bridges, wood species, wood in combination with other materials, durability, maintenance, fast replacement of old bridges or bridge decks, environmental issues, using modified wood, life length, vandalism, stress-laminated bridge decks, full load road bridges, use of hardwood, use of CLT, market and sales of timber bridge packages.

Background

Industrial design and manufacturing of wooden bridges for road traffic in Sweden started first in Skellefteå about 25 years ago in the company, Svenska Träbroar (later Martinsons Träbroar AB). The early start of this company came mainly out of innovative ideas, research and product development cooperation work between Martinsons Sawmill company and SP Wood Technology in Skellefteå. Cooperation between these parties and also later Lulea University of Technology, LTU, in Skellefteå have continued and today the company Martinsons Träbroar AB produces about 50 bridges per year of varying size on a market for wooden bridges. Presently, in Sweden, besides from Martinsons Träbroar AB also Moelven Töreboda AB produces wooden bridges. Cooperation between Martinsons Träbroar and Moelven Töreboda AB are conducted in projects from time to time. Cooperation between Scandinavian countries (Sweden, Finland, Denmark and Norway) in this area was conducted in the project "Nordic Timber Bridges" started in 1995 (1995-2000) and had a great impact on the development of timber bridges in the Nordic countries. "Nordic Timber Bridges" was an important project during the first phase of wooden bridges developments and introduction of wooden bridges in the Nordic market.

The market and especially culture and management regarding construction of bridges are different in the Nordic countries. The development of wooden bridges in Sweden, Finland and Norway came to walk different ways and R&D work came increasingly to be within each country and more of problem solving in specific projects instead of continues R&D work over time.

Outside of Sweden research and development for wooden bridges was started early by Forest Products Laboratory in Madison, Wisconsin in the US. Other producers and research organizations in Europe (in Switzerland, Germany, Austria) and outside Europe (Japan, Korea) exist or may exist and are partly known. However, cooperation and contacts with these organizations and other unknown actors in the field of wooden bridges are not established at the moment.

Continued research and innovation have always been and is still a key factor for the existence and growth of the companies and also for the growth of the whole of the market for wooden bridges. Issues such as new and improved design rules and regulations for wooden bridges, methods to design stress-laminated plates, design, calculation methods and innovative improvements of designs of joints and life-cycle costs are currently very important.

In the North of Finland, Norway and Sweden the wooden industry (sawmills, wooden manufacturing companies) are extremely important. The industry can generate work for many persons and also by using more wood in the constructions will have an impact on the environment. Developing and applying new/better products also in the future helps them to maintain their position in the market, and even widening of the market. Developing of new technologies regionally gives them a competitive advantage by staying a few steps in front of the competitors.

In order to achieve competitiveness requires R&D in a certain size which is difficult to achieve only within one Nordic country. It is therefore important to have a cross border cooperation to achieve this critical mass.

All this together leads to a conclusion that competence network is needed regarding wooden bridges and it is important start up a Nordic group in the benefit for Nordic wooden industry. The project, described in this plan, is a first step which sets the directions and goals to the further actions after the project is finished.

Market situation in the Nordic Countries and some European countries

One of the Cluster Wooden Bridges-project's steps was to find out primary obstacles in the form of laws, regulations, agreements or other motives which prevents the use of wooden bridges in Finland and Sweden.

This chapter deals with a general market situation for a number of countries in Europe. The market analysis should not be considered complete when the starting point was to get a first insight how wooden bridges accepted and managed in different countries.

1. Sweden

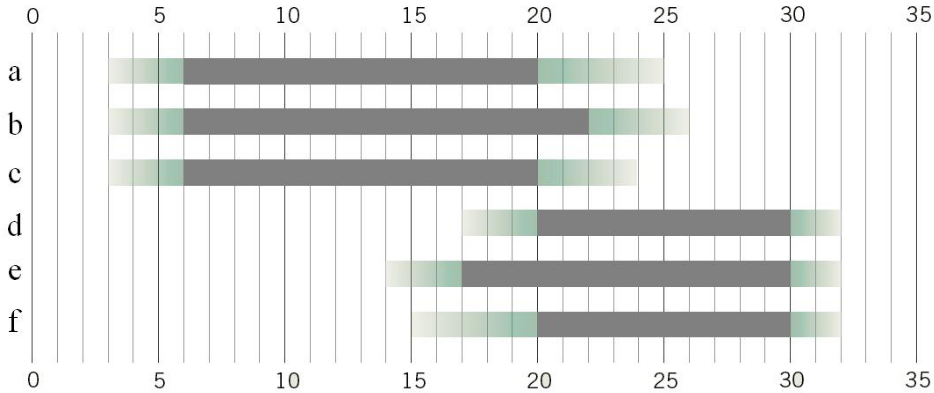
In Sweden bridges are built by the Road Administration of Sweden, municipalities and private road owners. The Road Administration also controls national transport system. In Sweden there are two manufacturers of wooden bridges and there are built around 40-60 bridges per year, mostly pedestrian and bicycle bridges. In total there are about 850 bridges in Sweden according to the Road Administrations database BaTMan (Bridge and Tunnel Management), see Table 1.

Built, year	All bridges	Timber Bridges in Sweden	
		Pedestrian	Full traffic load
Before 1990		25	10
1994		2	8
1995		6	15
1996		12	11
1997		19	21
1998		24	23
1999		11	25
2000		24	7
2001		30	22
2002	304	30	16
2003	283	31	15
2004	397	32	13
2005	277	33	19
2006	300	46	15
2007	327	51	21
2008	417	36	13
2009	267	27	18
2010	272	25	20
2011	220	23	21
2012	171	28	11
2013		11	1
Total	**3235**	**526**	**326**

Table 1 Timber Bridges in Sweden according to BaTMan. Bridges owned by Road Administration in Sweden and by 80 municipalities.(manufactures Martinsons Timber Bridges, Moelven Timber Bridges, Långshyttan, Versowood, Viacon)

1.1 Typical wooden bridges in Sweden

Stress-laminated timber (SLT) bridges have been used for many years in Sweden and are probable the most common solutions for bigger wooden bridges. For pedestrian bridges, glulam beams are common as bearing structure. There are a number of different type-designs. The span length often determines the choice of solution. In Figure 1, different solutions depending on the span are presented.



a- Pedestrian beam timber bridge
b- Stress laminated timber road bridge
c- Stress laminated timber pedestrian bridge
d- Box-beam timber pedestrian bridge
e- Timber truss pedestrian bridge
f- T-beam timber pedestrian bridge

Figure 1 Recommendations[1] of span lengths in different types of simply supported timber bridge decks. (Martinsons, 2010).

Two typical designs of decks that are used in Sweden is stress laminated decks and box beam decks, se Figure 2 and Figure 3.

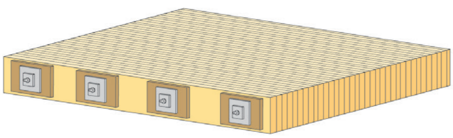


Figure 2. Stressed laminated deck.

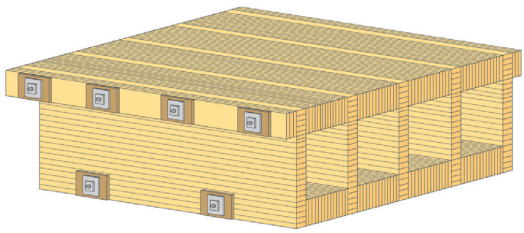


Figure 3. Stressed Box-beam deck

[1] Carlsson A., Romero M L.; Influence of Butt Joints on Stress Laminated Timber Bridge Decks, Master's Thesis 2010:137, CTH

Figure 4 Stress laminated timber road bridge, Klintforsån, Skellefteå, built in 1999.
Photo: Per-Anders Fjellström

Figure 5 pedestrian bridge, box-beam bridge with a span of 24,5 m, Nyköping, Built in 2007.
Photo: Moelven Töreboda AB.

1.2 Condition of Bridges in Sweden

This is a summary of discussion at a meeting between manufactures, SP and bridges owners about problems occurred at inspections during the last five years.

Edge of support beams of bridges
There is a need for development and test of detailed solutions for the edges of the asphalted plates. The objectives have to be standard solutions that are approved by the Swedish Transport Administration. Monitoring of older wooden bridges to examine the resistance can be a first step. Waterproofing, coating, water runoff and tie rods have to be studied.

Deformation of decks
Deformation of cross-laminated decks is a problem. The decks are cupping and there is no good explanation why. It don´t have anything to do with traffic load so it may depending of manufacturing process or changes in moisture? More research is needed to solve this problem.

Connections between bridge abutment and deck
Deformations of bridge decks, cracks in the asphalt, better solutions for the connection between abutment and the deck are some of problems that have been seen during the inspections.

Regulations and norms, inspection
What is needed for a better review and assessment of the durability of the Transport Administration? New models and methods are needed for evaluation and quality assurance of permanence. Better guidance and advice for listing of errors in BaTman.

Generally there seems to be an uncertainty regarding maintenance, long-time durability and design of details often linked to lack of knowledge.

2. Finland

In Finland bridge procurements are done by Finnish Transport Agency, ELY-centers, Metsähallitus, cities, municipalities and private road owners. The Finnish Transport Agency controls the development and use of the nationwide transport system. The ministry of Transport and Communication allocates the funds for roads, railways and waterways to the Finnish Transport Agency and planning and building of railways and big road projects are procured from service providers. ELY-centers are in charge of the condition and the development of the road network in their own regions. Metsähallitus is in charge of building and development of forest road network. In addition cities and municipalities are responsible for building and maintenance projects in their own region.

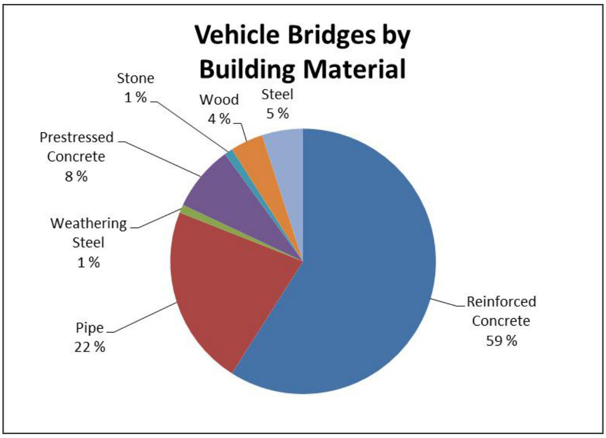
Versowood concern has produced timber bridges almost 30 years being biggest timber bridge manufacturer in Finland (Figure 6). They do about 20 timber bridges per year. In addition some glulam producers are providing glulam beams to bridge projects.

Figure 6. Timber bridge by Versowood [Reference: Versowood Oy].

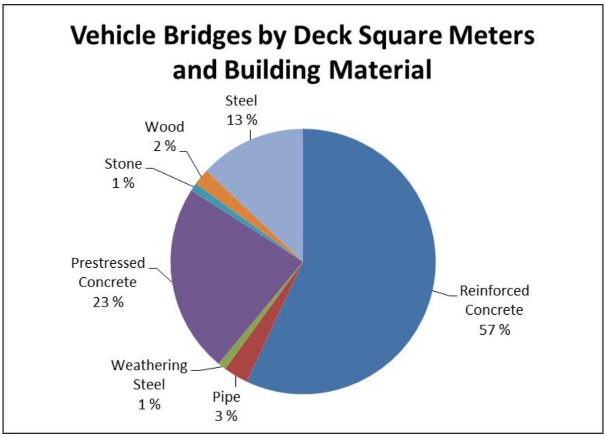
2.1 Bridge Statistics

There are about 450 000 km roads in Finland. Most of them, 350 000 km, are private or forest roads. Street network is 26 000 km. Finnish Transport Agency is in charge of 78 000 km of public roads. That is 17 % of all road and street network.

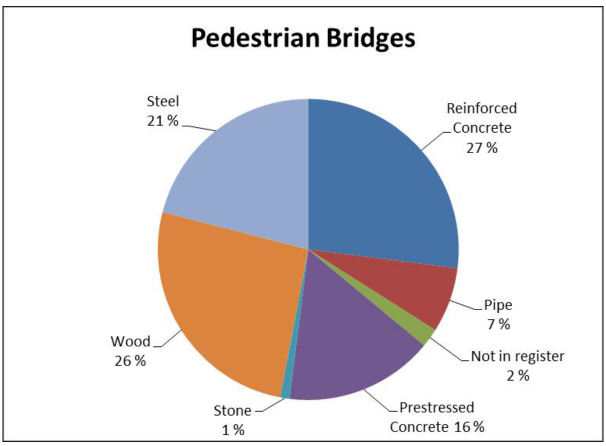
Bridges of Finnish Transport Agency
In 2013 Finnish Transport Agency had 14 784 bridges in its vehicle and pedestrian roads. 637 or 4,4% of these were timber bridges. Over 400 of these were road bridges, rest pedestrian and bicycle bridges. In addition there were 411 bridges with wooden deck. Vehicle bridges are divided by material in graph 1. When divided by deck square meters, it can be seen that timber bridges are small. Share of timber bridges is only 1,7 % of all bridges (Graph 2). There are relatively more pedestrian timber bridges in Finland than vehicle timber bridges, 200 or 6 % of all pedestrian bridges (Graph 3).



Graph 1. Amount of timber bridges is 4 % of all bridge types [Reference: Finnish Transport Agency].



Graph 2. Amount of Timber Bridges divided by deck square meter is 1,7 % [Reference: Finnish Transport Agency].



