accoya®

innovation in wood

STRUCTURAL DESIGN GUIDE TO EUROCODE 5

AUTHORS TO ACCOYA® STRUCTURAL DESIGN GUIDE

Andrew Lawrence is an Associate Director with Arup Technology & Research and a Chartered Structural and Civil Engineer. He is the leading timber specialist at Arup, a member of the BSI's UK Timber Design Code Committee and a judge for the UK Wood Awards. His projects have included the 2005 Serpentine Pavilion with Alvaro Siza, the Metz Pompidou in France, the Metropol Parasol in Seville and most recently the Timber Wave in London.

ARUP

Julian Marcroft is a chartered structural engineer, who spent 7 years at the Timber Research and Development Association (TRADA) and 3 years as product development manager at Gang-Nail Systems Ltd. In 1997 Julian jointly founded TimberSolve Ltd, a small consultancy firm group undertaking only timber engineering work and specialising in the development of products and advanced technical support for the construction industry and multinational companies engaged in the engineered wood product sector. Since setting up Marcroft Timber Consultancy in 2013 Julian has continued to work in this sector. Julian has been active in Code and Standards work over several years and currently chairs the BSI committee, which oversees the implementation of timber design codes, notably Eurocode 5, in the UK.

Marcroft
Timber Consultancy

David Crawford is a Research Engineer within the Centre for Offsite Construction & Innovative Structures (COCIS) whose area of expertise is predominately in structural timber design. David completed an MSc in Timber Engineering in 2010 and a BSc in Civil Engineering in 2009 at Edinburgh Napier University and his next career goal is to become a fully certified Chartered Engineer. David's areas of interest/expertise lie within massive timber construction, and the structural performance of modified timber. Since joining the COCIS team, David has been involved with a number of research/feasibility studies in partnership with a range of Scottish based SMEs, the UK Government Department and large-scale European Companies. Recent research interests include: assessment of structural performance of acetylated timber and acetylated timber for glue laminated timber fabrication.

Institute for Sustainable Construction

Dr Robert Hairstans is Head of the Centre for Offsite Construction and Innovative Structures (COCIS) Robert has extensive experience of the housing market and of lean production systems. He was a principal contributor to the Scottish Building Standards Agency Small Buildings Guide and an integral member of the IStructE's UK constitution for the Design of Timber Buildings to Eurocode 5. He is author of "Offsite and modern methods of timber construction – a sustainable approach", a principal investigator on the EPSRC-funded project "Structural Optimisation of Timber Offsite Modern Methods of Construction" and an expert within the Institute for Sustainable Construction (ISC), Low Carbon Building Technologies (LCBT) Gateway project.

Institute for Sustainable Construction

CONTENTS

INTRODUCTION

Until now, using wood in damp external conditions for structural applications has been a real challenge, chiefly because of the risk of fungal attack. The most effective preservatives are by definition toxic and so have environmental issues both in use and disposal. While there are a few species of wood with good natural resistance to fungal attack, they are often difficult to glue and only have a comparatively limited life. Additionally, such species are often of tropical origin and sustainably sourced supplies are becoming increasingly limited. As a result, other materials will often be used instead. With Accoya®, all that can now change.

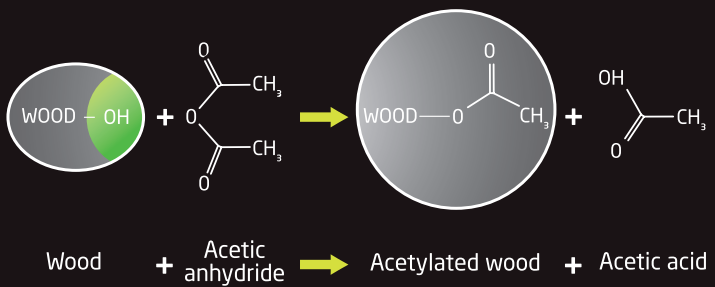
WHAT IS ACCOYA®?

Accoya® is wood that has been modified through a special patented chemical process developed by Accsys Technologies. This process involves acetylation in which the free -OH (hydroxyl) groups within the cell wall are replaced by acetyl groups. The acetyl groups contain nothing more than carbon, hydrogen and oxygen molecules, but because they are hydrophobic, they prevent water bonding onto the cell wall and so prevent the water causing swelling of the wood or providing a food source for the fungi that cause decay. Acetyl groups are abundant in all wood species and are found in other everyday products, such as vinegar, wine and aspirin.

Tests conducted over the 80 years since this form of wood modification was first invented demonstrate that wood modified to the standard achieved by Accoya® is very stable and also particularly resistant to decay. The extended treatment time (compared with conventional preservative treatments) combined with the use of appropriately selected permeable species, mean that members up to 75mm thick can be modified throughout their thickness. So, whereas with conventional preservative treatments the centre of the cross-section is generally untreated or only partially protected, with Accoya® the full cross section is modified and can therefore be safely cut and machined without the risk of exposing unmodified material.

In addition, acetylated wood is completely non toxic. Only the amount of acetyl, a compound which already occurs naturally in wood, is increased. Therefore Accoya® can be disposed of in exactly the same way as unmodified wood. Better still, because it will not have degraded, it could actually be reused on other projects.

Figure 1:



KEY FEATURES

DIMENSIONALLY STABLE

- Swelling and shrinkage reduced by 75% or more
- Doors and windows open effortlessly year round
- Reduced maintenance costs

OUTSTANDING DURABILITY

- Lasting 50 years above ground, 25 years in ground/freshwater
- Class 1 durability, surpassing even teak
- Virtually rot proof
- 70 year minimum service life stated by TRADA

PERFECT FOR COATING

- Improved stability means coatings last up to two times longer
- Easier to coat, less preparation and sanding required

Accoya® wood is produced from sustainably sourced, fast growing wood and manufactured using Accsys' proprietary patented modification process from surface to core.

BAREFOOT FRIENDLY

- Low thermal gain
- Barefoot Friendly
- Ideal for all decking situations in extreme temperatures

RETAINED STRENGTH & HARDNESS

- The process does not compromise the wood's strength
- Hardness is increased
- High strength to weight ratio makes it suitable for challenging applications

INSECT BARRIER

- Indigestible to a wide range of insects, including termites
- Greatly reduced vulnerability

EXCELLENT MACHINABILITY

- Easy to machine and process
- No special tools are required

FROM SUSTAINABLE SOURCES

- From FSC, PEFC and other regionally certified woods
- Naturally renewable

NATURALLY BEAUTIFUL WOOD

- Process does not compromise the wood's natural beauty

NATURALLY INSULATING

- Offers improved insulation in comparison with commonly used hardwood and softwood species
- Ideal for applications where energy conservation is important

NON-TOXIC & RECYCLABLE

- Protects the environmentfrom the harmful effects of common treatments
- May be safely reused, recycled and incinerated

CONSISTANT QUALITY THROUGHOUT

- Consistent, measurable modification quality from surface to core
- No need to apply chemical preservatives when cut or planed

THE STRUCTURAL POTENTIAL OF ACCOYA®

To date Accoya® has been used mainly for non-structural applications, such as external joinery. But arguably its highest potential lies in the ability to make large laminated members for external exposure. This has never before been possible without major limitation. The most durable wood species (all tropical hardwoods) which were traditionally used for bridges, such as ekki (azobe), generally cannot be glued - the same extractives which inhibit decay also make them difficult to glue. It is also increasingly hard to obtain sustainable supplies. Accoya® on the other hand is made from sustainable, plantation grown softwood, which is easy to glue. Furthermore, the dimensional stability of Accoya will reduce the amount of fissuring (therefore reducing the risk of water traps) and Accoya® is so durable that the consequences of water ingress are considerably less severe.

