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STUDY OF THE PROPERTIES OF RECLAIMED WOOD IN FURNITURE MANUFACTURING

Master´s thesis

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Technology of Wood and Plastic, KVEM 12/13

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Declaration

I hereby declare that this master's thesis is my original investigation and achievement, submitted for the master's degree at Tallinn University of Technology and has not been previously submitted for any other degree or examination.

All the work of authors, important aspects from literature and data used in this thesis are cited and in case of unpublished works, the authorship is presented in the text.

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MASTER'S THESIS ASSIGNMENT

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Study of the Properties of Reclaimed Wood in Furniture Manufacturing (in English)

Vanandatud puitmaterjali omaduste uurimine mööblitootmise eesmärgil (in Estonian)

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Aim and tasks of the master´s thesis: to understand and determine reclaimed wood, its properties and use in the furniture production.

ABSTRACT

This thesis focuses on reclaimed wood, its sources and potential use in the furniture production. In the recent years, reclaimed wood furniture has become increasingly popular due to its unique aesthetic appeal and the environmental awareness of the customer base. However, there are many aspects, which must be taken into consideration when dealing with reclaimed wood.

The main problems discussed in this paper are: which strength and structural properties aged wood have and how to determine the possibility to use reclaimed wood in furniture production.

The processes involved in using reclaimed wood to make furniture were described. Wooden boards from European Spruce (*Picea abies*) were obtained from a barn built in 1937 in South-Estonia. The specimens were prepared according to EN 325 and EN 326. Aged wood durability and resistance to cracking and drilling were assessed. Discolouration and moisture content were determined. Bending strength and surface hardness tests were performed according to EN 310 and ISO 3350.

Insects and brown rot damage were recorded, however in general the natural durability of wooden boards were evaluated high. Reclaimed wood showed lower bending strength and hardness than recent wood. Drilling resistance showed reclaimed wood inner stability after years of weathering and environmental modifiers.

As a result of this study it can be said that reclaimed wood has despite the decreased physical and mechanical properties a potential for using it in furniture production.

Key words: reclaimed wood, EN 326, bending strength, durability, drilling resistance, biological attack

FOREWORD

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LIST OF SYMBOLS AND ABBREVIATIONS

Glossary of terms:

Cupping - the distortion of a board that causes a deviation from flatness across the width of the piece (Rowell, 2005).

Delignification - removal of lignin from woody tissue by natural or industrial processes (Merriam-Webster).

The Forest Stewardship Council (FSC) - an international organisation that helps consumers protect the world's forests by providing certification that sourcing for lumber products is environmentally appropriate, socially responsible, and economically viable for the world's forests and the communities that depend on them. (Lumber)

Life cycle assessment (LCA) - an approach that covers the whole life cycle of a product or service. Two types: Cradle to Gate (raw materials to finished goods) and Cradle to Grave (considers everything from harvesting materials to the disposal of the finished goods) (Venditti) and Cradle to Cradle ("eco-efficiency" approach, reusing materials) (McDonough Braungart Design Chemistry).

Modulus of elasticity (MoE) – the strain curve in elastic deformation region (Thaler, 2013).

Natural durability – the inherent resistance of wood against an attack by wood destroying organisms. (Eesti Standardkeskus, 1994).

Reclaimed Timber/Lumber –timber/lumber that has been reclaimed for reuse. This includes old building materials as well as any other wooden materials that would otherwise not be utilised or reused. (Elmwood Reclaimed Timber).

Solid wood – whole wood, a wooden material between lumber and engineered wood, without any hollow spaces in its structure. (Floor N More).

Urban wood – wood that has already been used and will become discarded, for example old or broken wooden furniture, benches, fence rails, used lumber, shipping pallets, trees, branches, and other wood debris of construction and demolition (United States Department of Agriculture).

Volatile organic compounds (VOC) –according to the European directive 2004/42/CEVOC includes all organic substances with a boiling point lower than 250°C at 101, 3 kPa. (Franco Bulian, et al., 2009)

Abbreviations:

- EMC – equilibrium moisture content
- FSC – Forest Stewardship Council
- LCA – Life-cycle assessment
- MC – moisture content
- MoE – modulus of elasticity
- PVA – polyvinyl acetate
- SEM – scanning electron microscope
- VOC – volatile organic compound
- CIE LAB – Commission Internationale de l'Eclairage L*a*b*.
- *L* – luminance
- *a* - the red-green axis
- *b* - the blue-yellow axis
- *E* – colour difference
- m_H – the initial mass of the test piece, g
- m_0 – the mass of the test piece after drying, g
- ρ – density, kg/m3
- *m* – mass, g
- *v* –volume, m3
- F_{max} – the maximum load at the fracture point, N
- l_l – the length of the support span, mm
- *b* – specimen width, mm
- *t* – specimen thickness, mm

INTRODUCTION

Reclaimed wood allows creating unique furnishings with a help of nature. Its rough, worn and richness of colour and surface textures give furniture a native touch and something to appreciate.

People have been used to live with forests as a great source of material, but there must be a plan how to prevent deforestation and further damage to the existing trees. It can be said about reclaimed wood that it is like finding a reason to reuse material and search for new opportunities that nature gives to create something original and meaningful.

There are a lot of obstacles that need conquering when using reclaimed wood. The life cycle of wood is influenced by diverse factors, both wood-inherent (extractives, species) and environmental factors (climate, location, rain) (G. Alfredsen, et al., 2012).

The biggest destroying effect of degradation comes from the most faster and encompassing biological factors, where fungi and insects belong to (Musem, 2013). While the latter are trying to destroy wood, they are actually giving the wood its special look at the same time. The main problem is how to make this ageing stop and conserve wood from further progress.

Another hurdle is that as earlier treatment of the wood is unknown, unexpected problems with hazardous chemicals and biological factors erupt. This is the reason why reclaimed wood requires more processing than recent wood. It is also one, which limits the full advantage of using reclaimed wood in furniture production.

A further factor causing ageing is weathering. This is one of the most obvious factors reclaimed wood must face, but it should be controlled to prevent rotting and damage to heavy surface. Ageing takes place on barn walls, fence rails, old constructions, doors, tables etc.

Compared reclaimed wood with recent wood, reclaimed wood has different structural properties in areas, which is taken over by fungi and insects. Decades of weathering also give it a very different texture, which visually disaccords in cm^2.

The appearance of reclaimed wood is second to none, because it has been left to transform by many chemical, biological, physical and mechanical ageing processes. It has been affected by daily sunlight and environment for years, for example when preserving wood in the cold depths and natural chemical reactions then wood is transformed by the natural ageing process.

People have started thinking on how to damage environment less and instead, finding out various possibilities for recycling. Sharing knowledge about eco design and its importance for next generations also plays a significant role. In the future is not important to create something new, but to update and reuse old materials. There is only a need of minor modifications and waste to create an ultramodern reclaimed product, for example a window into a cupboard or a door into a table. Reclaimed wood could originate from historical buildings or even rivers, like driftwood, old mismanaged grinders and logging route.

Recovered wood should be certified to afford material with reliable information about its origin and treatment. In Estonia reclaimed wood is sometimes also certified by Estonian FSC, which *"certifies forests, as well as the products of vendors of forest down the chain of custody,- from lumber yards to paper mills".* (Lumber) FSC certification guarantees its new owner that the wood, natural environment and the ecosystem have been handled with respect (Alden). Unfortunately, the use of reclaimed wood as a material in furniture production is a rather new angle in Estonia and many people do not know that certified recycled wood pieces carry a higher value in view than without such a guarantee.

It is true that the recycled look is something only years of reckless ageing can make. A lot of people interested in reclaimed and distressed wood try to take a closer look at old wood with different ageing techniques and chemicals, because reclaimed wood cannot continue without limit. However, the act has not been successful. It is very easy to detect from hidden areas of a piece of wood (back and underside) whether the piece of furniture is actually made of reclaimed wood or just distressed. If the mentioned areas look old, worn or even with nail holes it is likely to have been reclaimed, but if it looks different from the upper or visible side, it is most probably distressed.

Recycled furniture is greatly esteemed by preservationists, architects and renovators. On the other side, regular homeowners prefer extraordinary furniture with a higher quality and value and definite kind of spirit. It is known that people live in a consumer society where unconventional counts. When it comes to reclaimed wood, originality is in a favourable position. It is even more so when using old material in a completely new concept, especially in a society where being environmentally friendly means a lot.

If wide plank flooring is found from old houses and historic residences, it will be dried and boards will be milled separately. Reclaimed wood should be handled according to the same standards as new virgin wood, but the result in case of reclaimed wood will be a dimensionally stable and uniform with the depth of grain and colour that are normally unexpected in case of solid wood. (Wellborn+Wright)

The aim of the study

The aim of this paper is to understand and determine reclaimed wood, its properties and use in the furniture production. Factors affecting the aesthetic and mechanical properties of reclaimed wood are evaluated. In order to achieve the goal, the following sub-goals were set:

- To determine reclaimed wood moisture content and density;
- To evaluate surface discolouration of reclaimed wood;
- To determine cracks in reclaimed wood;
- To assess natural durability of reclaimed wood
- To determine drilling resistance
- To determine bending strength and surface hardness of reclaimed wood.

Through experiments the objective is to analyse reclaimed wood boards from barn wall and assess its quality, by analysing wood surface (defects, splits, decay) and internal characteristics.