Graph 3. Amount of pedestrian timber bridges is 26 % [Reference: Finnish Transport Agency].

Most of the Finnish timber bridges were built in 1970s (Diagram 1). In the 1990s and 2000s timber bridges were built about 7 bridges per year. All in all, in the 1990s total amount of bridges build was about 330 per year. Now the number has decreased to 150-200 bridges annually.

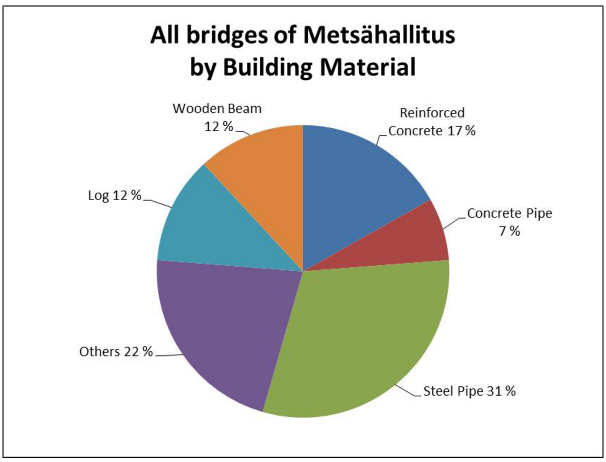
Year	Actual bridges					Pipe Bridges	Bridges Total
	Reinforced concrete	Prestressed concrete	Steel	Stone	Wood		
Not known	0	0	1	1	0	0	**2**
< 1900	3	0	6	28	2	1	**40**
1900 - 1904	1	0	1	22	1	0	**25**
1905 - 1909	2	0	2	25	1	0	**30**
1910 - 1914	2	0	4	10	0	0	**16**
1915 - 1919	2	0	0	10	0	0	**12**
1920 - 1924	11	0	3	4	1	0	**19**
1925 - 1929	47	5	8	9	1	0	**70**
1930 - 1934	144	7	32	24	5	0	**212**
1935 - 1939	249	7	37	35	4	0	**332**
1940 - 1944	17	0	4	2	0	0	**23**
1945 - 1949	52	2	19	6	0	0	**79**
1950 - 1954	358	2	24	2	4	2	**392**
1955 - 1959	816	7	55	0	7	4	**889**
1960 - 1964	870	16	44	0	20	165	**1115**
1965 - 1969	859	50	68	2	59	312	**1350**
1970 - 1974	895	39	68	3	146	312	**1463**
1975 - 1979	895	112	70	0	136	396	**1609**
1980 - 1984	705	129	92	2	86	294	**1308**
1985 - 1989	632	132	76	0	35	291	**1166**
1990 - 1994	863	227	119	0	43	398	**1650**
1995 - 1999	585	161	62	1	33	271	**1113**
2000 - 2004	343	127	37	1	29	288	**825**
2005 - 2009	289	152	38	0	27	379	**885**
Total	**8640**	**1175**	**870**	**187**	**640**	**3113**	**14625**

Diagram 1. Age of bridges divided by building material [Reference: Finnish Transport Agency 1.1.2010].

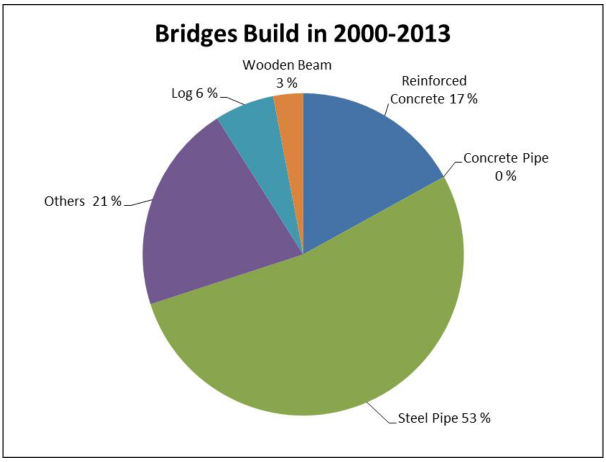
Finnish Transport Agency is also in charge of Finnish railway network. There were 2424 railroad bridges in 2013. Although there are no obstacles to build timber railway bridges, they haven't been done since the 40's. Instead railway overpasses are done also from timber.

Bridges of Metsähallitus

In the beginning of 2014 there were 1098 bridges in Metsähallitus data system. They were sorted by building year and building material. Amount of wooden beam bridges and log bridges was totally 24 % of all bridge types (Graph 4). Between 2000 and 2013 less timber bridges were built. Total amount of bridges was 223 (Graph 5).



Graph 4. Bridges of Metsähallitus [Reference: Metsähallitus].

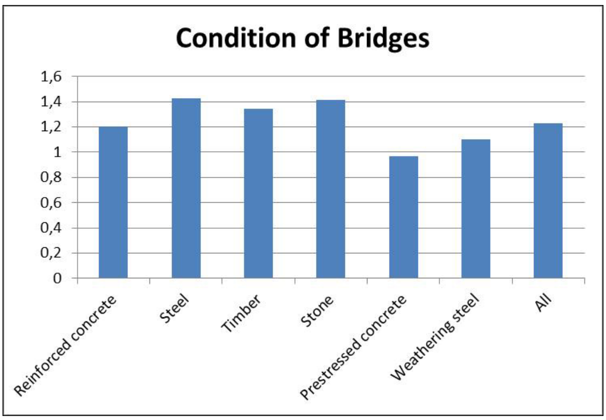


Graph 5. Bridges of Metsähallitus build in 2000-2013 [Reference: Metsähallitus].

2.2 Condition of Bridges

In application directive Of Eurocode 5 by Finnish Transport Agency designing lifetime for substructure of timer bridges is 100 years and 50 years for cover structures. On highway bridges lifetime demand can also be longer. This means that weather exposed parts need to be covered. On the other hand single component lifetime can also be shorter than 50 years if the component is easily replaced.

General condition of bridges is inspected in every five years by person who has competence for bridge inspections. In graph 6 is general condition of bridges owned by Finnish Transport Agency. They are divided by building material. As it can be seen condition of timber bridges are about same level than other bridges. Condition estimation class 0 is as good as new and 4 is very bad.



Graph 6. General condition of bridges. [Reference: Finnish Transport Agency].

2.3 Regulations

"Eurocode 5: Design of timber structures – Part 2: Bridges" is also used in Finland (SFS-EN 1995-2 EUROKOODI 5: Puurakenteiden suunnittelu. Osa 2: Sillat). In addition there is a national attachment by Ministry of Transport and Communications (National annex for EN 1995-2 in Finland) and application directive by Finnish Transport Agency (Liikenneviraston soveltamisohje Puurakenteiden suunnittelu – NCCI 5).

In Finland FISE competence is required for bridge designers by Finnish Transport Agency. According to FISE (Qualification of Professionals in Building, HVAC and Real Estate Sector in Finland) 39 designer has AA competence and 54 designer A competence in April 2014 [1]. These numbers include all wooden constructions. According to Finnish Transport Agency in year 2011 there was four engineering offices whose person in charge had A or AA competence of structural engineering [2]. At that time nine offices had timber bridge references [3].

Bridge constructors are required competence granted by RALA (The Construction Quality Association). In Finland there are 38 main contractors that have RALA competence and/or certificate to build timber bridges [4]. Competence is not depended on material so there is no list of companies that builds timber bridges.

As a summary it can be said that changing and increasing regulations are setting some challenges to timber bridge designing and constructions. At the moment for example decree of vehicles has an effect on design loads of bridges. However any laws or regulations are not preventing building or using timber bridges in Finland. One challenge is competences required for timber constructions. At the moment there is quite few person with competences required. According to Mikko Viljakainen from Puuinfo this is because there have been only few timber building projects. On the other hand applying of competence has been somewhat difficult because basic degree in building trade does not give one sufficient theoretical competence. This is about to change; from now on over two story high timber apartment buildings are required AA competence. This is going to increase applying of these competences. Puuinfo is going to ease this by starting further education to get AA competence in designing of timber constructions.

2.4 Summary

About 200 bridges are built in Finland every year. So far only few of them have been timber bridges. In 1990s there was a Scandinavian co-operation project "Nordic Timber Bridge". Since that Sweden and Norway have built several timber bridges and their knowhow is much higher than in Finland. In 1990s few timber bridges were built also in Finland (Figure 7), but after that timber bridges have been built only occasionally.

Figure 7. Bridge of Vihantasalmi. [Reference: Puuinfo]

In Finland first words that come into mind when mentioning timber bridges are usually durability, lifetime and maintenance. And those words are not presented in positive way. Timber bridges are often also perceived to be expensive. That is partly true because timber bridges are often built to be landmarks or as a work of art. When so, comparing of price is difficult. Timber bridges are usually public procurements and often when the request for offers is done it has been already decided what kind of bridge will be done and which material is going to be used. If timber has not been an option when designing it is highly unlike that later on it will be chosen to be the main building material.

Nationally important step to change this situation is timber bridge project that Ministry of Employment and Economy has started. Strategic Programme for the Forest Sector and Programme for the Wood Construction with their partners have started a national project which started in the beginning of 2014 and will end in September 2015. Project goal is to get together designer, buyers, builders and researchers to start actions that will increase amount of timber bridges to be tenfold compared to present.

More research data will be also achieved in the near future, because at the beginning of 2014 started international "Durable Timber Bridge" -project. It is a part of WoodWisdom-Net research programme and its overall objective in next three years is to develop durable timber bridges with a given estimated technical lifetime.

References:

1.http://www.fise.fi/default/www/suomi/patevaksi_todetut_henkilot/suunnittelu/uudisrakentaminen/puurakenteet/ updated 20.2.2014

2.http://portal.liikennevirasto.fi/sivu/www/f/urakoitsijat_suunnittelijat/taitorakenteet/ammattilaiset/suunnittelijat updated 21.12.2011

3.http://portal.liikennevirasto.fi/sivu/www/f/urakoitsijat_suunnittelijat/taitorakenteet/ammattilaiset/suunnittelijat/referenssikohteita/Puusiltoja updated 10.8.2011

4.http://www.rala.fi/palvelut/sertifiointi/ralan_rekistereista_loytyvat_siltahyvaksynnat_ja_-patevyydet/

3. Norway[1]

The total number of timber bridges in Norway is nearly 190, 80 road bridges and 110 pedestrian bridges including 25 bridges owned by municipalities. Of these bridges approximately 60 timber bridges can be attributed to the national road network and 70 timber bridges to the county road network. Norway has a long tradition of building with wood and has in recent years built a number of large bridges in wood.

Evenstads bridge, 1996 *Flisa Bridge 2003*

Figure 8 Examples of timber bridges with long spans in Norway.

Norway has a requirement of 100 year service life without heavy maintenance and the traffic load requirement is the same for all bridges. So far they have used structural and chemical protection (Cu and creosote treated) to achieve the requirements without comprehensive maintenance. Today Norway is trying to find other solutions to achieve the requirements without chemical solutions.

Advantages with timber bridges are architecture (new possibilities), sometimes the timber bridges are very cost-comparative and almost always environment friendly (low energy consumption, CO2-emission, renewable material).

Problems that have occurred are corrosion on the pre-stressed bars (probably because of water penetration into the location of the bars). The design of the membrane termination at the edge of the deck and the drop molding should probably be improved.

Figure 9 Corrosion on bars used as pre-stressed bars.

[1] Presentation made by Otto Kleppe, Norwegian Public Road administration in Finland 2013.

4. Other countries in Europe

4.1 Poland

Wooden bridges are used mostly only as a garden decoration in Poland. The bridges that are built in wood probably come from German manufacturers and are quite small. Poland, however, is a large country with a growing economy. Research and development within the wooden bridge area is little and there is an interest in the development of composite bridges.

4.2 Latvia

Over the past few years the public interest in wood as a building material have increased, but not enough to make serious investments in this area. Only a few bridges in the timber have been realized.

Some research and development work is made by Riga Technical University (Department of roads and bridges), "Forest and wood product research and development institutes" and entrepreneur "Marko KEA" regarding development of wooden structures as timber bridges. The work will include among other glulam structures and wood/concrete structures, recommendations for the design, maintenance and construction of timber bridges and investigation of moisture-related degradation of bonded structures in the Baltic Sea climate.

4.3 Spain

There are a least two manufacturers of wooden bridges in Spain. The largest wooden provider builds and designs 100 bridges per year. In the last few years because of the economic crisis they only build 10 bridges per year. Nearly all the bridges are pedestrian bridges. Customers are usually on a local level, municipalities, and traffic bridges in wood are not relevant today. There are no statistics on the number of timber bridges in Spain. The big problem is that it is often procured by one part and operation/maintenance is handled by other part and often no maintenance work. Materials for bridges are often purchased from Scandinavia.

4.4 Switzerland

Switzerland has a long tradition of building and managing wooden bridges. There are a number of design offices who have the knowledge to design wooden bridges and the construction is often done at the local level. A large number of bridge types are used and the bridges are built both for pedestrian traffic as for cars traffic.

The total number of wooden bridges are 1481 and in Figure 10, Figure 11 the bridges are presented according to total length and construction type.