For all of these reasons, Accoya® offers the potential to use wood in completely new structural applications, formerly the preserve of steel and concrete. Case studies later in this guide show how it has already been used for fully exposed bridge structures and ground beams, both never possible before. The possibilities are endless.

SCOPE OF THIS GUIDE

Before a particular species of wood can be used structurally, it needs to be tested to determine its strength and stiffness. Because acetylation changes the structure of the wood at the microscopic cellular level, it also changes its strength.

The proprietary Accoya® production process has been specifically designed to ensure that Accoya® wood retains good overall structural characteristics so that it can meet the exacting standards required for structural applications, both in terms of performance and predictability.

This guide provides structural design data based on extensive testing which has been undertaken at Edinburgh Napier University, SHR Timber Research Netherlands , the University of Göttingen and the University of Brighton. The guide enables the design of both solid and laminated Accoya® members to Eurocode 5. The guide also discusses the environmental credentials of the material and provides advice on design life, maintenance, connection detailing and specification.

OUTSTANDING PERFORMANCE

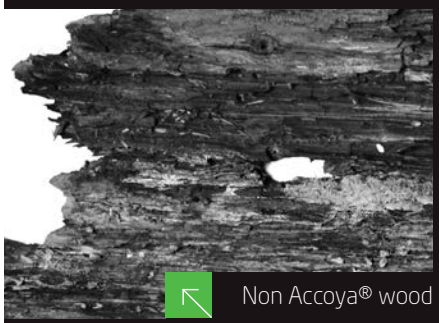
Durability

To determine the durability of wood against both fungus and termites, it has been traditional to use long term 'stake tests', where 50x50mm stakes are left in the ground and periodically tested with a lateral blow from a hammer.

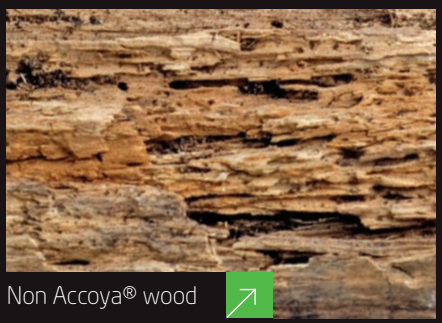
In recent years accelerated laboratory tests have been developed to compare the performance of modified woods, preservative treated woods and previously untested species, with the durability of known species and preservatives. Such tests are generally regarded as less accurate than the in-ground tests, but do enable a much quicker assessment to be made.

Since acetylated wood was first developed in laboratories nearly 80 years ago, a huge amount of in-ground testing has been undertaken, demonstrating its resistance to fungal attack. This is confirmed by the recent testing on Accoya® described below; excitingly recent tests also demonstrate Accoya®'s performance against termites by standard US, Japanese and Australian methods.

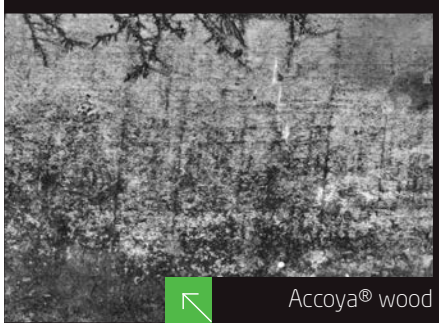
Accoya® manufacture has been underway since 2007. Some durability and exposure testing predates this commercial production, and in these cases, pilot plant samples were used. Pilot plant samples had a performance specification equal to or, in most cases slightly lower than the Accoya® produced commercially since 2007. Full durability test information is presented in the Accoya® Performance Brochure (www.accoya.com/downloads) and is incorporated in the National KOMO Product Certification on durability (see reference section on back page). A summary of the test is presented in this guide.



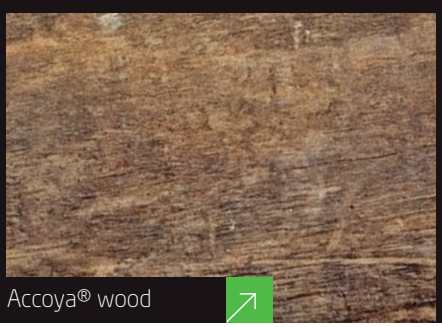
Non Accoya® wood



Non Accoya® wood



Accoya® wood

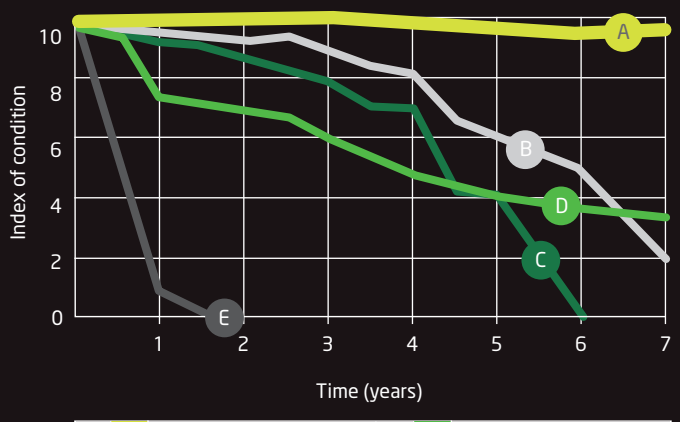


Accoya® wood

16 YEAR CANAL LINING TEST

In 1995, Accoya® and a control sample of unmodified wood were used to line a freshwater canal in Holland. After 16 years the acetylated wood showed no signs of decay, while the unmodified wood had been completely destroyed. Canal bank conditions are particularly punishing, because of the combination of water, microbe rich soil and air at the waterline.

Figure 2:
DECAY RATES OF FUNGUS CELLAR STAKELETS

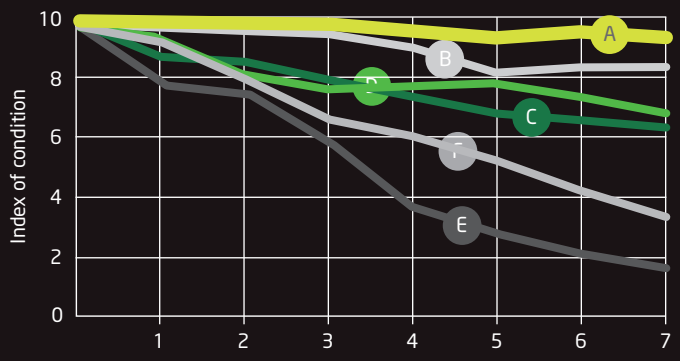


A		Accoya® wood	D		Merbau
B		CCA H4	E		Radiata Pine
C		CCA H3.2			

7 YEAR STAKE TESTS

SCION (formerly the New Zealand Forest Research Institute) has undertaken 7 year stake tests in accelerated decay chambers and also outside in ground contact to compare the performance of Accoya® with both naturally durable and preservative treated wood. As shown on the graphs opposite, the Accoya® showed almost no decay, making it significantly better than wood treated with chromated copper arsenate (CCA, itself now heavily restricted because of the difficulties of disposal) or even the most durable tropical hardwoods such as teak.

Figure 3:
DECAY RATED FIELD STAKES



A		Accoya® wood	D		Teak
B		CCA H4	E		Macrocarpa
C		CCA H3.2	F		Cedar

Decay/insect damage rating system (ASTM D 1758)

10 = No decay or insect damage
9 = Minor decay, 0-3% of the cross section
8 = Lightly established decay, 3-10% of the cross section
7 = Well established decay, 10-30% of the cross section
6 = Extensive and deep decay, 30-50% of the cross section
4 = Deep and severe decay, more than 50% of the cross section
0 = Failed

TERMITE TESTING, JAPAN WOOD PRESERVATIVE ASSOCIATION

A two year field test was conducted against two different types of termite in Kagoshima, Japan. Formosan termites (Coptotermes formosanus) are present in a dry area of the site and Reticulitermes speratus is active in a wet area. Collectively the sites also have an assortment of rot fungi present including white and brown rots.