1. LITERATURE REVIEW

1.1. Life-cycle assessment

As society grows wealthier people start to consume more, because they would like to have more novel and popular items than years ago (Commission, 2010). This makes production intensive and the amount of raw material increases while the old products find their way to the landfill. When talking about consumer society, there is a high risk of over consumption and waste. Today, the people's consumption habits have been taken under scrutiny and more thought is being laid on the future of environment.

Most environmental impacts occur at the stages of raw material supply, where the highest per-cent of impact belongs to human toxicity, global warming and acidification (Iritani, 2014). Usually the only recycling of wood is expressed by pellets, different wooden boards (like chipboard, fibreboard and MDF etc.), also getting energy of wood by burning wood releases and the contained carbon increases the carbon footprint. Using recycled wood as raw material instead of solid wood as furniture is growing in popularity day by day and becoming more contemporary, plus it minimises the potential impacts to world (Iritani, 2014). Suitable wooden materials for eco design are non-toxic, renewable, recycled and recyclable, and local

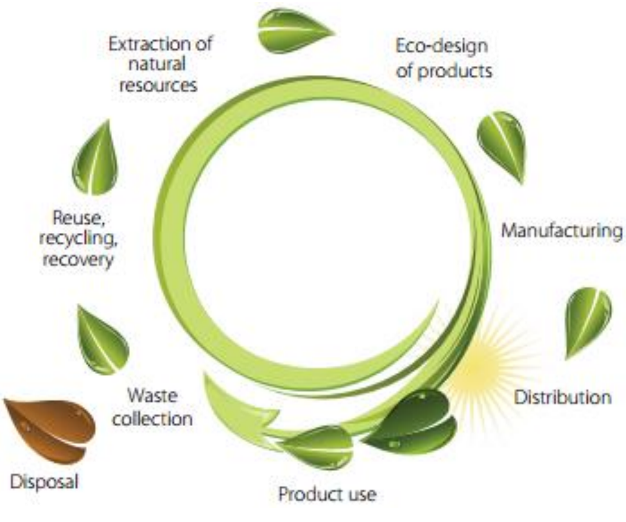


Figure 1. Life cycle assessment. (Iritani, 2014)

(Crossroads Recycled Lumber), like barns, fences, old broken furniture, shipping crates, old boats etc. Some old wooden material, which are impregnated with copper and arsenic creosotes are toxic to living being and could not be reused, for instance railway beams.

In the air and water there is a combination of different emissions due to burning and VOC that leads LCA as an essential approach around the world (Bove, 2004). Eco is the best choice for minimising the impact on environment while innovative technologies receive notable attention as well (Elmwood Reclaimed Timber). LCA involves processes through product life-cycle: raw material procurement, processing, manufacturing, usage, re-use, recycling until final disposal (Bove, 2004).

Energy impact is one of the most quantifiable aspects of environmental performances (Bovea & Vidal, 2003). The goal of using reclaimed materials for furniture is to reduce pollution, maximise energy use and incorporate a maximum amount of recycled materials. Through these approach materials, old techniques and new knowledge can be utilised in most favorable way. (Elmwood Reclaimed Timber)

There has been progress in the sense that people have started to „build“ different furniture pieces from pallets and already used wooden furniture is being given a new look or shape by adding imagination and freshness to it. It is a growing trend and people have started thinking more green than years before. It is important to see different opportunities to extend the life-cycle of wood. As can be seen from Figure 1, it is good for the environment when all the raw materials are environmentally friendly or reusable.

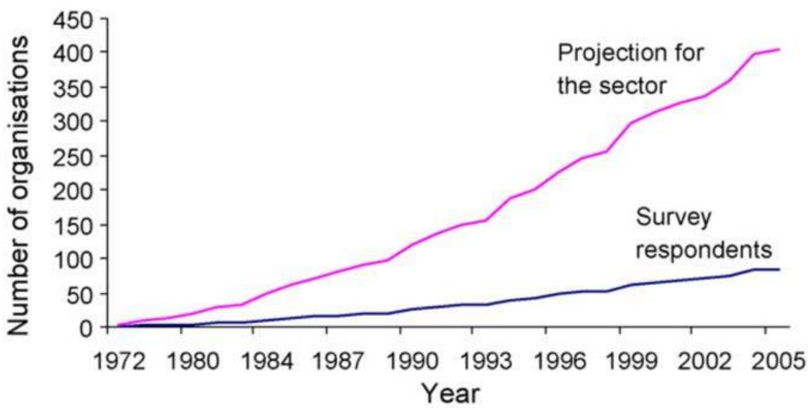


Figure 2. Growth of the recycling and reuse sector in the UK. (A. Curran, et al., 2009)

Until 2015, many recycling organisations have started to collect items that have failed quality control, but are still functional and safe for humans (A. Curran, et al., 2009). For example, since United Kingdom started with its first reuse organisations in 1970s, there has been a growth in the reuse and recycling sector as is vivid from Figure 2. This is something that is becoming more and more popular nowadays in Estonia as well.

1.2. Target market

First of all it should be mentioned that reclaimed wood is not as new as solid wood: uniform, traditional or low priced. Recycled wood furniture market is not very big, because the processes that wood have to pass before being turned into new furniture are quite time consuming and expensive. Reclaimed wood materials are more expensive than new materials because of their "one of a kind" quality and high cost of labour involved in the recovery and refurbishing processes (Wood R. , 2014). Here lies the reason why this kind of piece of furniture usually has a higher price than ordinary furniture, made from panels and where is no

Figure 3. Table made of reclaimed wood. (Heartwood)

or very little use of solid wood. Despite the higher cost, table (Figure 3), bed, cupboard etc. made out of recycled wood is something very special to have. Also, producing furniture through recycling is gaining more popularity through years. The greatest goal in creating recycled wood custom furnishings, which will maintain its importance among future generations and not only among those who are initially exposed to the raw material (Heartwood).

The main buyers of recycled wood furniture are outlined in Table 1 “Recycled wood furniture target market”. For example, well-heeled elders are a group of people who would like to have this kind of furniture at home. Also, successful people constitute a huge group. Successful usually means that this type of people would like to afford something out of the ordinary – recycled wood furniture is a very good possibility to satisfy this particular desire.

After demand, the price of reclaimed wood furniture is shaped by many other important factors that have a direct effect, such as basic material value, origin and its preservation, cost of production, the size of wanted furniture, production time and the amount of processes. The price of main items is shaped by the work it carries in it, its historical and memorable value, because the more weathered and rotten the basic material is, the more work it needs in order to get in a better shape.

Table 1. Recycled wood furniture target groups.

Potential target market	**Most important value for the group**
Well-heeled elders	Emotional bond
Successful people	Memories, popularity
Designers	Unconventionality
Art and recycling fans	Material reuse, individuality of the result
Innovation supporters	Innovative use of material
Admirers of vintage	Vintage touch

The larger the product, the higher the unit price of the product will be. It means that finding material for a bigger cupboard is much harder than for a smaller sofa table. In this instance, the availability of raw material has a major impact on forming the price.

The cost of recycled wood home furniture varies depending of the item and its design. Sometimes the recyclable matter makes wooden furniture more affordable than a new product, for example the piece of furniture is more rated when there are more people, who would like to own it. In addition to this, there are still enormous opportunities for unexplored recycled wood ideas and niche markets (G. Daian, et al., 2009) as well.

1.3. Sources

What should be the raw material for reclaimed wood furniture is a wide question, because many wood types would fit. Thus, barns (Figure 4), fences, rural structures, old broken furniture with its' high value would make perfect raw material. Also, unique pieces of reclaimed wood can be derived from rivers or other reservoirs and even beaches. Wood pieces found from the beaches are drier, brighter as well as lighter than those that have been aged as barn wood.

Figure 4. Old barn in the USA. (Distinguished Boards & Beams, 2014)

Most of reclaimed wood comes from construction, demolition and land clearing debris (James Keirstead, et al., 2013), which are full of valuable reclaimed material. Most common ways to eliminate this is burning or landfilling, but both of them present a major threat to environment. The rejected materials should be collected from construction and demolition waste and used in new appearance instead.

When talking about the importance of recycled wood then more than 7 trillion m^3 of lumber is produced for creating products all over the world since the 1900s, so using this particular wood a century later makes complete economic and environmental sense. (Anderson)

The most widely used types of wood of all time in Estonia have been pine *(Pinus Silvestris)*, European Spruce *(Picea abies)* and birches: Silver Birch *(Betula pendula)* and European White Birch *(Betula pubescens)*. Back in the 19th century, there were many different requirements for getting the best wood for buildings, furniture and decencies. Logging was a process, which needed a right timing and normal weather conditions. Even the lunar phases counted as the quality and durability of wood depended of the latter. It was presupposed that softwood must be logged at new moon and hardwood at full moon. Wrong timing for logging made wood easily mothy, high moisture absorbent, slightly rotted etc. Old wood is usually with higher quality, because it has been chopped down after having chosen the best timing and purpose. (Viires, 2006)

In the United States of America wood has been the main building and furniture material because of its strength, good price and possibilities. Longleaf heart pine *(Pinus palustris)*, White Oak *(Quercus alba)*, Rock elm *(Ulmus thomasii)* and American chestnut *(Castanea dentata)* have been the most used wood in American buildings and have now become most used as reclaimed wood to make furniture (Wellborn+Wright). Other wood that was used about hundred years ago included Redwood *(Sequoia sempervirens)* and Douglas fir *(Pseudotsuga menziesii)* which were widely used as building material in bigger conceptions before World War II. (Reclaimed Wood Barn). Barns served as the most common source for reclaimed wood and when they were dismantled, the wood became desirable for subsequent reuse. In the beginning of the 19th century, buildings were made of the nearest trees, so it was usually a mix of different types of wood as can be seen from Figure 5, which were ordinarily hand-hewn with an axe or an adze (Wellborn+Wright).