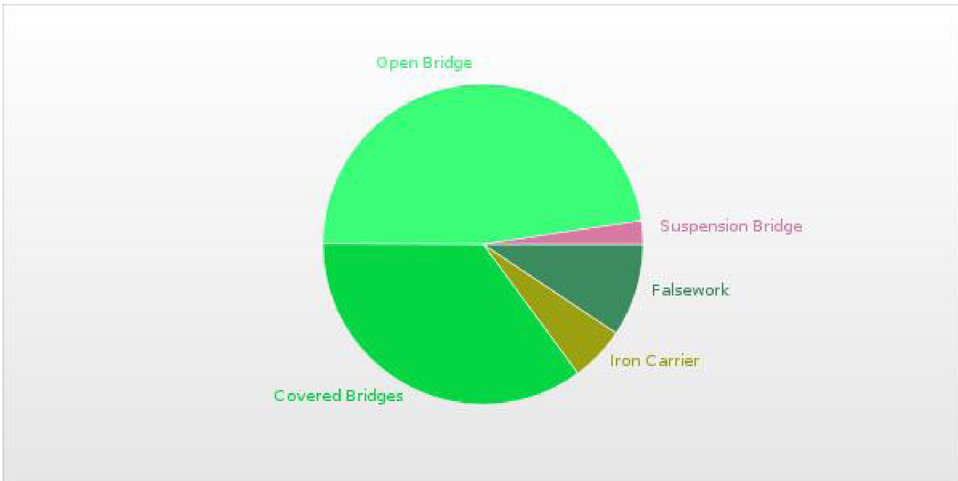


Figure 10 The number of bridges in different Construction types, (http://www.swiss-timber-bridges.ch/)

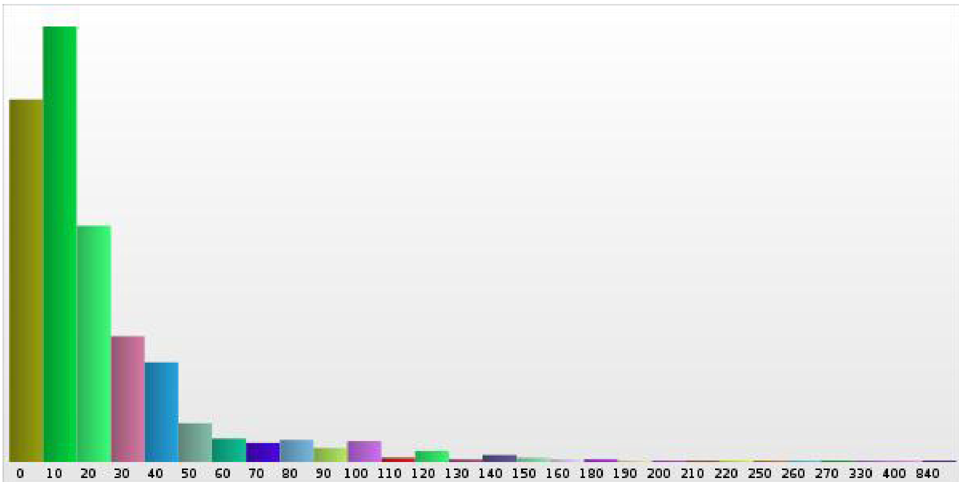


Figure 11 The number of bridges in different total length (http://www.swiss-timber-bridges.ch/)

4.5 Netherlands

Wooden bridges in these areas have a long tradition and are very popular. Wooden bridges fit well into the landscape or towns and are considered natural part and made of environment-friendly material. A great advantage with wooden bridges is the fast manufacturing and assembly time. The bridges are often delivered in prefabricated parts or pre-assembled parts to the construction site. Pedestrian and bicycle bridges dominate the market but also bridges with full traffic load occurs. The bridges are made of different woods, fir, pine, larch and African hardwood.

In the Netherlands and northern Germany have a number of major manufacturers which can be categorized as:

- Manufacturers of "only" timber bridges.
- Manufacturers of timber bridges and other types of timber structures.

- Design companies, management companies that cooperate with a manufacturer or procure with manufacturers of timber bridges.

Market situation in the Netherlands
In the Netherlands, approximately 50% of all pedestrian bridge are made of wood and the life is estimated at least 25 years (without maintenance work) so the aftermarket has today become a significant part of timber bridge manufactories market. How big the market for timber bridges are in the Netherlands today is difficult to estimate but on the basis that there are at least four manufacturers / suppliers and the largest supplier produces about 100-150 bridges per year it can be estimated market for new timber bridges approx. 150 wooden bridges per year.

Manufactures

Groot Lemmer
Groot Lemmer was established in 1920 and has over the past 35 years, made about 5500 bridges. Manufacturer of wooden bridges, piers, deck planks, railings and is a market for wooden bridges of hardwood. They also supply bridges of steel + hard wood and steel + hardwood + plastic. All hardwood (Ekke) used is FSC certified. Groot Lemmer is represented in six countries, the Netherlands, Germany, France, Denmark, United Kingdom and Japan.

The company carries out turnkey contracts including design, supply and installation with can also be subcontractors to the prime contractor.

Most of the wood is imported from Cameroon and are sawn to blocks with approximate dimensions. On customer request, other types of wood are also provided as Douglas Fair, acetylated wood, etc.

Figure 12 Example of bridges manufactured by Groot Lemmer, Photo: Groot Lemmer

For larger dimensions Groot Lemmer use dowel joints. This is a disadvantage when mechanical joints are not as effective as glued joints. Hardwood is difficult to glue (or impossible).

Groot Lemmer also manufacture anti-slip decks, see Figure 13. Aluminum plank is also used for various bridge projects.

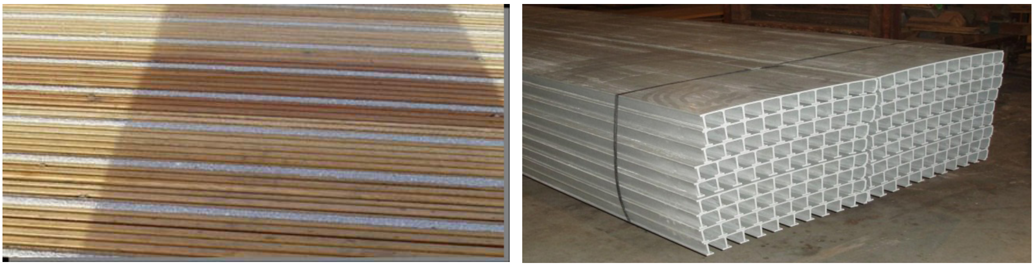


Figure 13 Example of anti- slip decks and decks of aluminium, Photo: Anders Gustafsson

Busmann

Ingenieur-Holzbau Busmann locaded in NW parts of Germany and have approx. 30 employees. They manufacture also of doors, windows, staircases, wooden etc. Busmann has built 2,200 bridges during the last 25 years. Work as main-contractor or sub-contractor, designer and build all types of bridges, see Table 2.

Typ	**Pine/Spruce/ Larch**	**Oak**	**Bongossi (Ekke)**		**Glulam**	**Steel**
			Balk	Dymlad balk		
Beam bridge one span	7,5	8,0	11,0	20,0	25,0	25,0
Beam bridge two spans						
Cable stay bridge, one pylon			30,0	50,0	50,0	
Cable stay bridge, two pylons			50,0	80,0	30,0	
Treusses		25,0		35,0	35,0	
Arch bridges				45,0	45,0	

Table 2 Compilation of approximate maximum spans for different bridge types, Baumann)

Generally for these manufacturers is that they supply wooden bridges made from African hardwoods although they also use European wood. The market consists of 80-90% of pedestrian bridges (sized for 5 kN/m2 according to DIN FB101).

Schaffitzel + Miebach

The company Schaffitzel / Miebach design and build wooden bridges. After many years of successful collaboration on a number of bridges, established Jürgen Schaffitzel, and Frank Miebach in late 2009 Schaffitzel / Miebach GmbH. Together, they offer everything from design to the finished bridge.

Important efforts are being made towards reducing environmental impacts during construction in the form of constructive use of wood instead of chemical preservative . The most visually striking wooden bridge 's truss is in Sneek - Netherlands , see picture. With a length of 32.00 m and a height of 15.00 meters. The structure of blocks glued laminated timber of acetylated pine (Accoya) and the modified wood has been used here for the first time in this form. Cooperation between universities and industry has been important for cooperation to develop this technology

Figure 14 Bro Sneek, full traffic load bridge. Photo: Anders Gustafsson

Regulations and standards for timber bridges in Germany, the Netherlands

The basis for all statistical calculations are to be found in the Eurocodes . National Application Documents and DIN standard is also the basis for the design.

- DIN 1052:2008-12 Design , calculation and design of timber structures - General rules and rules for buildings .
- DIN 1072:1985-12 Road and pedestrian bridges - Design loads -
- DIN 1074:2006-09 Timber bridges
- DIN 68800 Wood preservatives
- DIN Technical Report 101
- DIN EN 1995-1-1, EN1995 -2 , DIN EN 1991-1-3 , EN 1991-2 and DIN EN 1990:2010 .

To achieve the goal of increasing timber bridges quality, seven manufacturers, eight engineering firms and 12 universities /colleges put together " Quality Community Holzbrückenbau eV " where examples of calculations and details are compiled.

5. Great Britain

Market

Great Britain does not have the same tradition of wooden bridges like the Netherlands or Germany. Environmental awareness and to consider environmental impact, however, is increasingly important for the UK customer. Bridges owned by cities, municipalities and others, but a few rows the larger bridge owners include BRB (residuary) Limited., British Waterways, CSS, Deparment of Transportation, the Highway Agency, London Underground Limited and Network Rail.

Wooden bridges fit well into the landscape or townscape and is considered natural and made environment-friendly material. Walking and cycle bridges, piers can be accepted that it is built of wood. Traffic Bridges for full traffic load, the clients are probably very skeptical.

Most pedestrian and light vehicular bridges in wood supplied by three companies using tropical wood or pressure treated softwood. There are also some smaller suppliers. The British army is also building a number of bridges for training purposes.

Napier University has developed doweled solutions for bridges during several years and has built about 160 bridges of this type in the last 4-5 years. Doweled bridges are considered to be very cost effective way to build a bridge for pedestrians and light vehicles. Most of the bridges have been designed and manufactured by Forrestry Commission for its own use.

Figure 15 SLT-bridge solution. Photo: Anders Gustafsson

In the UK we have not found any "pure" wooden manufacturers. Import occur occasionally with various partners (including Groot Lemmer). Below are a number of smaller manufacturers which also supplies wooden bridges.

Dodson Macrae Ltd
Manufacture bridges of African hardwood, all kinds of bridges and has been operating since 1982.

Martins Child Limited – Cambridge
Martin Childs Limited is a company that specializes in the manufacture of wooden structures and prefabricated slip resistant planks. They have a factory in Brandon where they produce all types of wooden structures such as sluice gates, sluices, bridges, fences, benches, bollards, bollards and fenders, and more. Typically made of naturally durable hardwoods but can also be offered in softwood and steel.

Figure 16 Erection of a pedestrian bridge, Photo Martins Child Limited

Coed Dinefwr- Carmarthenshire, Wales
The company manufactures its products of sustainably wood materials as oak, Douglas fir or larch and the timber comes from Forest Stewardship Council certified Welsh woodlands. The company has their own sawmill. Coed Dinefwr can offer a design, manufacture and installation anywhere in the British Isles.

Concrete and Timber Services
CTS have designed and constructed bridges and structures since 1988 and are is one of the market leaders of footbridges. They offer footbridges bridges in steel and timber.

Other bridge builder and designers in Great Britain are ABC BRIDGES, Gloucestershire. Beaver Bridges. Shropshire and Strong Bridges, Perthshire, Scotland

Regulations and standards for timber bridges in the UK

With Eurocode 5 "Design of Timber Structures" is the first time that a limit state calculated crafted code used in the UK. Calculations for timber bridges shall be made in accordance with this code, however, is even older British standards are used. Along with Eurocodes there are a set of national annexes and information sheets / handbooks such as:

BS EN 1995-1-1: 2004 + A1:2008, Incorporating corrigendum June 2008.
Eurocode 5: Design of timber structures – Part 1-1: General – Common rules and rules for buildings.

BS EN 1995-2: 2004, Eurocode 5: Design of timber structures – Part 2:Bridges.

BSI NA to BS EN 1995-1-1:2004 + A1:2008, UK National Annex to Eurocode 5: Design of timber structures – Part 1-1: General – Common rules and rules for buildings.

BSI NA to BS EN 1995-2:2004, UK National Annex to Eurocode 5: Design of timber structures – Part 2:Bridges.

BSI Wood Information Sheet 2/3-10, Amended October 2002, Timbers – their properties and uses. TRADA

NA to BS EN 1990:2002+A1:2005, incorporating corrigendum December 2008 and
BS 5268-2: 2002, incorporating Amendment No. 1. Structural use of timber – Part2: Code of practice for permissible stress design, materials and workmanship. BSI

BS EN 14081-1: 2005, Timber structures – Strength graded structural timber with rectangular cross section – Part 1: General requirements. BSI

BS 8417: 2003. Preservation of timber. Recommendations. BSI [20]

For larger bridges, there is a comprehensive manual that is used in the construction of bridges "Manual of Contract Documents for Highway Works (MCHW).

Technology issues

In this part of the project technology problems and solution was discussed and the goal for this work package was to get a good understanding of current technology and priority areas for future R&D work.