Unmodified stakes (both of Japanese cedar and radiata pine) performed poorly, whereas the Accoya® was completely unscathed (see photos below).

Non Accoya® wood, wet test site

Accoya® wood, wet test site

Non Accoya® wood, dry test site

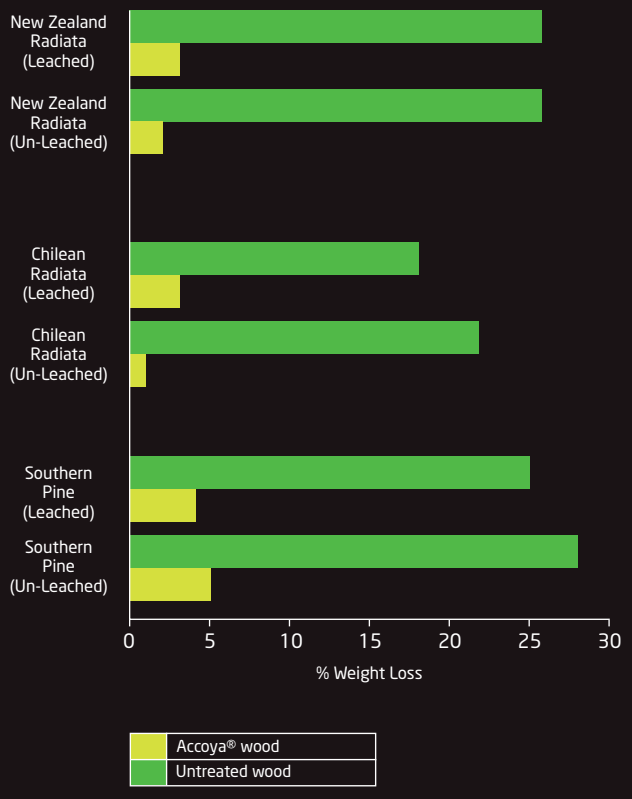
Accoya® wood, dry test site

TERMITE TESTING, LOUISIANA STATE UNIVERSITY

The Formosan termite is one of the world's most aggressive termites. Louisiana State University has conducted a 99 day Formosan termite 'choice' test (to AWPA E1), on 50x100mm control samples of unmodified radiata and southern yellow pine and also on Accoya®.

All four sides of the unmodified wood were heavily attacked, whereas the Accoya® only showed slight grazing. The results of standardised tests show that Accoya® is over 20 times better than the unmodified wood, measured by weight loss.

Figure 4:



Note: As required by the testing standards, tests were carried out on both leached and un-leached specimens. The leached specimens had been water impregnated and washed.

TERMITE TESTING, AUSTRALIAN FOREST RESEARCH COMPANY

The performance of Accoya® against attack by Australia's most economically destructive species of subterranean termite, Coptotermes acinaciformis, was determined by above ground exposure for five months at a field test site in the Northern Territory.

The field trial was conducted in accordance with the Australasian Wood Preservation Committee Protocols for the Assessment of Wood Preservatives (2007) which are appropriate for assessing the performance of both preservative treated wood, and naturally durable species. The performance of Accoya® was compared with the sapwood of radiata pine (which is susceptible to termites) and the heartwood of two naturally durable species (to AS5604-2005) - Western red cedar and spotted gum. Test specimens were soaked in water and vacuum oven-dried prior to exposure to seven different colonies of Coptotermes acinaciformis.

After the required five months' of exposure, Accoya® showed equivalent performance to the spotted gum and was significantly better than the Western red cedar. By comparison the radiata pine had lost over 80% of its mass and was largely destroyed.

MEAN MASS LOSS AFTER FIELD EXPOSURE TO COPTOTERMES ACINACIFORMIS

MATERIAL	MASS LOSS (%)
Accoya®	0.5
Spotted gum	1.0
Western red cedar	28.6
Radiata pine (unmodified)	82.6

DURABILITY - SUMMARY

Based on a review of the testing which has been undertaken, BRE have stated that Accoya® has durability Class 1 resistance against fungal attack to BS EN 350. Initial tests also suggest that Accoya® has good resistance against termites, but this has yet to be fully proven.

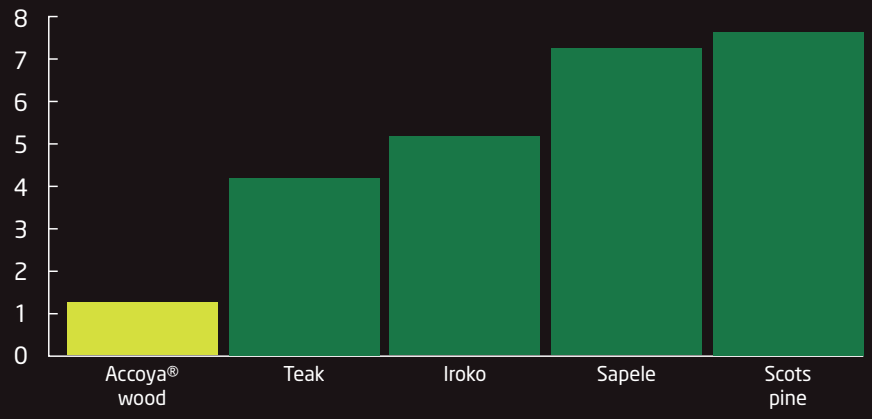
BS8417 indicates that durability Class 1 species can achieve a 60 year service life in ground contact or in contact with fresh water.

Dimensional Stability

Stability refers to the degree by which wood swells or shrinks with varying moisture content. This is particularly important for large structural members in an external environment, where varying seasonal humidity can cause the wood to shrink or swell, leading to the risk of splitting at the restraint provided by steel connection plates or surface fissuring as the surface dries and shrinks relative to the core. Such splits and fissures can trap water, increasing the moisture content and consequently increasing the risk of fungal attack.

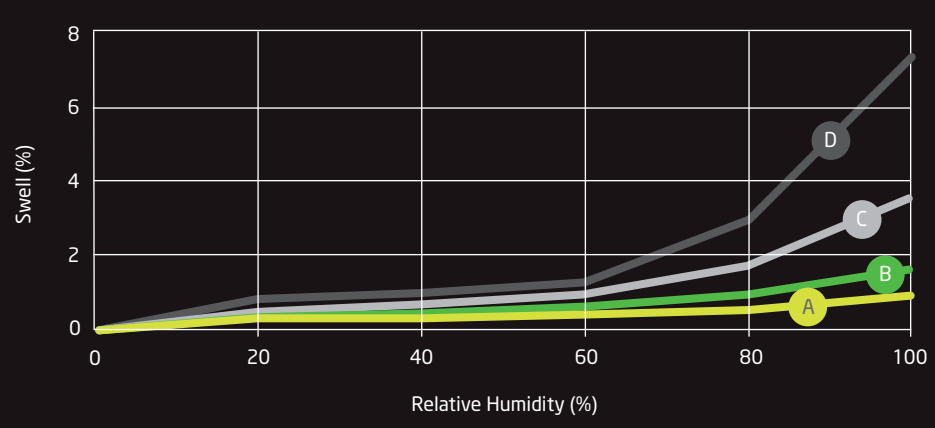
SHR Timber Research, Netherlands, has undertaken a series of tests to measure the shrinkage and dimensional stability of Accoya®. The first test measured the tangential shrinkage in going from fully soaked to oven dry. The second test measured the swelling with increasing relative humidity. Overall these tests show that Accoya® is about three times more stable than any other wood.