Figure 5. House of diverse hand-hewn types of wood. (Distinguished Boards & Beams, 2014)

Relying on the information that building material was usually logged down in time, the source material for reclaimed wood should be in a great condition and more durable than fresh solid wood in case of which the good advice from our ancestors are not followed. "*Experts in the field suggest that the strength, stability and durability of older trees is directly tied to the lack* *of air pollution during their 200 to 400 years of growth*." (Reclaimed Wood Barn) Those blanks that came from the trees that were dismantled in the early ages and became used in different areas have more growth rings than those made into furniture at the beginning of the 21th century. Some other sources for reclaimed wood are shipping crates, which are sometimes chemically treated to transport goods, thus this necessity should be made clear before use also old deconstructed boats that are prominent for its weather resistance (Beams, 2014).

There are many possible uses for reclaimed wood: flooring, beams, furniture, siding and panelling. *"Beautiful colour, stability, durability, hardness, texture and fragrance are all characteristics of reclaimed wood."* (Wellborn+Wright) What is positive in recycled wood is the fact that every piece of it can be used and the more different the pieces look like, the higher their value is.

1.4. Properties of reclaimed wood

Using reclaimed wood in different styled houses has been popular since the 1980s, but last years have witnessed its rise in green remodelling design (Home, 2014). It could have been used as crate or construction material, that was milled into reclaimed flooring (Wood V. R., 2013). Besides that, reclaimed wood is with its own past life in a new product, which preserves more outcome than solid wood, because reclaimed wood has lower moisture content and in that case it has higher durability and also added value (All-Recycling-Facts, 2014). Reclaimed wood is more stable than freshly cut wood, because it has been already part of the human activity and various people's habits have changed its characteristics. For example, reclaimed wood is used to traditional heating systems like oven and fireplaces in old houses.

Reclaimed lumber is popular for many reasons (Table 2): the wood's unique appearance, its contribution to eco, the history of the wood's origins (Jürmann & Kättmann, 2015), and the wood's physical characteristics such as strength, stability and durability. After harvesting it was left under the sun and rain, due to which the wood reached its original appearance. Every growth ring will be drawn out and depending on the type of wood, the grain pattern appears well (Mets, 2014).

The outflow of VOC (volatile organic compounds) from solid wood irritates people's sensors. The VOC amount depends of the wood's growing habitat, climate, nutrients and the drying and handling conditions of lumber later on wards. For example the emission from softwood after 28 days varies from 500 to 4800 $\mu g/m^2h$ and the dominating compounds were a-Pinene and 3-carene. (L.G.F. Tellnes, et al., 2012) Also in softwood growing in Nordic countries turpentine is produced. The latter has a high skin irritating effect rather than monoterpene, except for 3-carene - this active agent is lower (Valitsus, 2011). Turpentine in softwood is determined by resin acids, which is a by-product of cellulose production. For example, the output of turpentine in pine depends of the section of trunk. At the nutrient uptake, terpene hydrocarbons mixture evaporates and stays in a vaporised state. (Lesokhimik)

Table 2. Some of the pros and cons of using reclaimed wood.

Positive aspects	**Negative aspects**
Sustainability	Scarcity
An unique appearance	Price
Added interest	Legitimacy
Quality, strength, stability and durability	Previous wood treatments
Low moisture content	Crack may reduce resistance
Different types of wood	
Multiple uses	
Environmentally friendly	

When trees are harvested from the forest the carbon they obtained from atmospheric CO_2 via photosynthesis is removed (Wood R. , 2014), but it is still preserved in wood products as long as they are in use and until carbon disengages through burning (Oneil). Similarly carbon remains stored for its first use and beyond (Oneil), it is the main reason why one should prefer reclaimed wood to fresh cut wood, plus this way the carbon emissions would also decrease.

Reclaimed wood has many positive aspects that create the main stimulus that conduces people to use a material that already has its own story. Wood is an environmentally more sustainable resource than for example natural stones, because of its natural purpose of continuous growth. Wood doubles it by reason if it has been used before and next was made into perfect home furnishing until another more beneficial use (Home, 2014). Besides that it can be said that reclaimed wood is also environmentally friendly (Wood V. R., 2013). It has an unique appearance and added interest, because of the time it has been weathered and the story it has developed.

Through several decades that wood has been in different appearance, it has gone through changes in humidity countless times and altered into a more high-quality, stronger, stable and durable material (Home, 2014). Reclaimed wood furniture can be produced out of a variety of wood types, which is why sometimes they can fit well enough to create a new product, which differs almost 100% from others (Wood V. R., 2013).

Recycled wood has lower moisture content than primary wood. As a matter of fact, lower moisture content usually means higher durability (All-Recycling-Facts, 2014). It turns out that recyclable wood is used to be cheaper than recent wood and this is brought on by moisture content. If people pass through all of the steps of production by themselves, recycled furniture can be more advantageous than new solid wood furniture of the same type and measures.

On the contrary, there are negative aspects as well when talking about reclaimed wood furniture. The hardest part is the scarcity of reclaimed wood, because it is in finite supply as a consequence of the fact that old barns and warehouses with usable materials will run out someday (Trout, 2014). Another fact is that reclaimed wood has actually become more expensive than newly cut wood because of the additional costs of sorting the wood types and preparing them for use inside homes (Home, 2014). Additional costs are also dismantling the old barns and at the same time manage to do it with care not to provide any damages. As reclaimed wood is becoming scarcer, retailers are trying to create artificially aged wood, which makes consumers ascertain the reclaimed wood legitimacy (Home, 2014).

The hardest thing to do in case of producing furniture from reclaimed wood is to pre-establish the previous wood treatments of reclaimed wood. It is almost impossible to know what the wooden pieces are treated with, some barns might be treated with toxic chemicals, lead paint and VOCs (Home, 2014), which are dangerous to humans and environment. Different chemical treatments emit potentially toxic VOCs, which may cause allergic reactions and health effects.

However, positive aspects will outweigh the negative, because there are many possibilities of avoiding these kinds of problems and if the latter are avoided or eliminated, the use of recycled wood furniture will justifies its use.

The main requirement for reclaimed wood is that it must be dry (~6%), so that the possibility of decaying in the future would be brought down to zero. Furthermore, the longevity of wood is determined by different chemical, physical, mechanical and biological factors (Musem, 2013). Out-of-doors used wood is typically affected by sunlight, UV-radiance and rain, decay, insects or marine borers (Shmulsky, 2001).

1.5. The impact of fungi and insects on wood durability

The biggest influencers of the life cycle of wood include bio impairments and biological agents. (Shmulsky, 2001). According to the law of biocides, the harmful organism is any undesired organism or organism that is detrimental to human or its activities, produced or

Figure 6. Decayed beam. (Anthony R. W., 2007)

used products, animal or environment. (Ehitus, 2010) According to the standard EN 350-2: 1994 (European Standards, 1994) the influencers are: wood-destroying fungi, dry wood-destroying beetles, insects and marine borers.

In Estonia two main wood destroying biological threats are fungi and insects. The first one, fungi contribute to stain, soften and decay (Figure 6). Fungal vital functioning alters wood structure in most encompassing and soonest possible way. In order to operate, they need food, water, propitious amount of oxygen and sufficient environmental temperature (Shmulsky, 2001). In relation to it, the fungus feeds on minerals found from wood and as a result, density of wood decreases and detail becomes brittle. (Pilt, 2015)

Fungal decay

Wood-destroying fungi are divided into decay, soft-rot, staining and mould fungi – according to the type of degradation (Shmulsky, 2001). Decay is classified into blue stain fungi and *Aspergillus*. Blue stain fungi makes wood more porous and is situated deep in the wood. *Aspergillus* occurs when water content in wood is too high or there are other organisms on the surface of wood. As a consequence, the surface of wood will die, but mechanical properties (compression, shear, flexural and tensile) will stay the same. Moulds are expanding most suitably on boards covered with surfaces or on freshly sawn lumber. (Pilt, 2015).