Statement of current technology

The Älvsbacka bridge project (ref) has revealed some insights in the state of art for bridge monitoring sensors. Many of them induced by problems having several wireless sensor systems working in parallel not acting as of specification. Some of these problems have been solved during that project but a new generation of accelerometers need to be tested on the bridge. Also the mobile temperature and moisture meters seem to have some weaknesses in their long time behavior and other solutions may be considered to get stable long-time data. Success has been in using Laser scanning and high resolution GPS systems for complete 3D measurements and large scale movements. Lasers scan technology with competences and sensors well established both at CENTRIA (see appendix A) and the Wood Products Engineering lab at LTU and for high resolution GPS at SP. Different system for crack propagation quantification and monitoring in wooden beam has been tested.

Priorities for future work
Improved or new Database technology and interface development to reach a stable, easy handled and smart costumer oriented use of the monitoring system by:

- Test a new generation mobile accelerometers and moisture/temperature measurement meters both for security, precision and green long time behaviour.
- Monitoring system as LTU and SP Wood has developed will ultimately produce new ideas for measuring the vibration of wooden structures, monitoring of crack growth in timber structures and systems for monitoring of timber structures. Monitoring of timber structures is still in its infancy and there is much scope for further research. A new technology, "Operational Modal Analyis", which uses the ambient motions of the bridge to find bronze natural frequencies and damping values can be used to analyse data from the bridge.
- Multivariate modelling of the incoming senor data.
- Development of a low cost system for functional implementation in commercial timber bridges.
- System for crack propagation monitoring and analysis

Planning of future actions

"The Roadmap" on the Future Research Needs of WP4 aims to identify priority research topics and research gaps in the field of Timber Bridges. In doing so, it acts as a guide to help all those concerned with the necessary planning of future research and the pursuit of research funding in order to advance Timber Bridges to their optimum level in the coming years.
Task: to find out the current challenges, trends and new ideas when it comes to innovative

Introduction
A description of possible future development and trends must come out of a description of what is going on in the world in the timber bridge area right now. Such a description and also some future possibilities are described below subdivided into certain headlines. Sources for

the information come from contacts and discussions held in this project and also from results achieved in another international project regarding timber bridges. Not only the Finnish and Swedish situation is covered but also an international perspective is aimed at. Future possibilities are to go further and increase development work in the directions that are pointed out below.

Visual design of timber bridges
The geometry and type of timber bridge design can vary much in the same way as for steel or concrete bridges. Often timber is regarded as a beautiful material and a more solid impression can result from using timber for bridges due to the fact that wood is a light-weight material (compared to steel and concrete) and cross section dimensions can be made large. It is also possible to create curved or complicated geometry in a somewhat simpler and cheaper way by using wood instead of other materials. Otherwise the same types of bridge designs as used for steel or concrete bridges can be used for timber bridges.

Wood species
Pine or spruce is mostly used in northern countries but in other countries more exotic hardwoods are also used. The advantage with hardwoods is above all more durability but at a higher cost. Also the visual impression might be considered better using a darker wood material. Painting and impregnation is possible to avoid with hardwoods to a larger extent than when using softwood. Hardwoods can be used partly in a bridge, for vulnerable details such as railings.

Wood in combination with other materials
Finnish and Norwegian experience from using timber in combination with concrete shows good results. The strength of both materials is normally used with e.g. a lower subframe in timber and an upper surface deck made in concrete. Full cooperation with load transfer between wood and concrete is supplied for via shear connectors, often epoxy-glued in the wood material and cast into the concrete. The concrete may act as a shielding of the wood material from precipitation. Steel and wood in combination with load transfer between materials is also possible but also steel (or concrete) and wood can be combined without load transfer between materials. This is sometimes practiced by e.g. having an ordinary steel bridge fully covered with wood panels just to create the impression of a timber bridge. Reinforcement of wood with glass-fibers or carbon-fibers is possible both for new bridge designs but also especially in order to repair or raise load limits for old bridges. The critical points are the connections between the wood and the fiber material that should be designed to allow load transfer between materials in order to get the highest strength and stiffness out of the material combination.

Durability
The most critical issue for bridge designers and bridge owners is probably the durability of the timber in the bridge and the need to fore say the life length of the bridge. Using non-treated softwood and aiming for a long life means that the design must be carefully made and such that the water and moisture that inevitable comes into contact with the wood must be allowed to dry out easily during dry periods by using an open and airy design and e.g. not allowing bushes and soil come close to the wood material. Using treated (impregnated) wood reduces the need for a good water-proof design but impregnation is partly becoming forbidden or undesirable in many countries and the chemicals that are allowed to use are becoming less efficient compared to older sorts of chemicals. Use of hardwood or modified wood is also an option that increase durability but at a higher cost.

Local timber use
In some cases the bridge owners want the raw material for the bridge to be taken from trees near the bridge site. This desire to use resources as close as possible to the bridge site is a sort of advantage with timber bridges and is probably motivated by some environmental or emotional thoughts about reducing transports or other more delicate personal and special reasons that must be considered in special cases. This could be thought of as an advantage for timber bridges compared to bridges made out of other materials.

Maintenance
Regular inspection and maintenance is required for all types of bridges and obviously for all sorts of man-made constructions made out of any material in order for function and a long life. Timber bridges may be especially sensitive to a lack of maintenance. Bridge owners are responsible for maintenance but are sometimes not aware of it, don't take it seriously or don't have the resources needed to conduct maintenance which will in some cases lead to a shortening of life. This may as a consequence lead to a bad reputation for timber bridges since wood are especially sensible to water and moisture and neglected maintenance will inevitably lead to damaged wood. For the future, the subject of how to better advice and arrange inspection and maintenance is very important for an increased use of timber bridges.

Fast replacement of old bridges or bridge decks
With prefabricated timber bridges or bridge decks a fast and easy replacement is possible. E.g. old bridge decks made of any material may for special cases be replaced in a couple of hours with a new timber deck without much disturbance of traffic. This is a competitive advantage for timber bridges compared to steel and concrete bridges that come out of the light weight of timber bridges and the possibility to prefabricate, transport and easily erect the whole of or part of a bridge or bridge deck. Old concrete or steel bridge decks can be replaced in this way with timber bridge decks.

The timber bridge as a landmark
The use of a bridge with a special design as a landmark is sometimes thought of. This is not special for timber bridges but the possibilities to create new designs are perhaps easier with timber. Timber can be fabricated in very complicated shapes and very solid volumes can be prefabricated probably at a relatively low cost compared to other materials.

Environmental issues
Wood is a biological and natural material which gives it benefits compared to man-made materials such as concrete and steel when it comes to consumption of energy for the fabrication. CO-2 emissions for the fabrication and during the life of a timber bridge may be lower than for bridges made of other materials and this may also give environmental advantages for timber bridges even if these issues are vague and not fully understood today.

Impregnation
Creosote is perhaps the best chemical for impregnation but has become more and more forbidden to use in many countries. Other chemicals e.g. with a content of copper are allowed for impregnation but they are normally not as effective as creosote. Impregnation requires pine wood material because spruce cannot be impregnated due to the feature of sealed cells in spruce. Using impregnated wood for vulnerable outer parts of a bridge could be beneficial in many cases. Using hardwood reduces or modified wood reduces or eliminates the need for impregnation. Cost of impregnation is relatively low compared to using hardwoods or modified wood.

Using modified wood
Wood can be treated with chemicals in order to reduce the sensitivity to water and fungi, e.g. the acetylation process. Modified wood can get properties that result in low uptake of water, low shrinkage and swelling and high durability. The disadvantage is that the modification process can be very costly and as a consequence the price will increase. Also the modification can give other drawbacks e.g. aggravating corrosion of metals in contact with the modified wood.

Life length
A 25, 40 or 80 year life can be the requirement for bridge life. Also temporary bridges with much shorter life are built. A long life will require a careful design of details such as joints and abutments in order to avoid water and moisture uptake and facilitate quick drying of wet wood. Regular inspection, maintenance and (if needed) repair are in general essential to achieve long life. In general long life for timber bridges is not a problem if these issues are addressed properly and examples of timber bridge lives of many hundred years exist.

Vandalism
Wood and timber are sensitive to fire and examples of vandalism or intended attempts to destroy timber bridges exist. In some countries this fear is a reality and a disadvantage for timber bridges. There are examples of timber bridges equipped with flame and fire detectors directly connected to police and fire department. Also accidental fire risks exist due to fires in surrounding landscape.

Design with built-in rot protection
Water and moisture uptake in local points at joints and connectors and points where parts are attached means that the wood material will locally and eventually rot at such points. This happens if water goes into the wood material and can't dry out. Wood in general can stand water uptake if the water is allowed to dry out during dry weather but if the water gets trapped then rot will appear eventually. The solution to this problem is to design in a way to let water dry out by using an airy, open design, to cover exposed parts with galvanized steel plates and to avoid connection designs that will trap water in the wood material. Also impregnated wood or hardwood can be used in vulnerable places.

Stress-laminated bridge decks
A special type of mechanical design for bridge decks that is not used with steel or concrete decks is the stress-laminated timber bridge decks. These decks are very advantageous for several reasons. They consist of glulam beams put side by side and held together only by friction via steel bars through the beams that are pre-stressed on erection. This method gives a solid, strong and stiff bridge deck that is easily erected on site as a whole or in parts. The deck can be made very wide and also very long by distributing the length-wise butt-joints between beams all over the deck. The deck can be used as a bridge by itself for shorter spans equipped with guard rails on the sides or the deck can be used as a deck of a long span bridge e.g. an arch bridge.

Bridges with roofs
Old covered bridges with roofs have been used since long in mainly US, Switzerland, Austria and Germany. A roof means that the timber is covered and protected from water and snow with all the advantages that this means. Recent and new designs of timber bridges rarely use roofs but it is a fact that a roof may be very advantageous for a timber bridge from many points of view and may very well be a cost-effective solution that may be used also for large road

bridges nowadays. The roof and the walls may be built on the load carrying members at a relatively low cost and be designed to give a nice and beautiful aesthetic impression. The drawback may be increased wind loads that can be difficult to cope with.

Full load road bridges
Most timber bridges are used for pedestrian and low load situations. However, it is no problem to build full load road bridges and such bridges have been built and are built today. Timber bridges can be economically competitive compared to steel and concrete for certain span lengths and also for other reasons e.g. ease of erection, time of erection or environmental reasons. Reasons for not choosing timber as a bridge material may be lack of confidence of durability or just traditions and experience that result in the use of concrete and steel as building materials. It is believed that timber can very well increase its share of the market for full load road bridges.

Use of hardwood
There is a possibility to use hardwood from species that are very durable and resist rot and fungi even under moist conditions. This is practiced by some manufacturers for all parts of a bridge or just in exposed positions such as for railings. The esthetics of hardwoods is sometimes also an advantage that is relevant. The drawback is high price and also difficulties to dry, glue and design joints for some of these hardwood species.

CLT
CLT (cross-laminated timber) is sometimes used in bridges but hitherto not very much. There is some uncertainty in the performance of this material under changing moisture situations. The advantage is the mechanical properties of the material which are stiff and strong and rather "isotropic" since there is a mix of fiber directions in different layers. Also very solid and thick volumes of wood can be produced which may find its use in bridges. Maybe a material for the future?

Market and sales of timber bridge packages
Timber bridges are produced by specialized timber bridge producers, general bridge producers, timber building producers or by other means by other companies. The parts that are included in a bridge delivery may be only the bridge deck and other timber parts without the concrete abutments or the bridge as a whole with abutments. Also other subdivisions of the delivery are possible. For some procurements the customer does not specify the bridge material and the bridge supplier may chose the bridge material. In other cases the procurement is specified very much in detail by the customer. It is a general unanswered question whether it for the benefit of timber bridge use is better to offer the whole of a bridge including concrete abutments or just to offer the timber parts.

Laser scanning technology
Laser scanning techniques can be used for scanning the surrounding landscape before erection and also for scanning the position of an erected bridge. The use of the data is e.g. for ease of excavation of soil before erection and for monitoring displacements after erection.

Monitoring of bridges
Displacements, loads, moisture conditions, wind, temperature etc. can be measured in many points of a bridge with relative ease and with low cost as a function of time. Data can be transferred easily and instantly to an optional computer anywhere. This monitoring possibility gives the opportunity to monitor the life a bridge in detail and also possibly predict the life of it.

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APPENDIX C: Parikka H.; Accelerated weathering test

APPENDIX D: Pahkasalo M.; The Search for Vibration and Wood Moisture Sensors

APPENDIX A

Laser scanning and bridges

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Abstract

This document will first cover topic of the laser scanning and the equipment used for it. This is followed by introduction of laser scanner used by Centria and some of the essential computer applications used. At the end of document are some possible use cases and two projects relative to this topic.

1 Laser scanning

Laser scanning is a method from measurement field which gives precise three-dimensional information of objects without touching them. The measurement result is a large laser spot data, or the point cloud - any number of scans that have been registered together to form one large "cloud" of points - which enables the creation of accurate 3D models. Laser scanning is a great utility for example to measuring existing buildings, objects, bridges or even entire neighborhoods. Point cloud data gives easy and accurate way to measure for example, domain surface shapes and volumes. Actually the point cloud data is a huge set of Cartesian coordinates with color information in 3D space. This cloud can be georeferenced into different real life coordinate systems or virtual coordinate systems as well. Therefore it is also easy to combine point cloud data and modeled 3D objects from different scanning sources.