Figure 5:
TANGENTIAL SHRINKAGE* (%)



* typical tangential shrinkage from fully soaked to oven dry - the most extreme laboratory test

Figure 6:
RELATIVE HUMIDITY



Accoya® wood
A Radial swell
B Tangential swell

Radiata pine
C Radial swell
D Tangential swell

Unmodified wood

Accoya® wood

Unmodified wood

Accoya® wood

REDUCED MAINTENANCE COSTS

The resistance of Accoya® to fungal attack should avoid the need for any preventative maintenance. Where Accoya® is left uncoated, and exposed to the elements, a weathered grey appearance will develop over time, as with other wood types. There can be a transition phase of Accoya® when surface mildews and mould may be visible on the wood surface prior to it reaching a weathered grey appearance. These can be addressed on Accoya®, as with other timbers, with various preventative or remedial surface applied treatments.

Where a coating is specified for appearance this will need to be maintained. The life of applied coatings is partly limited by the seasonal shrinking and swelling of the wood surface. Accoya®'s dimensional stability ensures that film forming coatings will generally have a much longer life and therefore significantly reduce maintenance requirements.

Exposure testing has been undertaken on various coatings over 9.5 years at the Dutch Wood Research institute (SHR) (Report 3.330-366) and for a range of periods at several other laboratories. The Accoya® outperformed all other woods. Even after 9.5 years, the white paint tested needed no maintenance (see photo above). TRADA (Report TS//F12032) have reviewed the test results of 4 outdoor exposure trials of Accoya®, including a 13 year exposure in Sweden. The TRADA study concludes that it would be reasonable to assume at least a 50% increase in the life to first maintenance compared to unmodified softwoods and have acknowledged that this factor may increase as trials continue.

ENVIRONMENTAL CREDENTIALS

In comparing Accoya® with other materials, it is necessary to consider the sustainability of the wood which is used to make Accoya®, the various environmental issues associated with the chemical modification process itself, also end of life.

SOURCING AND PRODUCTION PHASE:

- All Accoya® wood is produced from well managed sustainable sources including FSC, PEFC and other regionally certified woods.
- Only abundantly available, and often fast growing source species such as Radiata pine, are used to create Accoya®, safeguarding a consistent supply and preventing deforestation of tropical forests.
- The Accoya® wood manufacturing process is non-toxic and adds nothing to the wood that does not already naturally occur in it.
- The Accoya® production facility meets the highest requirements with respect to health, safety and the environment as recognized by several ISO 14000-based certifications.

USE PHASE

- Enhanced durability, facilitating a longer lifespan, improved carbon sequestration potential and lower lifetime material consumption versus other materials.
- Proven quality: Accoya® has acquired several quality certifications (e.g. KOMO, RAL, BBA, WDMA, etc) and is warranted against fungal decay for at least 50 years above ground and 25 years in ground.
- Outstanding dimensional stability and improved hardness results in lower maintenance frequency (lower costs) and therefore less coating use and waste over the product's lifetime.
- Superior thermal insulation.

END OF LIFE PHASE

- Accoya® wood is fully reusable and recyclable. Reuse is recommended but Accoya® may be safely incinerated for bio-energy or composted to close the loop of the carbon cycle.
- In the Cradle to Cradle® philosophy, for which it holds Gold-level certification, Accoya® wood is understood to be non-toxic and 100% biodegradable.
- By products of the production process are reused, recycled to produce acetylated MDF Tricoya or sold for reuse by others including the food industry. Waste wood from construction projects gets high quality second life as input material for Tricoya, thus increasing the carbon sink effect of wood.

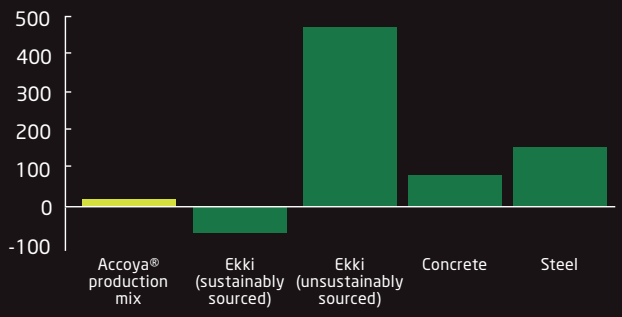
Carbon Footprint

A carbon footprint study for Accoya® was carried out by Camco, now Verco, in accordance with ISO 14040/44, based on a cradle to gate scenario.

The study used standard emission factors complying with the recommendations of the World Business Council for Sustainable Development and World Resources Institute's Greenhouse Gas Reporting Protocol and looked at the six greenhouse gases covered by the Kyoto Protocol in terms of their carbon dioxide equivalent.

The graph shows that Accoya® scores significantly better than steel, unsustainably sourced timber and concrete in terms of carbon footprint per year, but has a slightly higher carbon footprint than sustainably sourced Azobe / Ekki.

Figure 7:
ANNUAL EMISSIONS PER BRIDGE (kg CO_2 / YR)*



Carbon footprint comparison for Accoya® wood with material alternatives for the bearing structure of a pedestrian bridge

*Life Cycle Assessment of Accoya® wood in it's applications, Delft University of technology. Peer reviewed.

Ecolabels Acquired

CRADLE TO CRADLE GOLD

Accoya® radiata wood is one of the very few building products to have acquired Cradle to Cradle Certification on the Gold level. C2C evaluates products and materials for human health, environmental health and recyclability. Products are analysed within five categories - Material Health, Material Reutilisation, Renewable Energy Use, Water Stewardship and Social Responsibility. Accoya® radiata wood has been awarded the Gold Certification because it meets all the given criteria, including there being no trace of toxic chemicals, over 50% renewable energy during the manufacturing process and a material reutilization score of 89%. According to the certification body, MBDC, Accoya® radiata wood is a wood product that is designed to be a biological nutrient and is safe to return to the environment.

FSC AND PEFC

Of the various schemes for sustainable forestry available, the Forest Stewardship Council (FSC®) and the Programme for the Endorsement of Forest Certification (PEFC®) are regarded as the leading and most comprehensive certification programs available. Both programs not only focus on benign environmental performance, but also safeguard social interests for all stakeholders involved. Accoya® is available in both FSC and PEFC.

THE FUTURE BUILD

The Future Build is a green building materials portal that helps architects, engineers and contractors confidently select and source environmentally sustainable, third party certified products. Only products that have been assessed and selected according to stringent standards and criteria set by the carbon neutral Masdar City, Abu Dhabi, are listed. Accoya® wood was rated as excellent or A.

SINGAPORE GREEN LABEL

For the South East Asian market Accoya® received the Green Label of the Singapore Environment Council (SEC), which was set up to promote environmental awareness in this region. The 'Green Label' can only be obtained by compliance with the strict eco standards specified by the SEC's scheme and rigourous testing of the product for possible harmful content.

NORDIC ECOLABEL

The outstanding green credentials of Accoya®, have been officially recognised by Europe's Nordic nations with the award of the Svanen Ecolabel. The label, renowned for its rigor and transparency is the internationally recognised ecolabel for Norway, Sweden, Denmark, Iceland and Finland and was established in 1989 by the Nordic Council of Ministers. It was developed to help consumers and companies select products that are guaranteed to have met stringent environmental standards.

STRUCTURAL DESIGN IN ACCOYA®

EFFECT OF ACETYLATION ON PHYSICAL AND MECHANICAL PROPERTIES

Any chemical modification process that affects the chemistry of the wood cell wall polymers and/or their interactions will also affect the physical and mechanical properties of the wood. The key effects of acetylation are:

- Accoya® has a lower equilibrium moisture content than the parent wood;
- Accoya® has a higher density than the parent wood due to the weight of the added acetyl groups; however because the wood swells during acetylation, there are actually fewer fibres per cross section compared with the unmodified wood;
- Accoya® has a slightly lower tensile and bending strength than the parent wood.