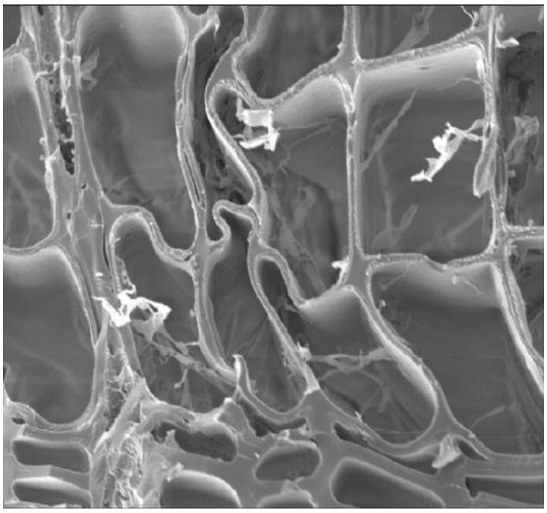


Figure 7. The SEM photo presents living brown rot fungi growing on a fragment of wood. (Barrat, 2010)

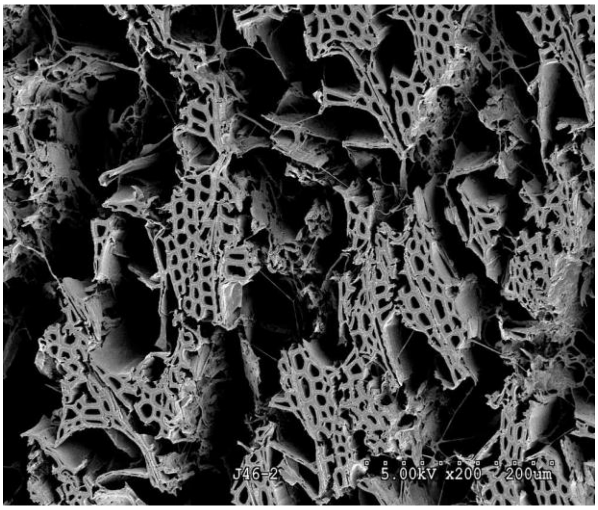


Figure 8. A SEM photo of wood has been decayed by white rot. (Foundation, 2015)

Wood decay fungi is distributed to soft-rot, white rot (*Sclerotia)* and brown rot *(Monilinia laxa)* (Pilt, 2015). It should be noted that fungi is a result of a process, not a wood decomposer itself. Soft-rot cannot be found inside the wooden buildings but they have ruined wooden basements instead. It is the last stadium of wood decay, where the bacteria is also included (Pilt, 2010), resulting in cellulose and hemicellulose decomposition. The most common in buildings is brown rot (Figure 7), which springs up after enzyme action from *basidiomycete* when fibers of cellulose and hemicellulose are broken down. Lignin is destroyed slightly, but will retain its brown colour. Soft rot is mainly caused by ordinary dry rot *(Serpula lacrymans)*, wet rot fungus *(Coniophora puteana)* and antrodia *(Antrodia sinuosa)*. White rot fungi (Figure 8) are capable of degrading all structural components (lignin, cellulose, hemicelluloses) (Rowell, 2005), but most of all it degrades lignin. As a result remains hemicellulose and cellulose, due to those rot receives its white colour. It has high tolerance of toxic environments, high temperatures and a wide range of pH, furthermore those enhance fungus capabilities (Moore, 2015). The main sclerotia causing funguses are *Armillaria mellea, Meripilus giganteusand Phellinus pini* (Pilt, 2010)

The moisture content of wood must be at least 20% (Anthony A. R., 2007). If wood is below the fiber saturation point, which is approximately 28% of moisture content, there is a smaller possibility for decay to attack the wood (Shmulsky, 2001).

Wood destroying insects

Another influencer of durability and mechanical properties of wood are insects that feed upon dry or fresh wood and live in wood with moisture damages. According to the Standard EVS-EN 335:2013 insects are mainly divided into two main groups: Coleoptera and termite. The latter are not located in Estonia. Coleoptera is divided into old house borer *(Hylotrupes bajulus),* common furniture beetle *(Anobium punctatum)* and powder post beetle *(Lyctus brunneus)*. Old house borer (adult 8-25 mm in length) damages many softwood species in Europe, the moisture content of which is at least 10%. Their gnaw grinding is regularly

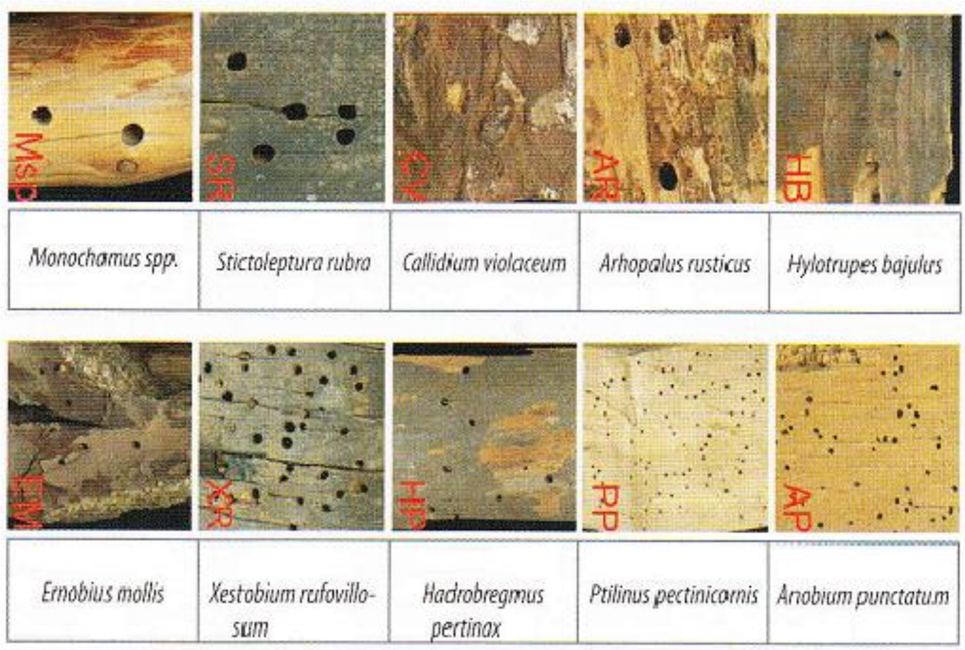


Figure 9. Flying gaps of main wood destroying insects. (Pilt & Noldt, 2013)

cylinder, coarse and light-coloured. Pupas develop faster after fungal attack in wood (Pilt, 2015). Pupas harm wood the most, because they carve out tunnels to make their spot for pupation near to the surface of wood. The life time of pupas is in relation with the environmental temperature and moisture content of wood. (Rentokil Eesti, 2015) Common furniture beetle (adult 5-10 mm) wound sapwood and their gnaw grinding is usually small and whitish. When comparing flying gaps of old house borer and common furniture beetle, first holes are more oval and bigger, about 3x6 to 5x12 mm. Gaps of beetle are round and about 1-2 mm. (Kalle Pilt, 2013)

It is easy to figure out, who lived in the boards, because insects leave its gnaw grinding (chewed wood particles and excrements together), flying gaps and tunnels behind, and all of these vary in shape, execution, size, tone, abundance, distribution and direction. (Pilt, 2010) Some of the holes are exposed in Figure 9.

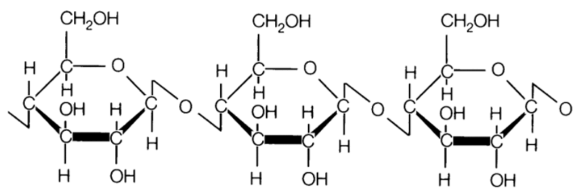
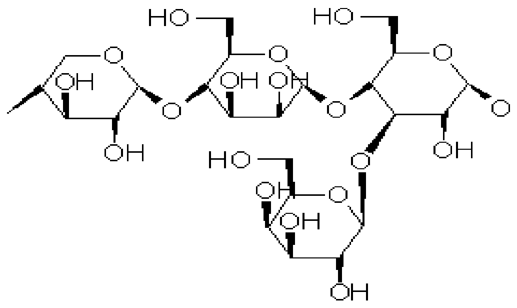
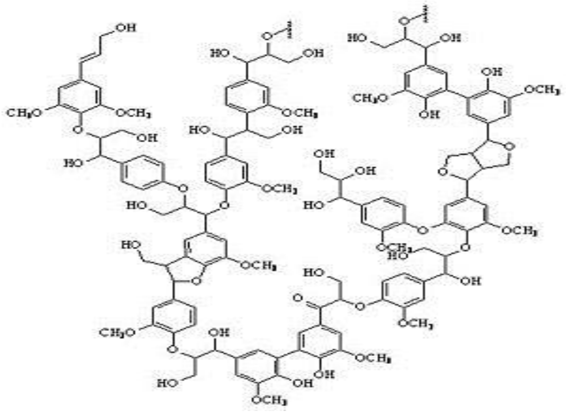
As a result of fungal attack in wood, the structural strength of wood (bending, torsional, compression and tensile strength in longitudinal and transverse) is substantially changing. Independent of the use of wood, after the attack by fungi, wood will lose its functional purpose and construction. (Keskus, 2015) Insects are less damaging to wood than fungi, thus they do not reduce the value of reclaimed wood.

1.6. Weathering

Weathering is the general term used to define the slow degradation of materials exposed to the weather (Rowell, 2005). When talking about physical impacts, the most determining agents are UV-radiance, the effects of temperature and change of water volume (Pilt, 2010). Weathering is the process that occurs when the sun is burning the surface of a wooden board, but rain cools it down again. If water swells with cold in winter, tensions in wood arise and when sun warms the surface of the wood, cracks become visible (Pilt, 2010). Through years these damages will become more serious and the strength properties of wood will decrease.