Point could data can be produced by terrestrial laser scanner, flying devices, such as airplanes, helicopters or model aircraft mounted by scanners and held by hand scanning devices. Today, there is a way to generate point clouds from photos as well with use of photogrammetry. Photogrammetry have with certain limitations become a respectable point cloud creation procedure. Laser scanners integrated into flying devices are suitable for large areas such range of several square kilometers. Terrestrial laser scanner is at its best with areas such range of couple of hundred meters. Terrestrial laser scanner is well suited for indoor scanning, for buildings and objects that are made by human being. There are also handheld laser scanning solutions that are excellent when scanning small objects but are usually not practical for scanning large objects.

There is huge variety of implementations of using terrestrial laser scanning. Firstly, in architectural field laser scanning have been used as tool for documenting of existing and as base of new design. Secondly laser scanning can be used for example as tool for focusing critical to the accuracy type elements in construction industry. There is also lot of implementations in area of landscaping, civil engineering and so on. “When everything needs to be right” – accuracy of millimeters gives great advantage to document and designing industrial objects. For example piping and complex installation of machines would be hard to document with any other method.

1.1 Hardware

3D laser scanners work by sending a laser beam all over the field of view. Whenever the laser beam hits a reflective surface, it is reflected back into the direction of the scanner. To determine the position in space, the Laser Scanner uses polar coordinates which consist of the horizontal angle, the vertical angle of measure and the measured distance. Individual scanned point clouds are later registered together using common references and the resulting point cloud with all point is ready for further processing.

The speed of light is precisely known quantity, so if we know how long a laser takes to reach an object and reflect back to a sensor, we can calculate how far away that object is. Laser pulse -based scanners ("time of flight") are based on this fact.

1.1.1 Leica ScanStation 2

Centria uses the Leica Scanstation 2 laser scanner. At 50 m range the ScanStation 2 can achieve a position accuracy of a single measurement of 6mm, a distance accuracy of 4mm, and an angle accuracy (horizontal/vertical) of 3.8 mgon. The laser spot size is 4mm at 50m. Modeled surface precision is 2mm. The scan density is less than 1mm, maximum. Laser scanning range is up to 300m. The scan rate is 50,000 points/second.

We are equipped to work in demanding conditions. Suitable digital aggregate guarantees availability of energy and even without aggregate we have 6 hours operating time with batteries. Leica Scanstation 2 is equipped with a digital high resolution camera. With camera we can have 360 degree panorama picture and therefore color value for each measured point. Also for working in demanding conditions we have Panasonic Toughbook computer for managing projects in the field.

There are few restrictive factors with scanning conditions. If colors are needed then scanning in dark is not possible. Scanning in small rain and fog is possible but causes errors and it is not recommended. Only real restrictive factors are heavy rain and temperatures under 0 degrees.

1.2 Software

For point cloud processing there are already plenty of software available. Here we present just a small subset of them. These are the most essential software that Centria uses for processing point cloud data.

1.2.1 Leica Cyclone

The Cyclone is a proprietary 3D point cloud processing software solution. It is made of many modules and some of them are essential when working with Leica ScanStation 2 scanner. Point cloud scanning can be done without buying any module license. Individual scans are saved to project database, these scanned point clouds are not georeferenced and are using Cartesian coordinates with scanner itself being origin.

Different point clouds can be combined using Cyclone-REGISTER module. Registering can be done by showing same positions from different point clouds and Cyclone application then matches these clouds as accurate as possible. Ending result is usually good, but there is much better way to do this. Before scanning we put targets around area of scan and surroundings. These targets are numbered and scanned with high precision. With target information Cyclone can merge point clouds faster and with better accuracy. It is also possible to import targets from text file with real coordinates. This way whole point cloud can be georeferenced into any Cartesian coordinate system.

Modelling point cloud into 3D-objects can be done with Cyclone-MODEL module. Modelling can be done manually using provided 3D primitives and using point cloud as reference. However better way is usually select some points for object we are about to model and ask Cyclone to model it. Cyclone will then look nearby points that could match to primitive we asked and use all those points to make 3D primitive that matches accurately of real object. Cyclone-MODEL has 3D primitives of building blocks used and excellent tool for modelling pipes, however it is not good for modeling complex objects. For complex objects modelling project can be exported in 3D DXF format and then continue modelling on other applications.

For big and complex projects Cyclone-SERVER module makes it possible for many members of team to work on same project at the same time.

1.2.2 Blender

The Blender is open source, cross platform suite of tools for 3D creation. Centria uses Blender to further processing material made with Cyclone and to convert them into different formats. However current version of Blender which at time of writing this is 2.70, does not have proper DXF-importer and therefore older version is needed. Good choice is Blender version of 2.49b.

Cyclone application can export models into 3D DXF format which then can be imported into Blender. However imported models do not have proper normals for vertices and model appears to be completely black. In addition all the faces in model have own copies of vertices. Because of this all objects seem to have flat faces even when smooth shading is selected. All these can be fixed in Blender manually but that would requires a lot of work. Therefore we have developed Python script to automatically fix normals and removing duplicated vertices from objects. After running script model already looks much better and is ready for further processing. With blender it is possible to create photorealistic pictures and animations or model can be exported for further processing in another application.

1.2.3 Cloud Browser

Sometimes customers do not have software to view point clouds. Therefore we have developed Cloud Browser application. With this application user can view point cloud using real colors or intensity mapped colors. Point cloud can be viewed from different angles or user may fly inside point cloud. User may also do some basic measurement by selecting points from point cloud. Many new features have also been planned.

1.3 Use cases for bridge building and monitoring

Laser scanning and point clouds can be used for a whole life cycle of bridge. Before bridge building starts surrounding area can be scanned and this information can be used for planning the groundwork. Amount of ground need to be moved can be calculated using point cloud and different bridge models can be tested with model of actual environment.

While building a laser scanning could be used to check parts before installation. This can speed up assembly when less time is spend on adjustment of mismatching parts. After building is done the bridge can be scanned and compared to 3D model and see how well it matches original plans.

Bridge can be monitored by periodically scanning and comparing point clouds to previous scans and detect changes. Point cloud could also be used for planning repairs. Also a laser Doppler vibrometer (LDV) is already used for bridge health monitoring.

1.3.1 Bridge part checking before install

Centria have participated in the project where laser scanning was used to check the bridge modules before installation. These modules were heavy and made mostly from steel, a few of those modules were also very long. Scanning was done in summer and since temperature affects to length of steel, it was necessary to keep records of temperature of every scan. Temperature recordings were used to do small adjustments for models. Models of parts were used to make sure that attachment points would match as good as possible. Bridge builder were also interested about arcs which were modelled using splines. Other parts of bridge modules were not modeled.

Bridge modules were installed using huge marine crane which have expensive rental. Because modules were checked beforehand all attachment points matched well, both time and money were saved.

1.3.2 Historically important bridges

Centria have participated to project where laser scanning was used to making accurate models of historically important buildings. There is nothing to prevent from using laser scanning to make accurate models of historically important bridges as well. In fact scanning have been already used for this purpose for many times around the world. New bridges can be also scanned and 3D-models could be used for example movies, games or simulations. In Finland laser scanning is used to save information about historical locations, however none of 33 museum bridges have been scanned yet. Four of museum bridges in Finland are wooden and oldest of them is Etelänkylän Isosilta in Pyhäjoki which was built in 1837.

1.3.2.1 Stonelick Covered Bridge

Stonelick Covered Bridge in Owensville, Ohio is one of the historic bridges that have been laser scanned. Bridge is 42.7 meter long and is supported by a 12 panel Howe Truss. This bridge was built in 1878 and it was laser scanned 2013. On February 11, 2014 the upper shell of bridge collapsed but County and the contractor have planned to completely rebuild whole bridge.

2 Finnish Transport Agency

Finnish Transport Agency is responsible for maintenance and comprehensive development of national road, waterway and railway networks. Finnish Transport Agency also maintains road bridges and railroad bridges (the replacement value of about 4 billion) as well as coordinates several development projects where new design tools and practices are being discovered (Tirkkonen, 2014). The Unit of Skill Structures operates the auspices of the Finnish Transport Agency and since year 2001 there has been maintained continuously research and development work within the framework of the projects like “Intelligent Bridge”, “5D-Bridge1” -2 and -3. The major objective of the above projects has been development of information modeling concerning bridge construction, renovation and maintenance as well as finding new ways to make use of 3D technology in designing process. The development processes have been carried out in cooperation with leading finish builders, engineering offices and software development offices which guarantees comprehensive information flow through every layer participating designing and implementation process. There is lot of development needed with 3D-modeling software but encouraging results have already been achieved and development process will be continued further (Heikkilä.R, 2014).

Traditionally in bridge design two-dimensional design has been utilized. The major problem is information dispersion of various different documents and certain constraints of clarity. The advantage of product model –based (three dimensional) modeling is demonstrative and three dimensional model of subject which enables use of meta-information and flexible customization in large variety of 3D modeling software. Additionally compared to the two-dimensional designing three-dimensional world offers more sophisticated tools and procedures for data visualizing, editing and dimensioning. 5D-Bridge project - led by Finnish Transport Agency -had been concentrated in development of common information model. In this common information model use of open source data formats guarantees flexible information transportation between variety of data sources and processing mechanisms. In addition concept of data collection, verification and processing have been studied. Figure 1 is described as a bridge design process of turning the thoughts of traditional 2D design towards 5D information modeling for use throughout the life cycle of the bridge. (Tirkkonen, 2014). It illustrates the 5D-life cycle - base data collection, designing process, construction process, testing, documentation and maintenance for us.

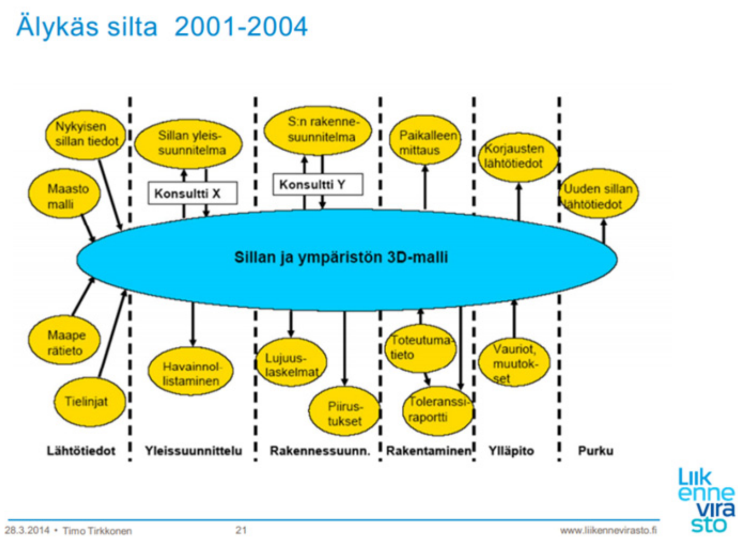

Figure 1. Bridge design process from traditional 2D design towards 5D information modeling.

APPENDIX B

Timber Bridges – Life Cycle Assessment

What has been studied in Finland?

Cluster Wooden Bridges

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Abstract

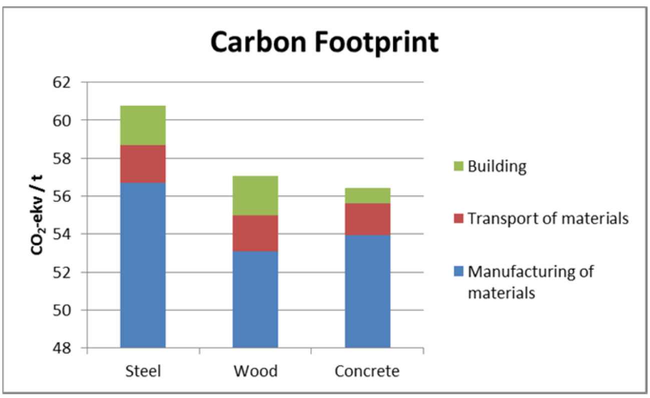
This document is a short summary of research results that have been done about life cycle assessment of timber bridges in Finland. Following three studies have been found during Cluster Wooden Bridges -project.

1 Carbon footprint of pedestrian bridge – examination of three bridge alternatives

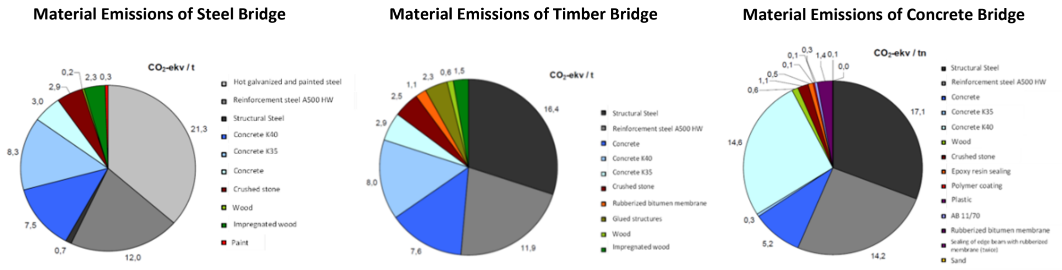
This study was done by WSP Environmental Oy for the city of Espoo in 2009. Aim of the study was to compare environmental aspects and effects of different type of pedestrian bridges. Carbon footprint of steel, timber and concrete bridges were evaluated by life cycle survey. Goal of this carbon footprint examination was to find out information about environmental load in different stages of bridge lifecycle. Examination object was a pedestrian bridge in Kauklahti, Espoo.