STRENGTH GRADING

In order to account for any effects of acetylation on structural properties, stringent strength grading procedures are applied by Accsys Technologies to produce the strength class C24 Accoya Structural. In the case of radiata pine these procedures were established in conjunction with SHR Timber Research as part of the programme to construct two 32m span Accoya road bridges in the Netherlands, described later in this guide.

In addition to meeting visual grading criteria, the radiata pine pieces, prior to acetylation, are graded to a prescribed setting using a machine measuring dynamic modulus of elasticity. In the case of southern yellow pine, this is purchased as 'select structural' in accordance with NLGA and NGRDL rules. For both species strength testing was subsequently carried out on a large number of samples in accordance with EN 408 ('Structural timber and glued laminated timber. Determination of some physical and mechanical properties.'). This testing showed that the strength graded Accoya (both species) meets strength class C24 of EN 338.

TEST INVESTIGATIONS ON ACCOYA STRUCTURAL

A wide range of test programmes to investigate the structural properties of Accoya® Structural have been undertaken as listed in the table above. Most of these test programmes have investigated the performance of Accoya® Structural in both Service Class 1 and 3 conditions and found that Accoya® Structural's strength and stiffness are reduced by a lower level than is the case for unmodified wood when subjected to elevated moisture levels.

STRUCTURAL PROPERTY	TEST METHOD	LABORATORY
Bending strength	EN 408	SHR Timber Research, Edinburgh Napier University, MPA Stuttgart
Modulus of elasticity	EN 408	SHR Timber Research, Edinburgh Napier University, MPA Stuttgart, Technical University of Munich
Tension strength parallel to grain	EN 408	Technical University of Munich
Compression strength parallel to grain	EN 408	University of Brighton
Compression strength perpendicular to grain	EN 408	University of Brighton
Shear strength at notched end of beam	Bespoke	University of Brighton
Embedment strength of dowel fastener	EN 383	University of Brighton
Shear modulus	EN 408	Edinburgh Napier University
Strength of end grain-to-side grain hanger connection	ETAG 015	Simpson Strong-Tie EU accredited laboratory
Withdrawal strength of nail	EN 1382	Simpson Strong-Tie EU accredited laboratory

DESIGN OF SOLID ACCOYA® STRUCTURAL MEMBERS

Solid Accoya® Structural members may be designed in accordance with EN 1995-1-1:

- The characteristic strength and stiffness properties given for C24 in EN 338 may be assumed;
- These shall be modified in accordance with the factors for solid wood in EN 1995-1-1 to obtain appropriate design values, with the exception of the value for k_{mod} (which shall be taken from the table below);
- Since Accoya® will mainly be used in external applications, the Service Class 3 values for k_{mod} (as in Table below) and k_{def} (as for solid timber in Table 3.2 of EN 1995-1-1) will generally apply;
- Note that in Service Class 3 under instantaneous or short-term load-duration, the mean and characteristic values for modulus of elasticity and shear modulus should be multiplied by 0.9.

Accoya® Structural is generally available in standard solid section sizes of 38 x 150 and 38 x 200mm. Larger members will need to be laminated.

	LOAD DURATION CLASS				
SERVICE CLASS	PERMA-NENT ACTION	LONG-TERM ACTION	MEDIUM-TERM ACTION	SHORT-TERM ACTION	INSTAN-TANEOUS ACTION
1	0.6	0.7	0.8	0.9	1.1
2	0.6	0.7	0.8	0.9	1.1
3	0.55	0.65	0.7	0.9	1.0

Values of k_{mod} for solid and laminated Accoya Structural

DESIGN OF LAMINATED ACCOYA® STRUCTURAL MEMBERS

The physical and chemical changes associated with acetylation, can affect the curing process of the glue line. In particular adhesives which require moisture for hardening can be affected by the particularly low moisture content of Accoya®.

Testing has so far been undertaken on Accoya® wood by Dynea and Henkel, in accordance with EN301 and EN302-1 (PRF adhesives) or EN 15425 (PU adhesives), to confirm that their adhesives are suitable for gluing Accoya®. These adhesives are listed in the specification clauses below. It may be possible to use other adhesives, but these would need to be confirmed by the relevant manufacturers.

Laminated Accoya® Structural members may be designed in accordance with EN 1995-1-1:

- The characteristic strength and stiffness properties given for GL24h in EN14080) may be assumed;
- These shall be modified in accordance with the factors for laminated wood in EN 1995-1-1 to obtain appropriate design values, with the exception of the values for k_{mod} and k_h
- K_{mod} shall be taken from the table on page 15;
- For members of depth h > 600mm, k_h shall be taken as $(600/h)^{0.1}$. For h ≤ 600mm, k_h shall be calculated in accordance with EN 1995-1-1, 3.3(3);
- Note that in Service Class 3 under instantaneous or short-term load-duration, the mean and characteristic values for modulus of elasticity and shear modulus should be multiplied by 0.9.

CHARACTERISTIC VALUES (in N/mm² or kg/m³)

	PROPERTY	SYMBOL	SOLID 'ACCOYA® STRUCTURAL'	LAMINATED 'ACCOYA® STRUCTURAL'
FIFTH PERCENTILE VALUES	**Bending strength**	$f_{m,k}$	24	24
	Tensile strength:			
	Parallel to grain	$f_{t,0,k}$	14	19.2
	Perpendicular to grain	$f_{t,90,k}$	0.4	0.5
	Compressive strength:			
	Parallel to grain	$f_{c,0,k}$	21	24
	Perpendicular to grain	$f_{c,90,k}$	2.5	2.5
	Shear strength	$f_{v,k}$	4.0	3.5
	Modulus of elasticity, parallel to grain	$E_{0,k}$	7400	9600
	Density	ρ_k	380	410
MEAN VALUES	**Modulus of elasticity:**			
	Parallel to grain	$E_{0,m}$	11000	11500
	Perpendicular to grain	$E_{90,m}$	370	300
	Shear modulus	$G_{0,m}$	690	650
	Density	ρ_m	460	460

SUMMARY OF MATERIAL PROPERTIES

For ease of reference, the material properties of solid and laminated Accoya® Structural for use in conjunction with EN 1995 are given in the table below.

Note that in Eurocode 5, the depth factor kh is standardised at different depths for solid and laminated wood; solid and laminated wood also have a different partial factor for material properties; overall this means that laminated wood is stronger in bending than solid wood, notwithstanding the fact that characteristic bending strength for both are 24 N/mm² in the table.

Note: Characteristic values are used in structural design and take into account the spread within results and represent a level close to the bottom end of the data set. This differs from the reported average values in general Accoya publications which are appropriate for non-structural use.

DESIGN OF CONNECTIONS

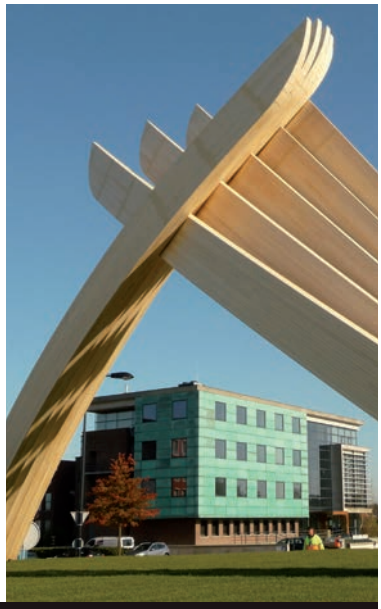
Connections may be designed in accordance with EN 1995-1-1. Advantage may be taken of the higher density of Accoya® due to the weight of the added acetyl groups.