The concept weathering comprises of many factors like moisture, sunlight, temperature (warm, cold), interactions with biological agents, chemicals, which may cause decay, checking, splitting, cupping and surface colour changes. Besides the main factors weathering depends on wood density, which in turn depends on growth rings that occur every year and also favourable climatic conditions – temperature and moisture above all. (Rowell, 2005)

Table 3. Structural units of wood.

	• Cellulose
	• Hemicellulose
	• Lignin

[1] **(Schauwecker)**

When comparing weathering with decay then weathering is affected by UV-radiation and impacts only the surface of the wood and the result will be visible only in a number of years, whereas decay fungi modify the whole wood and destroy it within few years. Through the weathering process, degradation reflects in surface fibers loosening, eroding, generation of cracks, raised grains and finally the surface maintains its patina grey colour. On top of that cellulose grains from the surface sections will remain, but lignin and hemicellulose will be degraded. Observing the amount of energy in UV range, it is evidential that bonds from wood chemicals will be breaking. The total degradation of wood from UV radiance depends on the ingredients of woods overlay and the lignin concentration, because lignin absorbs UV radiation of 295 nm into visible light spectrum. On the contrary, if UV radiation wavelength is lower than 295 nm, it will absorb in ozone, but not into the surface of wood. The denser the wood is the less UV radiation it will penetrate. (Rowell, 2005) Lignin itself starts degrading under consistent lightness at a wave length under 350 nm and photo bleaches or whitens from wave length 400 nm (Stephen Jones, 1997).

One of the important factors of degradation is the existence of free radicals. Commonly wood does not have free radicals, but after UV irradiation, the chemical bond dissociates and free radicals will be formed (Rowell, 2005). To continue the launch of free radicals the access of oxygen must be guaranteed (Sandoval Torres, Sadoth, et al., 2009). The carbon-carbon, carbon-oxygen and carbon-hydrogen bonds connect the cellulose, hemicellulose and lignin (Table 3) (Sandoval Torres, Sadoth, et al., 2009), which makes degradation process complex during weathering by sun.

Figure 10. Surface weathered by sun and rain.

To some extent wood is addicted to abrasion caused by particles, which are moving due to wind and rain (Pilt, 2010). Different chemicals in contact with water will do degrading as well. In 10-30 years wood strength would not change noticeable in case of contact with fresh water, after that hydrolyses will begin and resistance of upper surface will start decreasing. As an example, salt water will reduce strength parameters of wood in few years up to 26% (Pilt, 2010).

Unlike newly sourced wood, reclaimed wood has been weathered for many decades which gives it a different look, which is figured in Figure 10. Reclaimed wood will have a unique character to it and look aged and charming, offering a traditional or historical style in home. (Home, 2014) The best weathered wooden pieces for furniture are walls of old barns, wooden roofs and driftwood near beaches and reservoirs.

1.7. Naturally aged wood species

The most popular naturally aged materials are bog oak and brown oak, the ageing of which has taken years. Black oak, bog wood as well as brown oak are regular oak woods. Bog oak is aged in the mud of rivers or buried in a peat bog for hundreds or sometimes thousands of years (Wood-Database). The low oxygen levels in bog wood protect the wood from decaying, when iron salts and minerals are reacting with the tannins. As a result, oak achieves its distinct dark brown to black colour (Wood-Database), which makes it one of the darkest natural wooden materials in the world (Figure 11) (Puupank).

Figure 11. Sanded bog oak. (Wood-Database)

Figure 12. Sanded brown oak. (Wood-Database)

Brown oak has been infected with a fungus *(Fistulina hepatica)* that has an ability to turn the colour of wood into deep brown. After a little time, when the wood has been cut and dried, fungus dies and leaves a rich golden brown coloured lumber (Figure 12). (Wood-Database)

Due to the fact there is a limited supply of the bog or fungus aged oak material and its price is calculated in kilograms, it is one of the most valuable woods. Other things that contribute to the higher prices include patient treatments, sharp tools and a heightened attention while processing the material (Puupank). Some people are ready to pay extra for a bog oak and brown oak with an aged look.

Bog oak is most known but not the only wood that is aged in bog. There are also yew, which changes its colour to a reddish brown and the pine to a golden yellow. Bog wood and brown oak are both not produced into furniture, regularly used as decorative or wooden jewelry.

1.8. Artificial ageing of wood

As one of the problems of reclaimed wood is its scarcity then there is a seek fort he best artificial ageing method that would help to get the same wood pieces in a matter of minutes in contrary to years of ageing. Unfortunately, there are not many ways to manage wood that has not been in use for years or suffered under different weather conditions but still looks the same. Ageing time depends on the kind of wood (hardwood, softwood). If the unsurpassed look of wood has been worked out, its story and history will be absent, which debases its value and cost.

The leading way is to study weather in wood surface "forcibly" when guiding sunlight and rain directly onto the surface as through project COST Action FP 1303 – Cooperative Performance Test after what cracks, discolouration and moisture properties will be measured (C. Brischke, et al., 2014).

Figure 13. Brush sanding machine (Woodworking machinery).

Aged and worn surface comes out with a brush sanding machine for wooden surface - this can be seen from Figure 13. The device works fast and the surface will be given a great texture, although it is not the same as in case of real reclaimed wood.

The device is powerful as with a 7.8 a motor it delivers 3,500 rpm for fast and efficient paint and rust removal and its main function is to bring out wood grain. Brush sanding machine has innovative design for sanding flush to wall with the front and side of the sander. The adjustable front roller is used for applying uniform pressure onto the work piece. Also it is well balanced with a low centre of gravity for easy operation. (Woodworking machinery)

The best results with chemical treatment are received with Antique Patina. Wooden pieces covered with Patina will need more processing with mechanical equipment to obtain a better result, even though real recycled wood is still much more different.

With the help of a chemical Holz Antix 2008 oak can be given an appearance similar to brown oak after having been affected by fungi, i. e when the surface turns golden brown (Figure 14). At the same, when talking about the aspects of bog wood, Antique Patina can generate wenge a look as its surface have been burnt (Figure 15).

Figure 14. Oak surface covered with Holz Antix 2008.

Figure 15. Wenge surface covered with Antique Patina.

1.9. Technology

In order to make furniture the reclaimed wood has to get through many different processes before if compared with primary wood processing. All steps passed are in Figure 16 and explicated below.

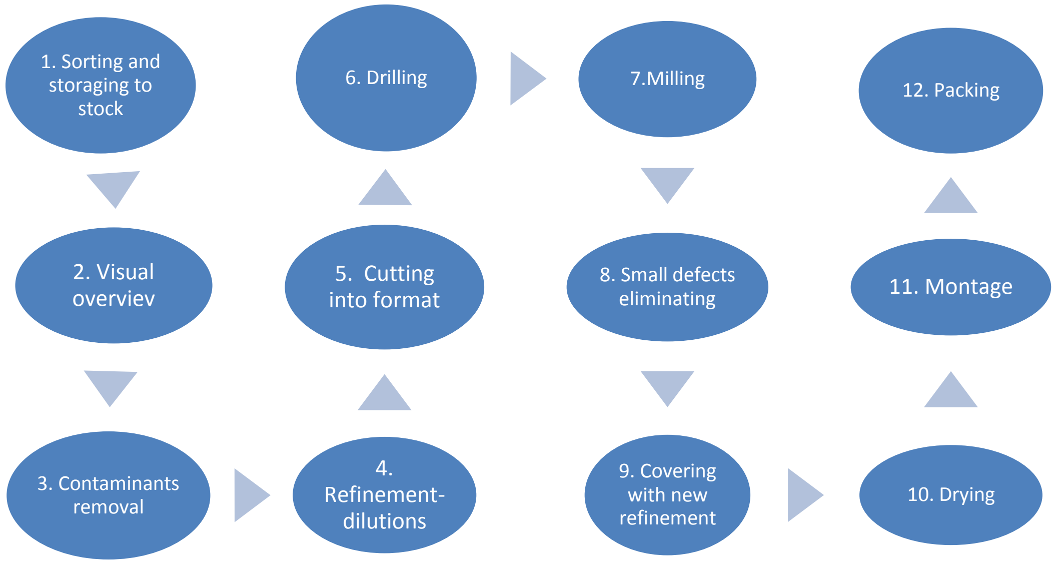


Figure 16. Process chart.

It is named as perfect-timing if reclaimed wood pieces and boards can be collected before burning or landfilling them. It is typical that construction and demolition waste is mixed with various wastes, so sorting is necessary. Technology involves hand-sorting, the removal of nails and screws and various connected wood details. (Reclaimed Wood Barn)

Of course the production will usually start with the idea of what to make out of old wood. This process is followed by the receipt of recyclable wood and a plan of where and how to stock it. The process, which includes finding and dismantling old buildings, is mostly time consuming because there is a need to sort out all reusable pieces, i. e preserve as much wood as possible. (All-Recycling-Facts, 2014) That is because wood pieces are all different and one never knows where some of these will be needed.

Loading of wood waste in reclaimed wood production should take place with human-power or via a front-end loader, because work with reclaimed wood usually requires manual labour consuming, and the machinery will be rather wasteful than beneficial and would not pay off.