Carbon emissions were evaluated through different life cycle stages. Those were manufacturing of materials, transport of materials, building of bridge, maintenance and decommissioning. Emissions from manufacturing of materials are counted based on emission factors. In all bridge option steel, concrete, crushed stone and wood are the main materials. In addition special materials like paints, plastics and rubberized bitumen are taken into account. Emissions from transport are counted based on transportation distance and emission of transport vehicle. Transport distance is 50 km with most of the materials. Steel comes from Northern Finland (650 km) and Siberian larch is imported (6500 km). When building bridges only straight emissions of machines are taken into account, like excavators and pile-driver.

Manufacturing of the bridge materials is biggest source of carbon emission in all three bridge options, about 94 % (Picture 1). Both transportation and building accounts only for 3 % of carbon emissions. Reference period of Carbon footprint is 100 years. Emissions during use consisted mostly of maintenance. Steel bridge is repainted two times and deck is renewed three times. Deck of timber bridge is renewed two times and roof once. Surface structure of concrete bridge is renewed once. When it is time to take bridges out of use all materials are considered to be recycled. In Picture 2 is shown material carbon emissions of different bridge types.



Picture 1. Carbon footprint of steel, wood and concrete bridge.



Picture 2. Material carbon emissions of steel, wood and concrete bridges.

As a summary, in this study carbon footprint is biggest with steel bridge and lowest with concrete bridge. Though differences are small. That is because pedestrian bridge is quite small project and material differences do not have significant influence. In addition foundations and pilings are similar in each bridge type.

2 Eco-efficiency of Vårnäs bridge structure

This study was done by VTT (Technical Research Centre of Finland). Aim was to compare eco-efficiency of two different bridge type; continuous span reinforced concrete slab bridge and gluelam beam bridge with concrete deck. Bridge span is 138 m and designed lifetime 100 years. In this study life cycle processes are purchase of materials, transport of materials, maintenance during lifetime and demolition of bridge. Building of bridge was not included.

Conclusions were that timber bridge needs about 30 % less material than concrete bridge. Timber bridge also consumes approximately 10 % less fossil energy than concrete bridge. After 100 years both bridges can be recycled up to 80 %. Burning of timber bridge materials gives 5000 GJ of energy. Corresponding amount with concrete bridge is about 3000 GJ. As a summary it can be said that according to eco-efficiency timber bridge is better in almost every studied category. Differences between bridge options would have been bigger for the good of timber bridges, if wood have been used more in timber bridge.

3 ETSI -project

ETSI (Bridge Life Cycle Optimization) was a co-operation project of four Nordic countries, Finland, Sweden, Norway and Denmark, during 2005-2012. Three Excel based software tools were developed for bridge buyers and designers; Life Cycle Cost (LCC), Life Cycle Assessment (LCA) and Life Cycle aEesthetics (LCE).

Costs of different life cycle stages can be calculated with LCC tool. Excel takes into account for example investment, inspection, maintenance, repair and demolition costs. Life cycle emissions can be evaluated with LCA tool. LCA software analyzes material, work and transport emissions that are related to bridge building and maintenance. Relative meaning of environmental stressors during life cycle can be analyzed with this tool. Emission categories are: global warming potential (GWP), ozone layer depletion potential (ODP), abiotic depletion potential (ADP), acidification potential (AP), eutrophication potential (EP) and abiotic depletion potential (ADP). Use of energy can also be monitored.

Third tool was software to evaluate bridge aesthetics and cultural effects. Aesthetic evaluation is based on grades that are given to different bridge parts, like beams and railings, and how the bridge preserves the harmony of the scenery. Based on aesthetic evaluation a correction factor is given to real costs of the bridge. Correction factor decreases when aesthetic evaluation increases. With this factor comparison costs of different bridge types can be calculated. More about ETSI project can be read from http://etsi.aalto.fi/Etsi3/index.html.

APPENDIX C

Accelerated weathering test

Cluster Wooden Bridges

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1 Introduction

1.1 General

Test is part of Cluster Wooden Bridges project.

1.2 Equipment under Test

QUV Accelerated Weathering Tester 73-thru 75-spray

Temperature and moisture meter: Vaisala HMI41 and HMP42

Spectrophotometer CM-2500d

Magnifiers Carton 30x, Hama 8x

Hygrometer Gann Hydromette compact A

1.3 Main Purpose

The main purpose of the test was compare weather resistance of the test samples followed the standard EN 927-6:2006

1.4 Personel

The test was carried out by: Hanna Parikka

2 Test Procedures

2.1 Weather Experiment

The weather experiment was performed in a QUV accelerated weathering tester. QUV simulates the sunlight with fluorescent ultraviolet lamps, rain and dew with water spray. The weathering schedule followed the standard EN 927-6:2006 (Paint and varnishes. Coating materials and coating systems for exterior wood. Part 6: Exposure of wood coatings to artificial weathering using fluorescent UV lamps and water).

An exposure cycle of one week consists of a condensation period followed by a sub-cycle of water spray and UV-A 340 irradiation as given in Table 1. The weather experiment involves a continuous light irradiation 2,5 hours following water spray 0,5 hour. The average irradiance was 0.68 W/m² at 340 nm wavelengths. The samples were placing in the QUV without an aluminum panels. Changes on the sample surfaces were estimated every 168 h. The total test time was 1344 hours.

Table 1. Exposure cycles

Step	Function	Temperature	Duration	Condition
1	Condensation	(45±3) °C	24 h	
2	Subcycle step 3+4		144 h consisting of 48 *cycles of 3 h consisting of steps 3 and 4	
3	UV	(60±3) °C	2,5 h	irradiance set point 0,68 W/(m²nm) at 340 nm
4	Spray		0,5 h	6 l/min to 7 l/min, UV off

2.2 Assessment of Cracking and Flacking

The cracking of coating was determined according SFS-EN ISO 4628-4 standard [1]. The quantity of cracking was assessed according to Table 2 and using an example figures (Attachments 1 and 2), depending on the type of cracking. The average size of the cracks was assessed according to Table 3.

Table 2. Rating scheme for designating the quantity of cracks.

Rating	Quantity of cracks
0	none, i.e. no detectable cracks
1	very few, i.e. small, barely significant number of cracks
2	few, i.e. small but significant number of cracks
3	moderate number of cracks
4	considerable number of cracks
5	dense pattern of cracks

Table 3. Rating scheme for designating size of cracks.

Rating	Size of cracks
0	not visible under x 10 magnification
1	only visible under magnification up to x 10
2	just visible with normal corrected vision
3	clearly visible with normal corrected vision
4	large cracks generally up to 1 mm wide
5	very large cracks generally more than 1 mm wide

The depth of cracking was determined if it was possible. The depth of cracking was classified in three main types:

a) surface cracks which do not fully penetrate the top coat (i.e. checking);
b) cracks which penetrate the top coat, the underlying coat(s) being substantially unaffected;
c) cracks which penetrate the whole coating system.

The flaking of coating was determined according SFS-EN ISO 4628-5 standard. The quantity of flacking was assessed by according to Table 4 and using an example figures (Attachments 3 and 4), depending on the type of flaking.

Table 4. Rating scheme for designating the quantity of flaking.

Rating	Flaked area
0	0
1	0,1
2	0,3
3	1
4	3
5	15

Table 5. Rating scheme for designating the size of areas exposed by flaking.

Rating	Size of cracks
0	not visible under x 10 magnification
1	up to 1 mm
2	up to 3 mm
3	up to 10 mm
4	up to 30 mm
5	larger than 30 mm

The depth of flaking was determined if it was possible. The depth of flaking was classified in two main types:

a) coat(s) flaking from an underlying coat
b) the whole coating system flaking from the substrate

2.3 Color Measurement

The color of different treatments was determined using Spectrophotometer CM-2500d from Konica Minolta. The CIELAB system (According to Commission International de l'Eclairage-CIE) is characterized three parameters, L*, a* and b*. L*axis represents the lightness, a* and b* are chromaticity coordinates. In the CIELAB coordinates, +a* is for red, -a* for green, +b* for yellow, -b*for blue and L* varies from 100 (white) to zero (black) (Picture 1). The color changes ΔE* were measured after every 336 hour using D65 light source as established by CIE 1976. The color change ΔE* consist from the ΔL*, Δa* and Δb* values:

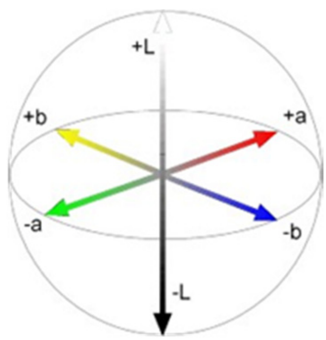
$$\Delta E^* = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \quad (1)$$

$$\Delta L^* = Lf^* - Li^* \quad (2)$$

$$\Delta a^* = af^* - ai^* \quad (3)$$

$$\Delta b^* = bf^* - bi^* \quad (4)$$

ΔL*, Δa* and Δb* are the changes between the initial (i) and the final (f) values. A low ΔE* corresponds to low color change [2].



Picture 1. CIELAB coordinate [2]

3 Test

3.1 Test Materials and Finishing

Test materials were micro grooved spruce and impregnated pine witch were finished as seen in Table 6. Samples 1-8 are different kind of varnishes that are toned to brown. Samples 9-20 are white paints, NCS 0502Y. Surface treatment was done by hand spray gun except top coat in samples 15 and 16. There was five different paint manufacturers.

Table 6. Test piece materials and finishing.

Sample 1	Spruce	water based wood protector, toned (100 g/^{2}) + acrylate lacquer (200 γm)
Sample 2	Impregnated pine	water based wood protector, toned (100 g/^{2}) + acrylate lacquer (200 γm)
Sample 3	Spruce	water based wood protector (100 g/^{2}) + toned primer + toned alkyd-acrylate lacquer (175 γm) + tonedalkyd-acrylate lacquer (175 γm)
Sample 4	Impregnated pine	water based wood protector (100 g/^{2}) + toned primer + toned alkyd-acrylate lacquer (175 γm) + tonedalkyd-acrylate lacquer (175 γm)
Sample 5	Spruce	oil based primer + natural oil based stain
Sample 6	Impregnated pine	oil based primer + natural oil based stain
Sample 7	Spruce	wood stain (100 g/m^2) + wood stain (100 g/m^2)
Sample 8	Impregnated pine	wood stain (100 g/m^2) + wood stain (100 g/m^2)
Sample 9	Spruce	water based wood protector (100 g/^{2}) + acrylate paint (225 g/m^2)
Sample 10	Impregnated pine	water based wood protector (100 g/^{2}) + acrylate paint (225 g/m^2)
Sample 11	Spruce	acrylate paint (100 γm [thinning 10%] + 100 γm)
Sample 12	Impregnated pine	acrylate paint (100 γm [thinning 10%] + 100 γm)
Sample 13	Impregnated pine	water based wood protector (100 g/^{2}) + alkyd-acrylate paint (175 γm) + alkyd-acrylate paint (175 γm)
Sample 14	Spruce	water based wood protector (100 g/^{2}) + alkyd-acrylate paint (175 γm) + alkyd-acrylate paint (175 γm)
Sample 15	Spruce	oil based primer + polyacrylate paint (brush application, ca 200 g/m^2)
Sample 16	Impregnated pine	oil based primer + polyacrylate paint (brush application, ca 200 g/m^2)
Sample 17	Spruce	acryl dispersion (150 γ) + acryl dispersion (150 γ)
Sample 18	Impregnated pine	acryl dispersion (150 γ) + acryl dispersion (150 γ)
Sample 19	Spruce	acrylate paint (150 γm)
Sample 20	Impregnated pine	acrylate paint (150 γm)

The visual changes (cracking and flaking) on sample surfaces were estimated every 168 h. At the same time samples were photographed. Color measurement was done at the beginning, every 2 weeks and at the end of the test.

3.2 Assessment of Cracking and Flaking

Assessment of cracking was done under good light. The cracking quantity results are summarized in Table 7 and the cracking size results are summarized in Table 8.

Table 7. Cracking quantity.

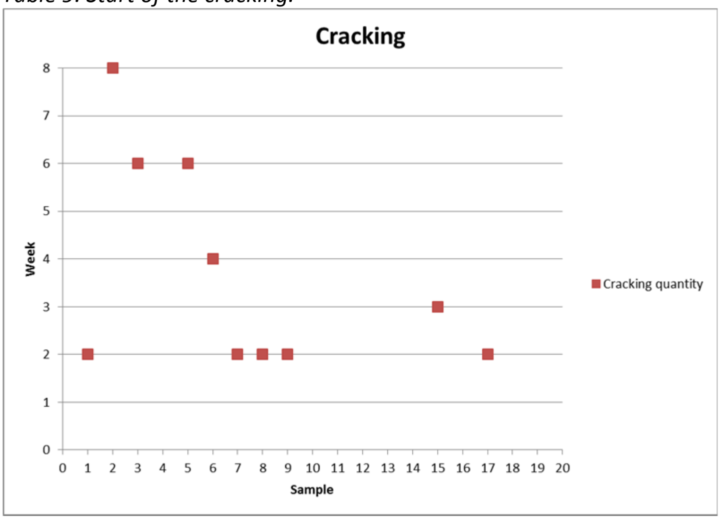
	Cracking quantity							
	week 1	week 2	week 3	week 4	week 5	week 6	week 7	week 8
Sample 1	0	1	1	**2**	2	2	2	2
Sample 2	0	0	0	0	0	0	0	1
Sample 3	0	0	0	0	0	1	1	1
Sample 4	0	0	0	0	0	0	0	0
Sample 5	0	0	0	0	0	1	1	1
Sample 6	0	0	0	1	**2**	2	2	2
Sample 7	0	1	**2**	3	3	3	3	3
Sample 8	0	1	1	**3**	3	3	4	4
Sample 9	0	**2**	2	2	3	4	4	4
Sample 10	0	0	0	0	0	0	0	0
Sample 11	0	0	0	0	0	0	0	0
Sample 12	0	0	0	0	0	0	0	0
Sample 13	0	0	0	0	0	0	0	0
Sample 14	0	0	0	0	0	0	0	0
Sample 15	0	0	1	1	1	1	1	1
Sample 16	0	0	0	0	0	0	0	0
Sample 17	0	**2**	2	2	2	2	2	2
Sample 18	0	0	0	0	0	0	0	0
Sample 19	0	0	0	0	0	0	0	0
Sample 20	0	0	0	0	0	0	0	0

Table 8. Cracking size.