For dowel type fasteners (nails, screws, dowels and bolts) this will generate higher embedment, and where applicable withdrawal and head pull-through, strengths.

The following characteristic densities (ρ_k) may be assumed:

- Solid Accoya® 380 kg/m^3
- Laminated Accoya® 410 kg/m^3

The dimensional stability of Accoya® will also be of advantage when using large bolt groups. Many other species are at increased risk of splitting due to the restraint provided by the steel plate or cross grain timber to which the bolts are often connected.



STRUCTURAL SPECIFICATION CLAUSES

SOLID ACCOYA® FOR STRUCTURAL USE

'Accoya® Structural' shall be acetylated wood radiata pine or southern yellow pine manufactured by Accsys Technologies. It should have been structurally graded in accordance with the grading rules established by SHR Timber Research and Accsys Technologies, which have been demonstrated (by testing in accordance with EN 408) to produce 'Accoya® Structural' of Strength Class C24 to EN 338. The material shall be marked 'Accoya® Strength Class C24'.

Note for specifiers: the surface classification of Accoya® is predominantly four sides clear and is comparable to the A1 grade described in the 'Accoya® Lumber Grading Manual' which can be found at www.accoya.com/downloads.

Note for specifiers: Solid Accoya® for structural use is designated as 'Accoya® Structural' and distinct from the general appearance grades of Accoya® used for non-structural applications.

LAMINATED ACCOYA® FOR STRUCTURAL USE

Laminated Accoya®Structural shall be manufactured in accordance with EN 14080 from "Accoya® Structural" laminates. Adhesive shall be either Aerodux 185 from Dynea (a PRF) or Purbond HB S309 (a Henkel brand Polyeurthane) and shall be used in accordance with EN 14080 and with the manufacturer's recommendations.

Note for specifiers: The adhesives are different. PRF is a brown adhesive whereas PU is colourless. The Dynea and Pubond adhesives do not require the wood to be coated to protect the glueline, however other products may do so. Manufacturers guidelines must always be followed.

A minimum number of 4 laminates is required to achieve strength class GL24h.

STAINLESS STEEL FIXINGS

Flitch plates shall be stainless steel minimum Grade 1.4404 or equivalent to EN 10088. Fixings shall be stainless steel minimum grade Grade A2 to EN ISO 3506. See Accoya® Wood Information Guide for further details at www.accoya.com/downloads.

Note for specifiers: Accoya® contains a small amount of residual acetic acid from the modification process. While it is less acidic than oak or several tropical hardwood species, in order to ensure an adequate life for metallic fixings it is recommended to use stainless steel. If discoloration is a concern then grade A4 fixings will be required.

SURFACE SPREAD OF FLAME TREATMENT

To architect's specification.

Note for specifiers: Flame Spread Tests by the Southwest Research Institute in the USA in accordance with NFPA 255 (ANSI, UL 723 & UBC 8-1) demonstrate that Accoya® achieves Class C surface spread of flame and is comparable with most timber species. (See the Accoya® Performance Brochure for full test details). Summary brochure at www.accoya.com/downloads.

STRUCTURAL CASE STUDIES

Two heavy traffic road bridges

Two Wooden Bridges for Heavy Road Traffic up to 60 Tonnes in Sneek, the Netherlands

Constructed in 2008 & 2010, the two 32m span bridges at Sneek in Holland are a landmark in timber bridge construction. Bridges are arguably one of the most structurally demanding applications for timber. Not only must they carry significant loads (in this case 60 tonne lorries,) but they must do so safely for many years, despite being fully exposed to the weather.

Traditional timber bridges relied on a roof to keep the timber dry and stop it rotting; the roof was very effective and several hundred such bridges still survive in the United States. But of course the roof came at a cost and so once timber preservatives were developed, these offered a cheaper way of protecting the timber. The most famous examples are the highway bridges built in Norway in the 1990s. These are robustly designed with CCA treatment on the individual laminates, and an oil-based creosote protection to the overall glulam combined with copper caps to help keep the timber dry. Preservatives are necessarily toxic and the most effective preservatives such as CCA and creosote are now heavily restricted because of health and environmental concerns in use and disposal. In response, the central European countries have readopted the idea of a roof, but this time provided by the deck, thus avoiding the cost of a separate roof. The result is very robust but can be architecturally limiting, because the structure must be kept below deck level for protection.

The bridges at Sneek are the first to incorporate laminated softwood elements, without reliance on toxic preservatives or a protective roof. The bridges were the result of an architectural competition and were inspired by both the trussed form of the traditional covered bridge and also Sneek's historic water gates; the ingenious form of the bridges gives the impression of passing through a gateway. By curving the two trusses towards each other, it was possible to provide clearance for two lanes of traffic while limiting the overall height of the bridge.

There was a real desire to use natural materials and because timber is so easy to machine, it particularly leant itself to such curved forms.

The trusses were built up from doubly curved twisted glulam members, created by curving thin singly curved beams about their weak axis and then gluing them with, In this case, aero dux 185 Dynea (PRF), the most water resistant timber adhesive, with its characteristic dark brown glue line. The members are connected using 2m long glued in steel rods each 48mm diameter, achieving an incredibly strong and stiff connection. A steel rod concealed within the bottom chord and with large end thrust blocks, is used to make the critical connection between the rafters and tie of the trusses.

> "SEARCHING FOR A BRIDGE MADE OF WOOD WITH A SERVICE LIFE OF AROUND 80 YEARS SEEMED AN IMPOSSIBLE TASK UNTIL WE DISCOVERED ACCOYA®"

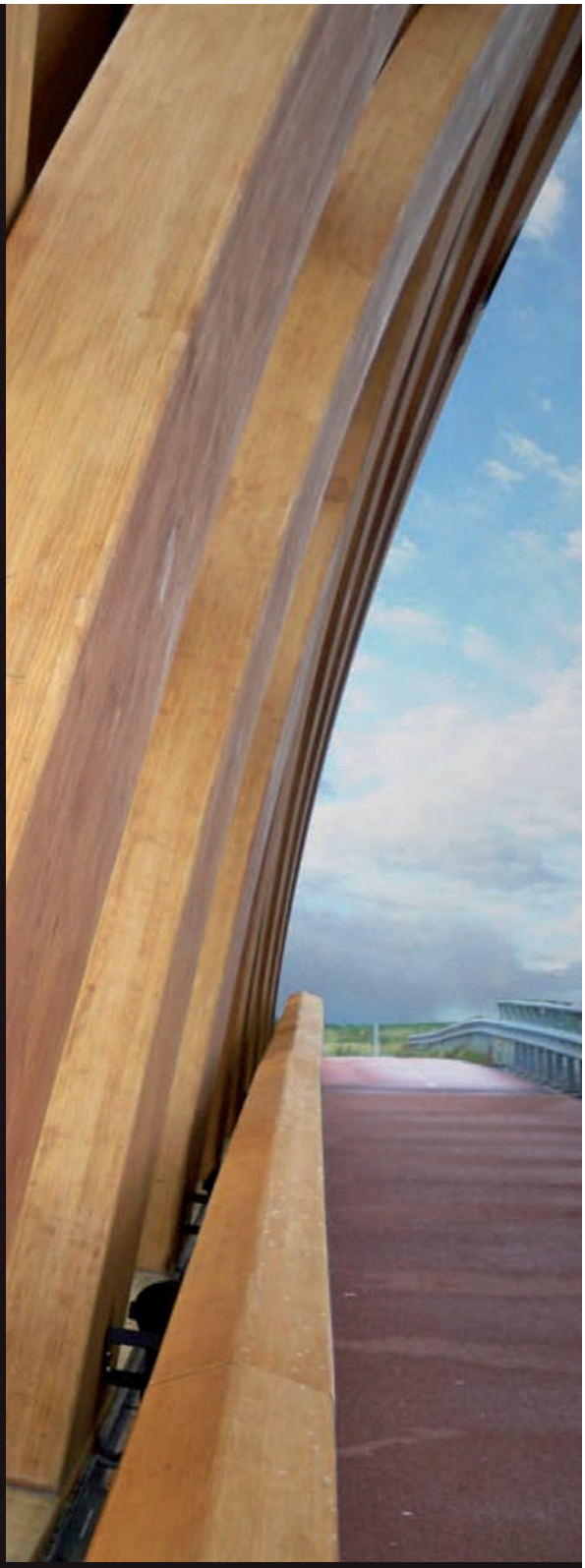
S. Hoitinga & P. de Jong
Friesland local authority