Different types of wood can be divided in many ways: on the basis of the type of wood, size, ageing as one product can be made of various pieces wood species, but according to Merike Erkmaa (Appendix 7) furniture is generally made of one particular type. The best places to storage material are sheds and stockpiles on the ground, but these need to have optimal storage conditions. Wood should not be stored on the floor but it can be kept sorted onto pallets according to measurements. Visual inspection is also an important action because not all of the scrap wood waste is suitable for reclaimed products. Visual overview encompasses options like what kind of contaminants recyclable wood has and how can they be removed. Sometimes wood waste has insufficient properties for getting high quality furniture from recycled wood which still has its own attributes. It can be determined via visual examination whether reclaimed wood can be used to produce another piece of furniture or it is too decayed and damaged by the environment before. The suitability of wood can be controlled by drilling machinery RESISTOGRAPH® or ultrasound surveyor that will take out fungal damages as well as those of insects and areas with lower resistance.

Wood must be clean from any other greases, foreign bodies, fungi and insects. Furthermore, all the containing nails, metal fixings, plastics and glass should be removed. Most typical contaminants are materials such as soil, grit, stones, glass and bricks. Making sure that places where nails, screws and other hardware are attached, are visually inspected with magnets on metal detector and eliminated with tongs or a hammer (Wildman) as the aged surface of wood must stay unharmed. Reclaimed wood furniture production is not big enough to invest into magnetic removal and sorting systems. Non-ferrous materials like copper, aluminum, zinc and brass can be removed in handicraft as well to avoid harming the wood surface. Most usable methods for foreign bodies, refinement, insects and fungi removal are outlined in Table 4.

After that, reused wood is moved to the next process where grit, paints, preservatives, coatings, binders and glues are removed. Finishing can be made sure with visual observation or by consulting with chemists. Reclaimed wood can have traces of cement, tar or preservatives. Creosote can usually be detected by smelling the wood; lumber treated with creosote is not a good choice for reclaimed wood working projects. Pressure washing is not suggested as it damages the surface of recycled wood when the moisture gets inside the board cracks or even breaks it into pieces. When the surface of wood is not rotten or attacked by insects, it could be washed with wet cloth, but it is important to keep it away from moisture absorbance to assure the subsequent use of reclaimed wood. (Tõnu Vainküla, et al., 2012)

Various performances require the most that recyclable wood has not been treated with paints or other finishing materials. Nonetheless when treated, the design, labour, construction and demolition will take more time (All-Recycling-Facts, 2014). One big problem regarding reclaimed wood is that its earlier treatment is unknown. There are many possibilities of investigating it. When removing old refinements, the first thing to do is make sure the origin of reclaimed wood, because some of the chemical contaminants can be toxic, therefore, it needs special equipment to clean when planning to use it as furniture. According to the interview with Ivari Maar (Appendix 8), the best choice for removing finishing's is lightly abrading the surface with sandpaper until most of the refinement is removed. Surface should certainly not be burned with hot air, which waves will go inside the material and infracts it instead.

Table 4. Ways to remove foreign bodies, refinement, insects and fungi.

Foreign bodies removal	Previous finishing's removal	Insects removal	Fungi removal	Grit, mud and sand removal
magnets	hot air blowing machine	temperature change (-25^{o}C to +55^{o}C	damp or electrostatic rags	cleaning with wet rags
handicraft	scraper, sanding	glue traps	steam cleaning	brushes
tongs	infrared colour removal boxes	light traps	chlorine based cleaning agents	light washing
metal detector	lacquer thinner or paint remover	outdoor maintenance	cutting damaged surface out	sanding
hammer	wood detergents and steel wool	insecticide	fungicide	terrace cleaner
	green soap with lime paste	kiln drying	sanding	Finishing machines
	baking soda with vinegar			
	caustic soda			

[2] Appendix 7
[3] Appendix 8
[4] Appendix 9
[5] (Jürmann & Kättmann, 2015)
[6] (Tõnu Vainküla, et al., 2012)

Thicker coats of paint can be removed with the hot air blowing machine, bubbling colour can be removed with a scraper (Antiigiveeb). When the refinement removing area is wider, abrading would not help and instead, infrared colour removal boxes come into use. Another choice is varnish softener or paint remover, old spirits and waxes can be removed with wood detergents like spirit + turpentine, spirit + salt ammoniac, spirit + acetone and steel wool (Antiigiveeb). It is environmentally friendly to use green soap with lime paste. Good surface cleaners from mud, grit and sand are baking soda with vinegar. In contrast, it can be done with caustic soda, but it is considered to be toxic.

Collected recycled solid wood pieces must be clear and without bigger defects. It is possible to avoid them by behaving the surface with care. So it is not recommended to use different mechanic separators and surface cleaners. Recycled wood furniture needs to always have quality in the forefront. Remaining dirt or marks on the surface of the boards can be eliminated by sanding or with a planer (Anderson). Another good machine is Fladder finishing machine, which will remove grit, prints of fungi etc. in an easy way.

Figure 17. On the left is a regular reclaimed wood surface, on the right reclaimed wood processed with a planer (samples from SINCE Design OÜ).

Some of the reclaimed wood producers are using a planer to recover the first appearance of wood and not to use the weathered and aged surface (Figure 17). It is one possible way, but the weathered surface is more valuable than the wood inside. Necessity to make a difficult decision rises, i. e whether to prefer an aged look or a look, which resembles to recent wood.

It is important to make a production plan as well, because without the latter some steps of production can be missed or messed up, so the loss of manufacture material may be greater as it could be when producing recycled solid wood furniture.

It is important to take into account that reclaimed wood is more expensive than new solid wood. The edges of reclaimed wood must be cut into size and width, rotten spots must be eliminated, therefore expenses increase 30-40% (Woodworking). The more substandard material is, the higher will be its expense ratio and work there needs to be done, before producing furniture.

Figure 18. Rojek FSN 300 N (Machinery).

Depending on different raw material sizes, some of the pieces must be glued together or fixed in other ways (for example by lamellae's or minifix sets) to get the best sized board. The following processes are almost the same as in case of ordinary furniture manufacturing: cutting into correct sizes, drilling, sanding, varnishing.

A format saw can be used when needing to cut wood into right format that will become used as a detail of a product. It can be done with the most common format saws as Griggio or Altendorf. The cutting of reclaimed wood is not laborious, but wood should be behaved in caution that cracks could not continue.

Towels, lamellae and/or other fixer's holes are drilled using a hand drill. For cutting different edges regular milling machine for example Rojek FSN 300 N (Figure 18) can be used.

Small defects that disturb can be removed by best choice and dropped out knots can be hidden by filling putty. For instance in the interview with Gerda Kättmann, minor holes can be repaired with a mixture of linseed oil and chalk. Another good idea is to make replacement for knot out of the same blank and fix it by using PVA wood glue (Tõnu Vainküla, et al., 2012).

Refinement should be ordinarily done with waxes and oils. Sometimes colouring is the next step. Refinement can be done with colour gun Xcite TM Airmix, because this way it would take less time. Regular drying chamber or open air is used for drying the surface of wood. After refinement, last but not least, is the montage and packing reclaimed wood furniture piece into film or cardboard.

1.10. Posterior maintenance

Wood needs to be protected against external agents, which degrade it and modify its structure and properties. Humidity, sunlight, temperature fluctuations and biological attacks cause the ageing of wood (E. Sansonetti, et al., 2012). To make wood secure from those and more time-proof, it should be covered with special coatings and paints that make reclaimed wood structure more durable.

It should be kept in mind that even wood preservatives will change wood properties. It is demonstrated that preservatives provide wood up to 10% smaller strength properties than untreated wood. For example properties will decrease in 50% by treating wood with acids like hydrochloric acid, nitric- or sulphur acid under 10–15˚C (Pilt, 2010).
According to Caroline Metzelaar's (see Appendix 6) preferences there is no need to use varnishes, the main goal is to keep the surface as untouched as possible. She further recommends cleaning the table tops with a dry or damp cloth. Every furniture piece could need various cares. It depends of the manufacturer's suggestions. In fact for stubborn stains a damped soft cloth covered with cleaner or a hardwood floor cleaner should be used. Many cleaners have disinfecting and dirt removing properties that can harm wood surface (Elmwood Reclaimed Timber). When wood is not covered with any finishing the best used cleaners are ordinary lukewarm soap water, but it must be dried quickly after that. When considering conserving reclaimed wood furniture then keeping the furniture away from heavy moisture is of utmost importance.

Reclaimed wood needs some special care, so it could not be wiped with a cloth, because in that case wood grains snag the cloth and leave behind strands and fibers (Elmwood Reclaimed Timber). There is no need to use scrubbing or cleaning sponge, because it harms the surface. Reclaimed wood furniture must not get in contact with ammonia-based or dust cleaners, water nor vinegar solutions.

2. MATERIALS AND METHODS

The research was carried out in laboratories of Chair of Woodworking at Tallinn University of Technology, where test samples were maintained under standard climate conditions for further analysis. Experiments were made according to the relevant test standards. Experimental conditions were estimated on the basis of international standards and various scientific articles.

2.1. Specimen preparation

Reclaimed wood boards from European Spruce *(Picea abies)* were obtained from a barn built in 1937 in South-Estonia which was dismantled in the summer of 2014. For those 77 years spruce wood boards were under different weathering conditions, like UV radiation derived from the sun, rain, storms and also different temperatures: about -30°C in winter and +35°C in summer. The density of the wood was quite high, because the growth rings were narrow and closely next to each other. When the age of wood was assessed by counting the growth rings, it was discovered that the test specimens were more than 60 years old. Boards have maintained their appearance well, especially taking into mind that these were used as barn doors, situated in the west side of the barn. As a result they were influenced by the setting sun. Besides the degradation of sun, cracks, traces of the existence of insects and fungi were also recognised. It means that boards are not rotten and can still be used, though some wood-destroying fungi traces, insect holes and trails can be detected.