	Cracking size							
	week 1	week 2	week 3	week 4	week 5	week 6	week 7	week 8
Sample 1	0	**2**	2	2	2	2	2	3
Sample 2	0	0	0	0	0	0	0	**2**
Sample 3	0	0	0	0	0	**2**	2	2
Sample 4	0	0	0	0	0	0	0	0
Sample 5	0	0	0	0	0	**2**	2	2
Sample 6	0	0	0	**2**	2	2	2	2
Sample 7	0	**2**	3	3	3	3	3	3
Sample 8	0	**2**	2	3	3	3	3	3
Sample 9	0	1	1	1	**2**	2	2	2
Sample 10	0	0	0	0	0	0	0	0
Sample 11	0	0	0	0	0	0	0	0
Sample 12	0	0	0	0	0	0	0	0
Sample 13	0	0	0	0	0	0	0	0
Sample 14	0	0	0	0	0	0	0	0
Sample 15	0	0	**2**	2	2	2	2	2
Sample 16	0	0	0	0	0	0	0	0
Sample 17	0	**2**	2	2	2	2	2	2
Sample 18	0	0	0	0	0	0	0	0
Sample 19	0	0	0	0	0	0	0	0
Sample 20	0	0	0	0	0	0	0	0

In Table 9 is shown week when cracking started on test pieces. One of the varnish samples didn't have cracking. With paint samples, only three samples cracked.

Table 9. Start of the cracking.



No flaking was noticed on test samples during test.

3.3 Color Measurement

Color measurement was done every two weeks. Every sample was measured from five points in the direction of the wood fibers. Results of samples 1-8 are shown in Table 10 and samples 9-20 in Table 11. The human eye can perceive color differences approximately 0.5 ΔE*ab in CIELAB units [3].

Table 10. Color change, samples 1-8.

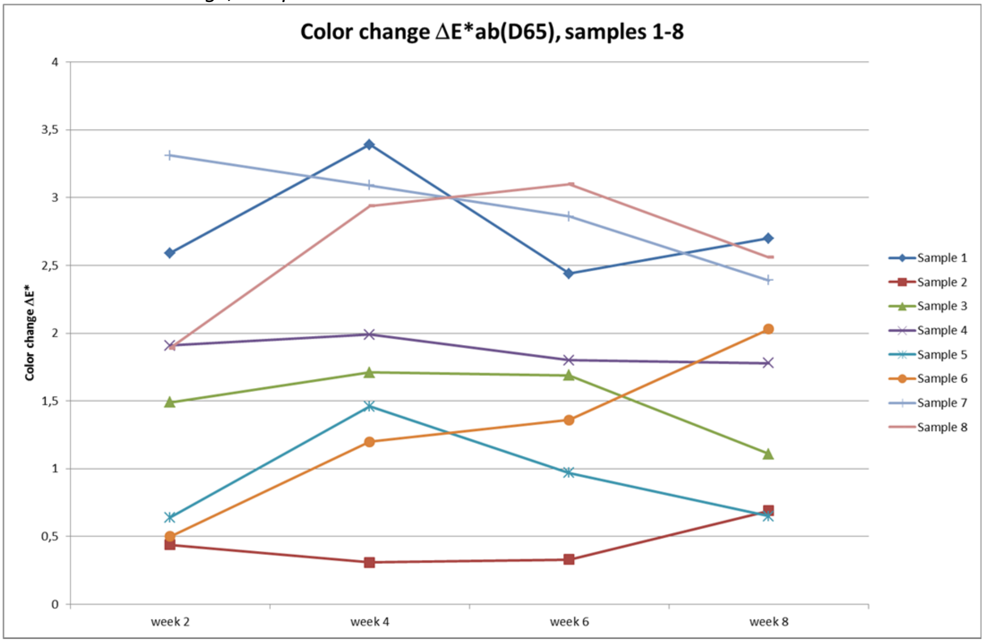
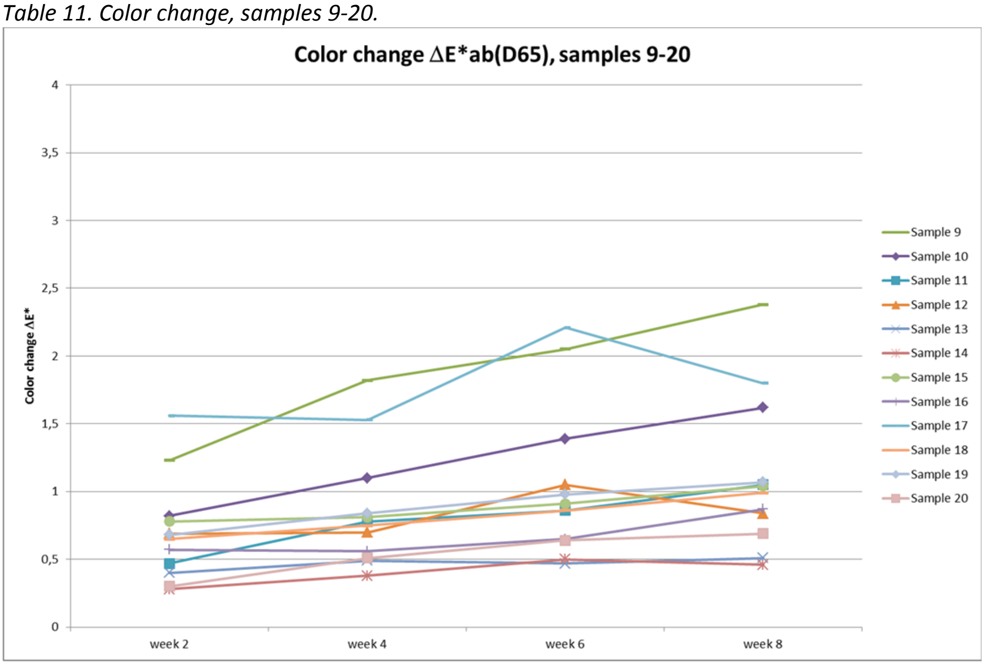


Table 11. Color change, samples 9-20.



4 Summary

Samples 1-8 were finished with toned varnishes. In samples 1-4 primer coat was wood protector and top coat was lacquer. Samples 5-8 were oiled or stained. As it could be assumed lacquer gave better protection against sun and rain. Sample 2 kept its color best, on the other hand sample 1 had one of the biggest color change and they are finished alike. It seems that wood material, micro grooved spruce vs. impregnated spruce, affected on that. Color change was most even between samples 3 - 4 and 5 - 6. Color changes in samples 1, 7 and 8 were the highest. These same samples cracked already at week two. Sample 4 did not have any cracks during this test.

Samples 9-20 were finished with white paints from different manufacturers. Some of them had also wood protector as primer coat. Biggest color change was in samples 9, 10 and 17. Smallest color change was in samples 13 and 14. Only samples 9, 15 and 17 were cracked during the test. All in all color change and cracking were smaller with samples 9-20 than with samples 1-8.

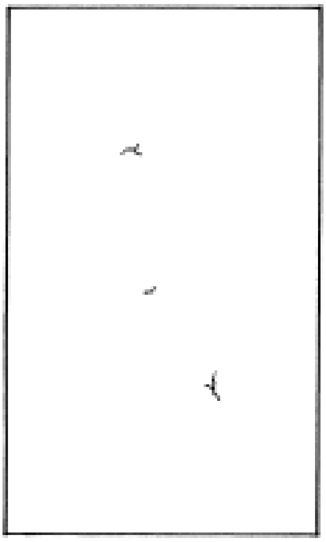
References

[1] SFS-EN ISO 4628-4 Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Part 4: Assessment of degree of cracking

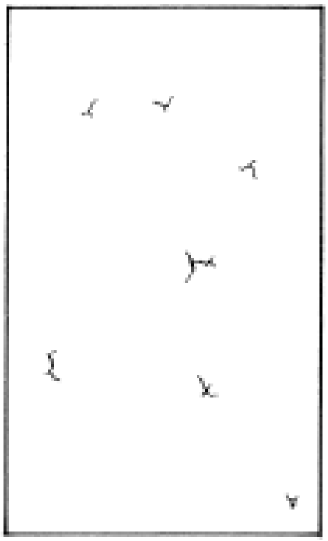
[2] Minolta, Precise Color Communication – Color Control from Perception to Instrumentation

[3] Jouni Hiltunen, Accurate Color Measurement

Attachment 1. Cracking without preferential direction (panels area 1 dm² to 2 dm²)



Quantity (density) 1



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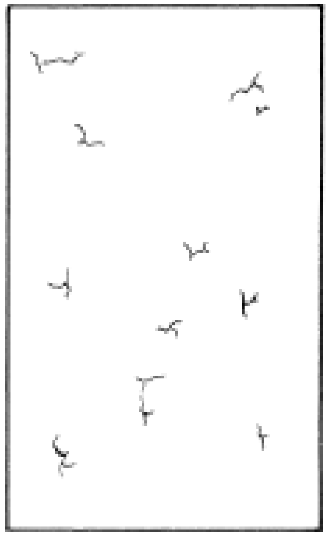

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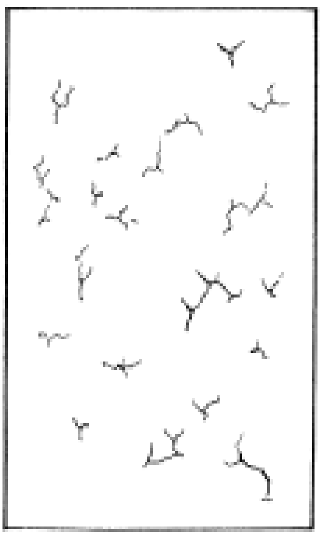
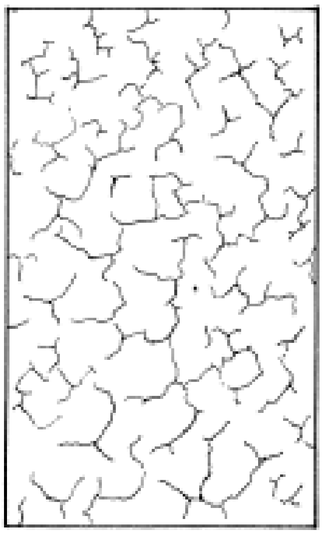
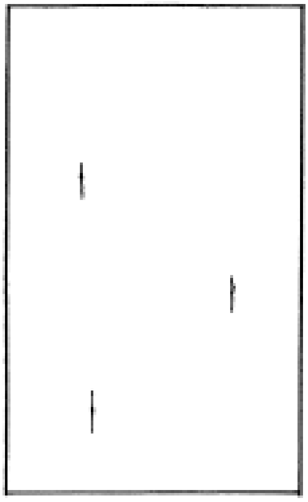


Quantity (density) 4



Quantity (density) 5

Attachment 2. Cracking in one preferential direction
(For example due to brush marks or wood grain, panels area 1 dm² to 2 dm²)



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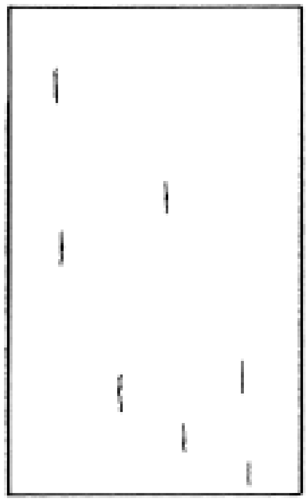

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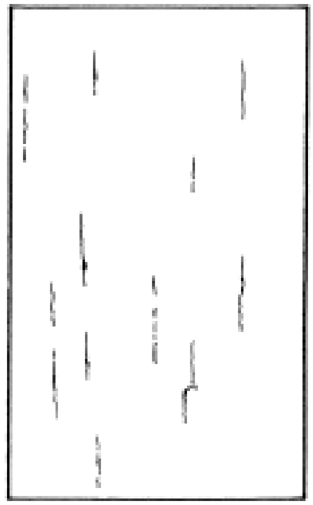

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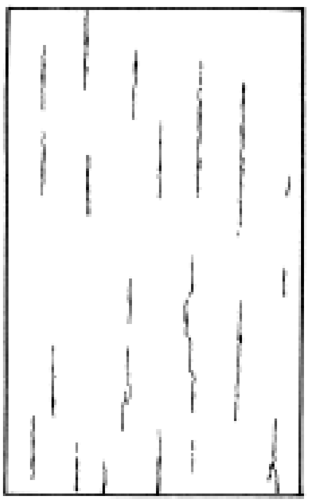