Without Accoya®, the bridges could not have been achieved in their current form:

- Water could have become trapped between the members where they meet, slowly soaking into the timber and causing decay; by contrast Accoya® is significantly less susceptible to the effects of moistute ingress;
- Large laminated members exposed to the rain are liable to swell; as they dry in the sun the exposed faces shrink relative to the core and fissure, creating potential water traps; by contrast because Accoya® is so stable, the amount of swelling and thus the risk of subsequent fissuring is small;
- The risk of swelling also means that it is not normally possible to use bonded steel connections in external glulam structures because of the movement of the timber against the restraint provided by the steel.

The Dutch Highway Authority approved the use of Accoya®, demonstrating their confidence that the material could offer the required 80 year design life.

The bridges were assembled 1km from the site inside a heated tent to ensure adequate curing conditions for the epoxy used to glue the bonded rods. The entire bridges (each weighing 30 tonnes) were then transported to site. The bridges were the first structural use of Accoya®, a material which till then had been thought of more for joinery.



Contractor
Schaffitzel Holzindustrie GmbH, Schwäbisch Hall

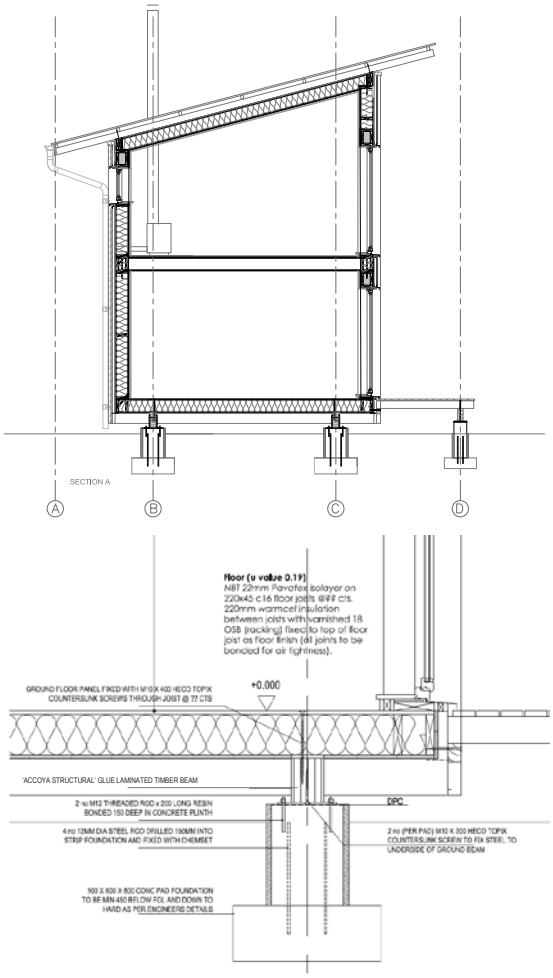
Engineering
H.E. Lüning Adviesbureau voor technische houtconstructies; Oranjewoud Mobiliteit & Infrastructuur; GLC Houtconstructies

Project Location
Across A7 near the city districts of Akkerwinde and Molenkrite in the Netherlands

Architects
Achterbosch Architectuur - Hans Achterbosch; Onix - Alex van de Beld, Haiko Meijer

Principal
Province of Friesland

Date
First bridge 2008; second bridge 2010



Dunsmore house foundations

Accoya® wood used in an innovative, sustainable structural application in Scotland

DUNSMORE HOUSE FOUNDATIONS

There is a growing interest in designs which have minimal impact on the landscape and which minimise the amount of embodied carbon.

Dunsmore House is a two storey platform frame in the Scottish Highlands supported on just eight shallow pad foundations. Concrete posts project from the pads to support the ground beams. In order to minimise the embodied carbon the ground beams, like the frame, were constructed from timber. The ground beams are well protected from the rain and so the risk of permanent wetting leading to decay is relatively low. However, there was a concern that seasonal shrinking and swelling of the timber ground beams might affect the level of the house.

Thanks to its stability, Accoya® offered the ideal solution. A test programme was developed to determine the structural properties of the Accoya® and much of that data has helped inform the data in this guide.

OTHER APPLICATIONS

The advantage of Accoya® is that it offers the potential to use timber in external applications, where it could not previously be used because of the risk of decay or dimensional movement.

One obvious example is the external columns supporting the edge of a timber framed canopy. Traditionally these were best constructed in steel. Timber columns would require either a generous overhang to keep the base of the column dry or careful detailing to ensure water could not become trapped between the column and the steel base, often leading to visually rather awkward details. Accoya® offers significantly more architectural possibilities - the columns can now be in timber to match the frame and awkward architectural details to try and keep the base of the column dry can be avoided.

Architect	Project location	Date
Neil Sutherland Architects	Stitenham, Ardross, Scottish Highlands	June 2012

Lighting poles

Accoya® Wood Blends Nature with Style at Biltmore Restaurant, USA

THE SCENARIO

In the upscale area of Biltmore, Arizona, the new concept Hillstone Restaurant by the Hillstone Restaurant Group was designed to intentionally blend the indoor and outdoor experience. The design is purposely casual yet high-end with moveable glass walls that open views from the restaurant through to the natural southwestern surroundings. A mix of natural materials was carried through from the interior to the exterior including stone, copper and wood.

THE SOLUTION

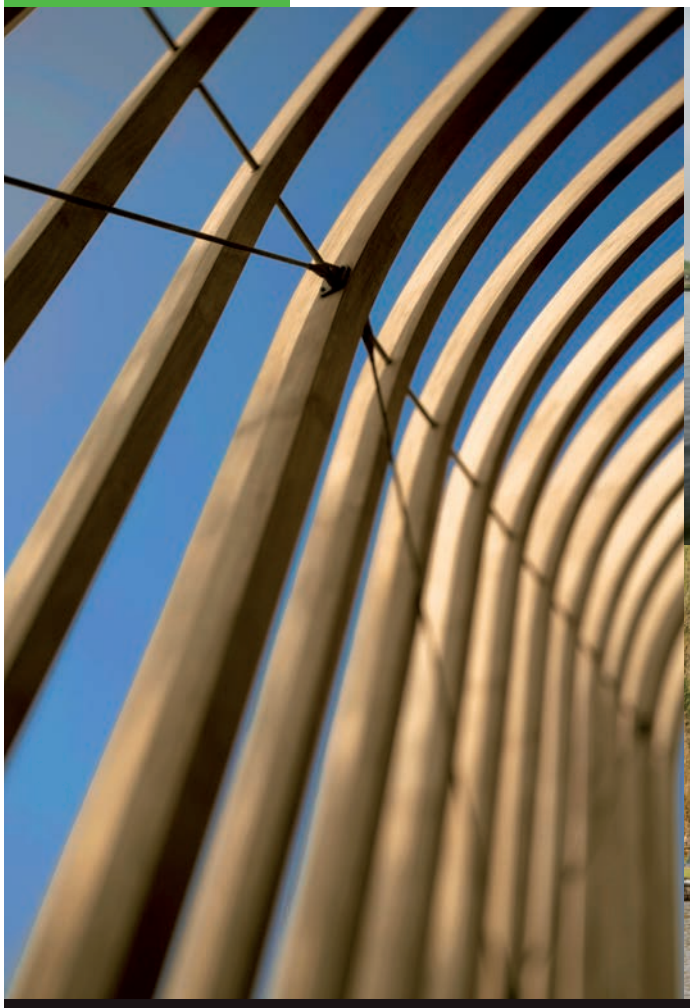
Transitioning between the indoors and the outdoors was done through the meticulous selection of design and materials. Particular emphasis was placed on using sustainable materials and obtaining LEED certification. The design combined unique interior elements, such as moveable walls and energy-efficient window systems, with natural exterior materials such as Accoya® wood.