Most of the samples were prepared according to the standard EN 326 (European Standard, 1994). Those wooden panels are in tangential direction with the width of 27 mm. Testing samples had the criteria of longitudinal axis that should be perpendicular with the length of the panel. The specimens were held under a relative humidity of 23 % and by temperature of +21 °C. It must be stated that specimens were cut without affects (knots, fungi attacks), which could have an influence on the test results. Specimens were marked with identification numbers.

The specimens were conditioned according EN 325 (European Standard, 2012) of test pieces at 20 ± 2 °C with the relative humidity of 65 ± 5% till constant mass was reached. Constant mass is considered to be reached when the results of two successive weighing operations, carried out at an interval of 24 h, do not differ by more than 0.1% of the mass of the test piece.

The specimens in this work are six 1.2 m spruce boards taken from different areas of barn and dried in a normal room with a moisture content of~24% and by the temperature of +21°C. After moisture evaporation, boards were sawn into smaller pieces to carry out the experiments. All the samples were taken from the barn side walls with great caution in order not to break them.

Since reclaimed wood is poorly accessible in preferable dimensions, the amount and most suitable dimensions of some tests were unattainable, therefore some specimens sizes were not 100% cut according to standards. Photos of wooden planks are shown in Appendix 1-5.

2.2. Test methods and standards

Test methods were selected according to the best practice from literature to find out aged wood properties, which are essential and characteristic, when dealing with reclaimed wood. It should be taken into account that tests were done with unmanufactured reclaimed wood specimens; weathered surface was not planed or sanded down to maintain reclaimed wood unique appearance for furniture. Test characteristics with number of specimens and standard numbers are presented in Table 5.

Table 5. Tested characteristics.

Tested characteristics	Standard	Amount of test samples	Amount of measurements
Discolouration	ISO 12647-3:2013	6	36
Moisture content	EN 322:1993	14	28
Drill resistance measurment	-	6	14
Cracking determination	-	6	95
Strength properties	EN 310:2002	10x2	20
Janka hardness	ISO 3350:1975	3	12
Durability	-	6	18

2.3. Drilling resistance measurement

It is usually complicated to find out if reclaimed wood pieces can still be used or not, how good is the quality, how will cracks and cavities aggravate production and how long the impairment of the wood has taken. Furthermore, device can be used to gain wood density and growth rates. To avoid wrong decisions through furniture manufacturing, a

Figure 19. RESISTOGRAPH®.

RESISTOGRAPH® (Figure 19) is used for measuring the drill resistance of a wooden board. This device was used to determine the durability and possibility of using aged boards in furniture production. It is also feasible to ascertain whether the wooden board is coniferous or deciduous: if the drilling resistance graphic goes slowly up and suddenly down, the test specimen is softwood, but if it is the other way around, it is hardwood (Pilt, 2015). RESISTOGRAPH® technical parameters are outlined in Table 6.

Table 6 Technical parameters of RESISTOGRAPH® 4453-P.

Aspect	**Parameter**
Resolution	1/10mm
Weight	4. 0 kg
Speed	up to 40 cm/min
Drilling depth	45 cm
PowerPack	12V power supply (172 Wh)
Memory	up to 500 measurements

[7] **(Rinntech)**

In order to maintain the result a thin (thickness < 3 mm) and shaft needle was grinded into the boards of reclaimed wood on two sides in radial and tangential directions. It can be drilled into a board as thick as 1500mm, because of its long needle. Test specimens were not cut, because RESISTOGRAPH® can be used for drilling resistance tests of wood under different angles and register measurements in every 0. 1 mm. Recorded results are printed as a graph on a paper. The machine identified early wood and latewood and took out the outcome of different sections.

2.4. Discolouration

Discolouration was measured on the surface of the samples of reclaimed wood that have been exposed to different weathering conditions for about 77 years. To compare results with recent wood colour measurements were taken. Discolouration investigation was conducted with colorimeter Minolta Chroma Meter CR-121 by the standard ISO 12647-3:2013. Further on, the change of colour was evaluated by the International Commission Illumination colour model CIE LAB (L*a*b) which includes all the perceivable colours (Tammert, 2013) (Figure 20). The three dimensional LAB basics are: Lightness L describes material lightness, a - depicts colour from green to red, b - colour from blue to yellow (Paas, 2009).

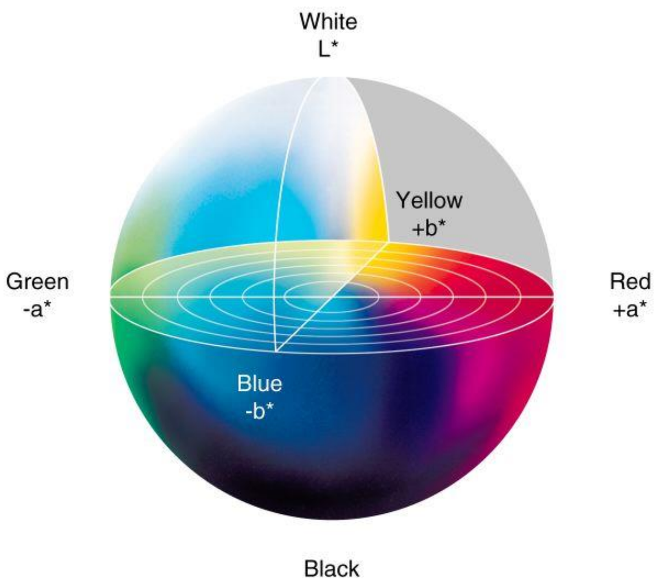


Figure 20. CIE LAB colour space. (Williams, 2002)

Discolouration were measured with colourimeter from six different boards and six different measuring points were selected, which is drawn out on a Figure 21. As a result were got 36 measurements, which were taken into account when calculating discolouration ΔE of reclaimed wood boards related to fresh cut spruce.

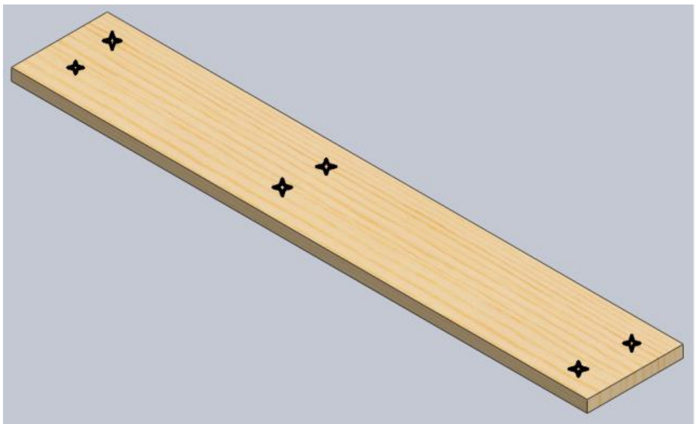


Figure 21. Areas of dicolouration measurements.

The colour of spruce tests were measured after board had been aged for 77 year and compared the results with spruce solid wood colour. To calculate the discolouration value were used the following formula (1):

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

where

ΔE - The total colour difference, unit

ΔL - The differences in lightness, unit

Δa, Δb - chromatic coordinates, unit

2.5. Wood resistance to cracking and its assessment

Through weathering processes, where climate changes a lot and sun dries boards that had got wet through raining, cracks appear. To make sure how cracks change the characteristics of reclaimed wooden boards were primarily assessed visually. The measurement was taken, if a crack was longer than 5 mm. Also it must have been determined whether cracks extended to the other side of the board or not. Measurements were obtained with a regular calliper ruler (average uncertainty ±0,2 cm).

To derive at a conclusion, the following measurements are essential:

- Total crack length;
- Number of cracks;
- Mean maximum crack width (C. Brischke, et al., 2014).

2.6. Natural durability of reclaimed spruce

Specimens durability was reviewed, rated and classified after reclaimed wood pieces moisture content were standardized according to room conditions. The durability of wood was assessed visually, where broken, missing or deteriorated components were identified (Anthony R. W., 2007).

Spores from fungi and insects were estimated visually with a help of specialist Kalle Pilt. Some specimens needed closer observation and were sent to laboratory for testing.

2.7. Determining the moisture content and density of wood

Reclaimed wood moisture content will be near close to the moisture content in the surrounding air g. In contrast when wood is dried until it is joinery dry, its moisture content will be 8 ±2% (Puumarket). The moisture content of reclaimed wood has been achieved according to standard EN 322:1993 (European Standard, 1993).

Reclaimed wood boards were dried under the relative humidity of 24% and room temperature of 22 ± 2 °C, before placing them in an oven. The method is about cutting out samples measuring mass and dimensions of initial specimens. Afterwards samples were dried in oven at 103 ± 2 °C till constant mass was reached. Specimens were cooled to in room temperature, each piece of wood were measured and weighted to an accuracy of 0, 01g to avoid an increase in moisture content that would be greater than 0, 1% (European Standard, 1993).