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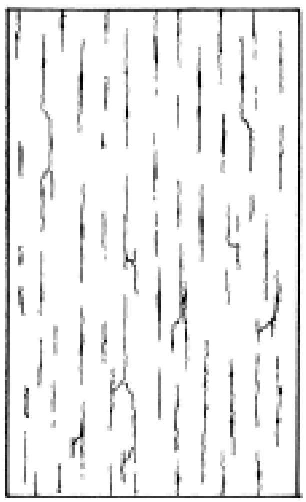
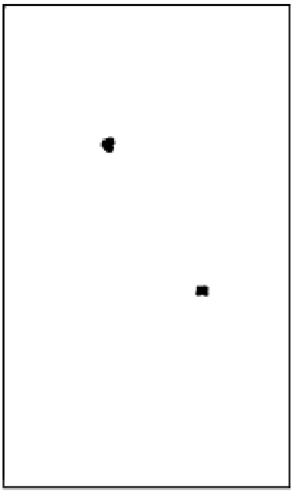


Quantity (density) 5

Attachment 3. Flaking without preferential direction (panels area 1 dm^2 to $2dm^2$)



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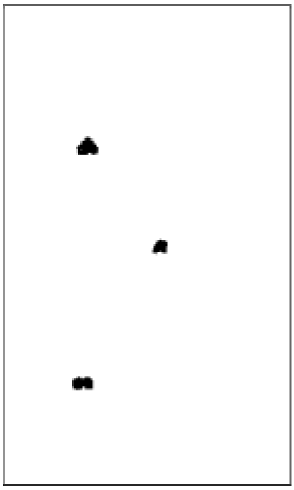

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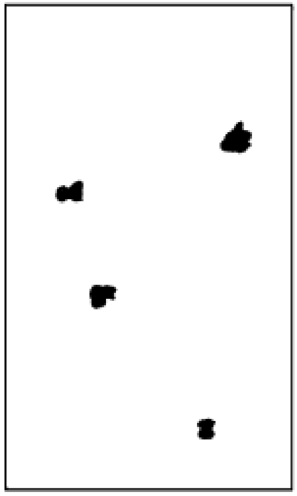

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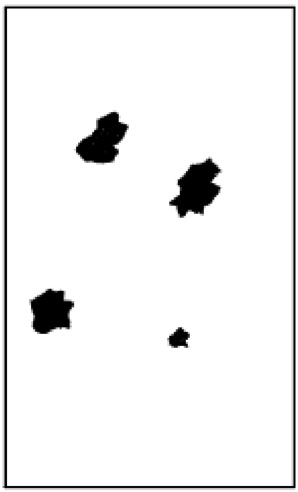

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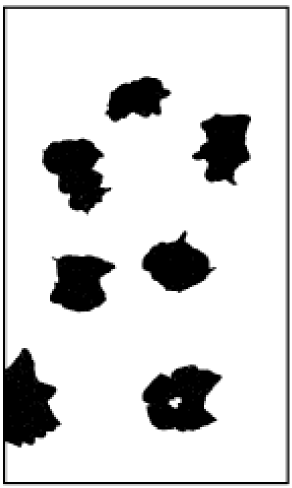
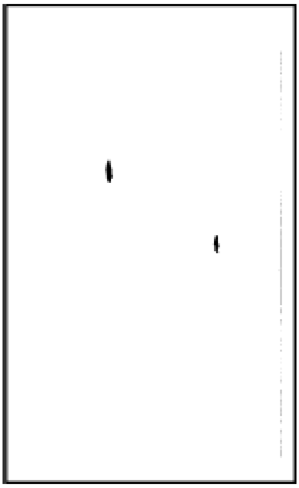
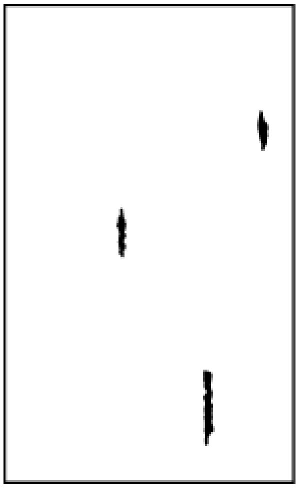


Quantity (density) 5

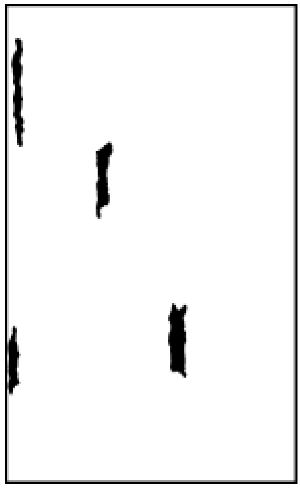
Attachment 4. Flaking in a preferential direction (panels of area 1 dm^2 to $2dm^2$)



Määrä (tiheys) 1



Määrä (tiheys) 2



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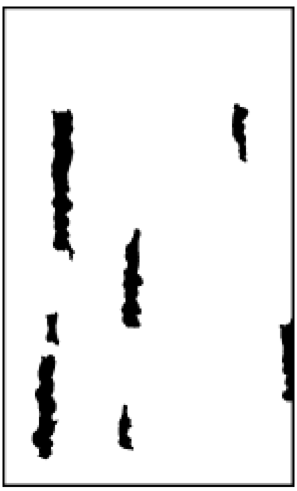

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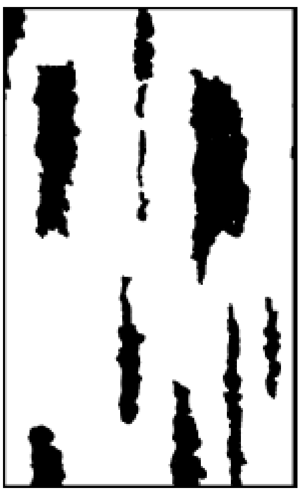

Määrä (tiheys) 5

APPENDIX D

The Search for Vibration and Wood Moisture Sensors

Cluster Wooden Bridges

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Introduction

In this work we have been searching for the market to find out more suitable vibration and wood moisture sensors. The preferred data transmission link for the sensors was wireless. Planned case in the use of the sensors was for continuous in situ measurements in a wooden bridge. There were a few wanted features for the devices. They should be wireless. They should be easy to set up and build in. Battery life should be long lasting and easily replaceable when or if necessary. Semi-active RFID short communication distance data logger sensors could be an acceptable compromise in some use scenarios.

1 Notices of the monitoring systems

Monitoring systems for measuring the behavior of the wooden bridges has many phenomena to measure. In this work we focused on and wanted to find out sensors to measure moisture content in wood and vibrations in wooden structures. The sensor devices would be a moisture transmitter and a vibration transmitter. There were both wired and wireless devices available. In the case of the wired sensor device has an analog output, it can be digitalized on-site by connecting up into an ADC capable device. To achieve wireless data collection the connected device has a radio.

1.1 Using WSN in the monitoring systems

In the case of continuous and long-term monitoring of wooden bridges a wireless sensor network is one of the options to choose. It should be noted that, a big majority of the freely available wireless sensor products are just a part of the bigger monitoring system. The monitoring systems and their dedicated devices are not cross compatible between another in most cases. That is because of each company has their own proprietary communication links for their own product families. Typically the monitoring system product family consists of sensors, routers, gateways, software, and even cloud services. If the used radio device standard in the wireless sensor product is not proprietary, then it is most likely built on either IEEE 802.11 or IEEE 802.15.4. In Europe the most common radio frequency bands are 433 MHz, 868 MHz and 2.4 GHz.

1.2 Using RFID in the monitoring systems

The following well known generic facts are recommended to take into consideration if someone is planning to use the RFID devices. The communication distance for passive RFID tags is only a few meters away from the tag reader device in optimal conditions. That is because of the passive tag simply reflects back a small amount of the power emitted by the tag reader device. Semi-active tags has a built-in power source and so they can sense and log data independently of the reader device. Semi-active tags are also called as semi-passive tags or as battery assisted passive tags. The communication distance can be greater because of the semi-active tags are using their own power. Another semi-active tag advantages compared to passive tag are higher reading success rates and lower latency. The semi-active tags are still used by with the same reader as the passive tags. Active tags are totally different from that. They have a longer reading range because of active tags contain a radio transmitter. Active tags contain a built-in power source like semi-active tags and so they can operate independently of the reader device. By using semi-active or passive RFID sensor tags the measured data usually had to be gathered by a person with his hand held RFID tag reader device. Active RFID sensor tags can be used similarly to typical wireless sensor network devices.

2 Notices of the vibration transmitters

The sensor that is used to measure vibration of the bridge is typically an accelerometer. The sampling rate per axis should be usually below a few hundred hertz to be well suitable for structural monitoring. The most of the sensor devices the sampling rate is possible to configure by user. Of course there are moreover things to take into consideration than just the sampling rate, like output range and sensitivity just to name but a few.

3 Notices of the moisture content transmitters

Moisture content in wood is typically measured with direct contact measurement by the sensor probe electrodes driven into the wood. This type of sensor actually measures the electrical resistance of the wood. The electrical resistance is then translated into the moisture content. Another type of the moisture sensors relies on dielectric properties and requires only surface contact with the wood. Additional temperature sensor is used for temperature correction of the moisture content readings. To calibrate the sensor for wood specie the correction factor can be applied.

4 The table of search result

Wireless Moisture Transmitters for Wood

Manufacturer	Device Model	RF	Distance	Battery life	Ref.
Logica H&S	LG36 MoistureMouse	433 MHz	Approximately 50m in free space	Up to 2 years in continuous use	[1]
OmniSense LLC	S-900-1-2.0,±0.3°C/±2.0%RH-EU	868 MHz	Up to 100 meters	Typical battery life of 15+ years	[2]
General Electric Company	HygroTrac	868 MHz	Range of 46-122 meters	15 years nominal	[3]
Lignomat USA Ltd	Transmitter MC	433 MHz	Up to 305 meters	Up to 10 or 15 years	[4,5]
SMT Research	SMT-A2 (+PMM) *	2.4 GHz	1000m (free air)	Up to 3 years	[17,18,19,20]

*Not European version

Wired Moisture Transmitters for Wood				
Manufacturer	Device Model	Output	Sensor type	Ref.
Delmhorst	MTC-60	4-20mA or 1-5V, 0-2V	Any standard or special application Delmhorst electrodes	[6]
Delmhorst	MTV-60	0-10V	Any standard or special application Delmhorst electrodes	[6]

Wireless Vibration Transmitters					
Manufacturer	Device Model	RF	Distance	Battery life	Ref.
OmniSense LLC	S-25 -EU	868 MHz	Typically 61- 91 meters	AC Wall Adapter	[7,8]
I-Care SPRL	I-CARE WIRELESS SENSOR	2.4 GHz	Range of 50-500 meters	Typically 5 years	[9,10]
Walker Wireless	WiFi Wireless Vibration Sensor	2.4 GHz	?	Typical 1 year	[11]
microsensys GmbH	TELID®382.3D+	13.56 MHz	0-5 cm	up to 5 years (Working Time: one measurement cycle STOP FULL)	[12]
LORD MicroStrain®	G-Link2-LXRS	2.4 GHz	Range from 70 m to 2 km	?	[13]
LORD MicroStrain®	G-Link-RGD	2.4 GHz	Range from 70 m to 2 km	?	[14]
GAO RFID Inc.	2.45 GHz Active RFID Vibration Sensor Tag 127004	2.45 GHz	Range of 0 to 100 m	4 years	[15]
ElectroTech Kalix AB	TRITON	125 kHz + 868 MHz	Up to 15 meters	5-8 years	[16]

References

[1] http://www.logica-hs.com/en/sensors-and-wireless/lg36-moisturemouse-transmitter.html

[2] http://shop.omnisense.com/p/53/wireless-t-rh-wme-sensor

[3] http://www.ge-mcs.com/en/moisture-and-humidity/moisture-meters/hygrotrac.html

[4] http://www.lignomatusa.com/MoistureMeter/Transmitters.pdf

[5] http://www.lignomatusa.com/wireless.htm

[6] http://www.delmhorst.com/Moisture-Meters/Other-Markets/Moisture-Transmitter/MTC-60

[7] http://shop.omnisense.com/p/76/s-25-wireless-vibration-sensor

[8] http://www.omnisense.com/oms_cds/media/S-25_quick_start.pdf

[9] http://www.wirelessvibration.eu/wireless-vibration-temperature-sensor-transmitter.html

[10] http://www.wirelessvibration.eu/wireless-vibration-network.html

[11] https://www.walkerwirelessco.com/sites/walkerwireless/files/wifi_vibration.pdf

[12] http://www.microsensys.de/fileadmin/user_upload/datasheets/sensoren/TELID382_3D_003.pdf

[13] http://files.microstrain.com/G-Link-2-LXRS-datasheet.pdf

[14] http://files.microstrain.com/G-LINK-RGD_Datasheet.pdf

[15] http://www.gaorfid.com/RFID-PDF/127004.pdf

[16] http://www.craycom.se/crayeng/pdf/craycom-triton-sml.pdf

[17] http://smtresearch.ca/products/point-moisture-measurement-sensor-pmm

[18] http://smtresearch.ca/sites/default/files/resource/RS-1063%20PMM%20Datasheet%20Web.pdf

[19] http://smtresearch.ca/products/a2-wireless-data-loggers

[20] http://smtresearch.ca/sites/default/files/resource/RS-1100%20SMT-A2%20Datasheet%20Web_0.pdf

CLUSTER WOODEN BRIDGES

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