THE RESULT:

The use of Accoya® wood in this often overlooked application offered the design team a thoroughly natural look and feel throughout the restaurant setting. Accoya® wood is a durable, long-lasting and aesthetically pleasing material that blended the interior elegance with the exterior southwest environment. “Not once have I seen lighting poles this elegant,” said the senior project architect.

> “WE COUNT ON ACCOYA® WOOD TO PROVIDE LONG-LASTING PROTECTION, STABILITY AND DISTINCTIVE AESTHETIC APPEAL”
>
> Dan Kohnen,
> president of Structura

Manufacturer	Project location	Date
Structura	Biltmore, Phoenix, Arizona USA	December 2010
Distributor		
Universal Forest Products		



Cladding, decking and structural beams

Exciting Design uses Accoya® Wood for a Sustainable House in Horning, UK

THE SCENARIO

The Haven project in Horning, Norfolk, is the perfect example of the increasing trend for greener buildings. The new house and boathouse combination is a gracefully designed, sustainable design perfectly complementing and enhancing the picturesque waterside village of Horning.

THE SOLUTION

The Accoya® wood, supplied by International Timber ltd, was used for cladding, decking and screening. Architects, Lambert, Scott and Innes modernised the design by creating a unique, curved, glue-laminated rear screen; this was influenced by the marine character of Norfolk and is designed to resemble a traditional wooden boat construction. The Accoya® screen was made in The Netherlands and was manufactured by Newham & Abel Ltd. It was coated with merbau - WoodGuard Color PRO; the same finish was used for the cladding. The entrance floor of the house is set at 1.3m above ground in order to avoid the flooding that is prevalent in the area.

The distinctive boathouse, also covered in sustainable Accoya® wood, is a fantastic addition to this riverside property. It is purposely designed to be set above the water level, allowing any flood water to flow safely through its base. It is a perfect and secure place to store a boat in all weather conditions.

THE RESULT

The Haven project demonstrates the versatility, extreme durability and structural properties of Accoya®, especially in such unconventional conditions. The beauty and flexibility of Accoya® wood make this unique design both practical and graceful.

Architect
Lambert, Scott and Innes

Distributor
International Timber

Screen Manufacturer
Newham & Abel Ltd

Project location
Horning, Norfolk
United Kingdom

Date
2011

Art & sculpture

Accoya® Art & Sculpture Design in Istanbul, Turkey

THE SCENARIO

Odeaubois (sculpture) and ACT Lighting Design (lighting & scenography) created OVO, an art installation with sensory lighting and a scenography that concentrate, magnify and diffuse positive energies. On the 31st of March 2011, the first permanent installation of OVO was unveiled at MARMARA FORUM, Istanbul, Turkey.

THE SOLUTION

The designers were looking for a wood species that would meet the obligations of their design environmentally. Accoya® wood was chosen because it meets the sustainable forest management responsibilities through its PEFC and FSC schemes.

THE RESULT

The Accoya® structure is made from 356 individual pieces which are bolted together invisibly. On first sight the visitor sees the shape of an egg, which then reveals the inviting entrance to the centre.

"WITH A PASSION FOR ECOLOGY AND A REAL LOVE FOR WOOD, ACCOYA® TICKED ALL THE BOXES FOR OVO. WE NEEDED A SIMPLE, NATURAL AND DURABLE MATERIAL FOR OUR CREATION AND IT SUITED OUR DESIGN WELL"

Mostafa Hadi and Pol Marchandise,
Sculptors and Artists, Odeaubois

Client
Act lighting Design & Odeaubois

Sculptors
Mostafa Hadi and Pol Marchandise

Architect
Tabanlıoglu Mimarlık Architecture, with contributions by Multi's in-house architects; T+T Design

Distributor
Van Steenberge, Belgium

Project location
Istanbul
Turkey

Date
March 2011

Brettenham House
19 Lancaster Place
London WC2E 7EN
United Kingdom

T: +44 (0) 207 421 4300

Postbus 2147
6802 CC ARNHEM
The Netherlands

T: +31 026 320 1400

5000 Quorum Drive #620
Dallas, Texas 75254
USA

T: + 1 972 233 6565

REFERENCES

Cossalter, C., Pye-Smith, C. (2003). Fast-Wood Forestry, Myths and Realities. CIFOR, Jakarta, Indonesia.

Crawford, D., Hairstans, R., Alexander. J. & Bongers, F. (2012) Assessment of the structural performance of Accoya® wood" Proceedings of the 12th World Conference on Timber Engineering, 15th to 19th of July, Auckland, New Zealand.

MAF (2008). Afforestation Grant Scheme Guidelines. Ministry of Agriculture and Forestry (MAF), Wellington, New Zealand.

McDonough, W. and Braungart, M. (2002). Cradle to Cradle: Remaking the Way We Make Things. North Point Press, New York, USA.

Sikkema, R., Nabuurs, G.J. (1995). Forests and wood consumption on the carbon balance. In: Climate change research, Eds. Zwerver, S., Van Rompaey, R. S. A. R., Kok, M. T. J. and Berk M. M. Elsevier, Amsterdam, the Netherlands.

SKH (2007). KOMO Product certificate Modified Timber Accoya® (certificate nr 33058/07) according to BRL 0605 'Modified Timber'. SKH, Wageningen, the Netherlands.

Tjeerdsma, B.F. (2006). Letter about "toxicity acetylated wood" (23 May 2006). SHR Stichting Hout Research, Wageningen, the Netherlands.

Van der Lugt, P. (2008). Design Interventions for Stimulating Bamboo Commercialization. PhD thesis. Delft University of Technology, Delft, the Netherlands.

VROM (2009). Website - Waste Management File. www.vrom.nl/pagina.html?id=9263#a60 Dutch Ministry of Housing, Spatial Planning and Environmental Management (VROM), the Hague, the Netherlands.

Wagner, R., Marutzky, R. (2008). Letter with "Statement about energetic processing of Accoya®" (in German). Wilhelm-Klauditz-Institute Holzforschung, Fraunhofer Institute, Braunschweig, Germany.

FSC
www.fsc.org
FSC® C012330
The mark of responsible forestry

NORDIC ECOLABEL

CERTIFIED
cradle to cradle
GOLD

GreenLabel SINGAPORE
035 - 033
Made from renewable materials

ACCSYS GROUP

www.accsysplc.com
www.accoya.com

Patents: Australia 2005212139, Canada 2556438, Chile 45.802, China 100537163, ZL 2008 1 0190821.0, Europe 680810, 1781442, Japan 4629055, Indonesia ID P00334463, Morocco 32127, New Zealand 531217, 4629055, Singapore 163367, South Africa 2010/05240, UK 2456915, 2474154, 2485945, US 8173224, 8512815

accoya®