The moisture content (*H*) is given by the following formula (2):

$$H = \frac{m_H - m_0}{m_0} x100, \tag{2}$$

where

m_H – the initial mass of the test piece, g

m_0 – the mass of the test piece after drying, g

If moisture content was calculated, the next step was to calculate reclaimed wood density to compare it with the density of freshly cut spruce, which is 405 (kg/m3) (Wood-Database). Formula for density is the following (3):

$$\rho = \frac{m}{v}, \tag{3}$$

where

ρ – density, kg/m^3

m – mass, g

v –volume, m^3

2.8. Modulus of elasticity and bending strength

Strength properties of reclaimed wood were measured through three point bending test according to the standard EN 310:1993 (European Standard, 1993). Specimens width b were cut into 50±1 mm. Nominal thickness was 10mm, according to that length of the specimens were 255 mm.

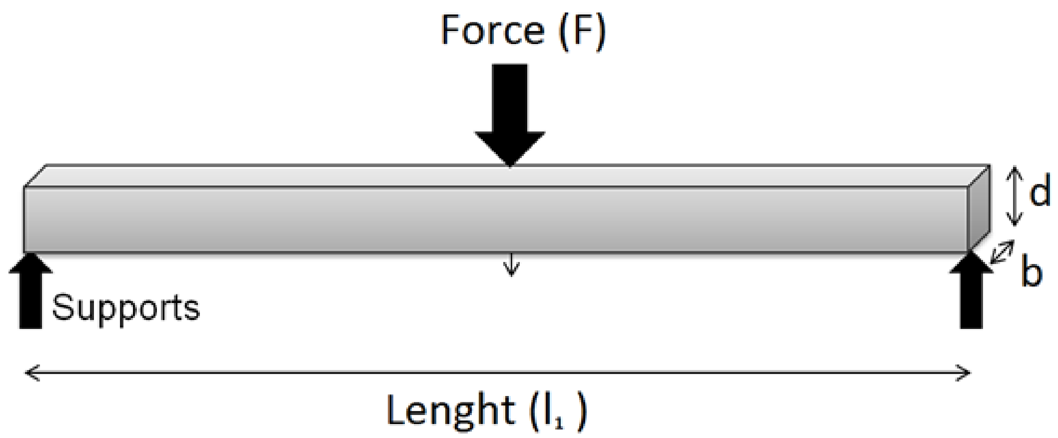


Figure 22. Flexure strength testitng.

Test specimens were conditioned to constant weight under the relative humidity of 65±5 % and temperature of 20±2 °C. To receive results, attempts were made with two groups of reclaimed wood pieces in longitudinal direction: reclaimed side up and reclaimed side down. Measures of the samples were 255x50x10 (mm) and room parameters were 24 °C and 28% of humidity. In total 20 reclaimed wood specimens and 12 recent spruce specimens were prepared end tested.

The flexural strength (Figure 22) is calculated by the bending machine as follows (4):

$$F_m = \frac{3F_{max}l_l}{2bt^2} \tag{4}$$

where

F_{max} – the maximum load at the fracture point, N

l_l – the length of the support span, mm

b – specimen width, mm

t – specimen thickness, mm

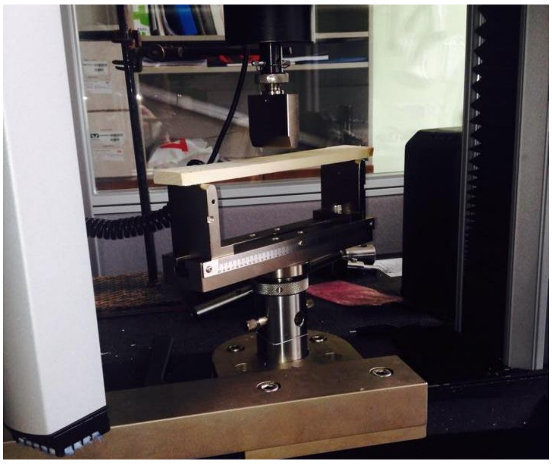


Figure 23. Bending test machine Instron 5866.

Tests were carried out with the bending machine Instron 5866 (Figure 23), the technical parameters can be seen from Table 7.

Table 7. Bending machine Instron 5866 technical parameters.

Aspect	Parameter
Load capacity	10 kN
Maximum speed	500 mm/min
Minimum speed	0,005 mm/min

[9] (Instron specification)

2.9. Testing the Janka hardness

Hardness is the property of a material to resist other bodies attacking it. Janka hardness is

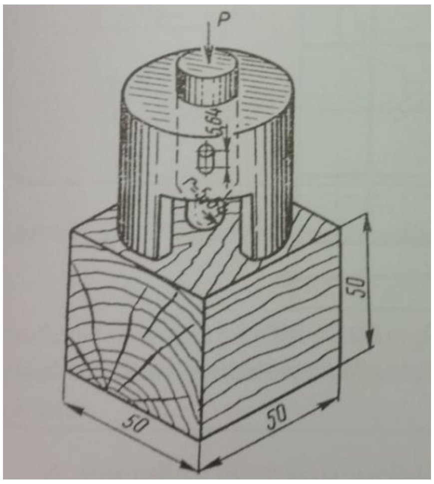


Figure 24. Testing the Janka hardness.

adapted Brinell method for wood, which shows how wood withstands hits, indentations or wear. Through testing with a bullet of the diameter of 11, 284 mm (Figure 24), the hardness of Janka is determined (E. Saarman et. al, 2006). According to ISO 3350 the load per minute was applied at a rate of 3-6 mm/min. In this study the testing speed was 5 mm/min.

Test specimens for this test were larger in length and width, because the availability and size of reclaimed wood are limited. The amount of tests were 12 for three boards with the measures of 194x80x26 (mm), which means that both sides of the specimens got tested for two times from different spots. The machinery used was Board Property Tester IB600 and is partially seen from Figure 25.

Figure 25. Board Property Tester IB600.

3. RESULTS AND DISCUSSION

3.1. Effect of drilling resistance

RESISTOGRAPH® is a machine, which shows all cracks, delamination, decay and growth-ring density structures of earlywood and latewood. Test pieces were drilled with RESISTOGRAPH® in width and thickness directions (Figure 26). Higher line belongs to latewood and lower line to earlywood. Drill resistance machine determines wood type. If the

Figure 26. Measuring with RESISTOGRAPH®.

profile of the drilling curve went slowly up and after that dropped quickly down, it was coniferous tree. It was due to the differences between latewood and earlywood, therefore latewood was more difficult to penetrate and needs more power, than to penetrate earlywood. Softwood is with higher drill resistance by greater amount of latewood and wood density, while earlywood have lower density and its resistance to RESISTOGRAPH® had decreased. (Frank Rinn, 1996)

According to RESISTOGRAPH® nearly all of the testing samples were free of serious damages by fungi and decay. Regularly by insects or fungi damages caused decay were able to determine by obvious decline of the line. The low profiles from intact were a sign of decay, because the curve profile dropped, when needle went into the decayed area of the wood. “*The mean level of the charts closely correlated with the gross density of dry timber.”* (Frank Rinn, et al., 1996) Decay decreases density of wood, equally the mechanical penetration resistance of wood drops. The surface which firstly seemed decayed, were only scratched and it came out by drilling. From Appendix 9 can be seen (tests from board which is taken from board no 1, Figure 33 and Figure 34) a decay caused by fungi from nr 1 samples and from 3 different locations. First and second tests are taken almost from the same location and third one from short distance away. If the profile drops below the lower earlywood resistance level in almost intact rings, it means that this spot is damaged by fungi or pith (Frank Rinn, 2012).

If weather were dry in the summer, it can be seen from growth-rings as well by a narrow ring with less latewood. (Frank Rinn, 1996). From testing samples, can be seen that trees are grown for years in natural way and their growth is not induced. In addition their growth rings are acquired to be really thin, as a result density of the wood were higher than of those which have had a fast growth. From Figure 27 can be seen a slight resin tunnel, which is drawn on the graph with a falling the line.

Figure 27. RESISTOGRAPH® identifies all of the annual rings and wood damages .

With resistograph can be determined wood approximate age with the growth ring width - the narrower the ring, the highest age (Frank Rinn, 2012). Gross density of wood likewise depends of wood age, moreover cross-density will be higher if tree is growing rapidly. From Figure 27 can be seen that wood sample has 16 growth-rings through its thickness, nonetheless it is only one board of the tree, which mean that tree had more than 16 growth-rings before it was chopped off. So many rings per 2.7 cm make tree very suitable for furniture and construction material, also in recycled way.

Determining wood properties with RESISTOGRAPH® drilling device draw out that every one of test specimens can be successfully used to produce unique reclaimed wood furniture with its history and different ageing characters.

3.2. Discolouration

Due to many years of weathering boards have gone through discolouration process from conventional creamy or yellow-whiteness spruce board to greyish-brown as can be seen from Figure 28. The area of different shades of grey depends on the placement of boards: if they have been under sun or protected from direct sunlight and how have they faced other environmental impacts. The ultimate cause of colour changes of these six boards was UV-radiation.

Figure 28. European spruce surface colour and appearance as a fresh solid wood and as a reclaimed wood. Left one is fresh spruce wood (Wood-Database) and images from reclaimed wood test specimens are in the center and on the right.

Since boards were used as barns door material it were constituted of many boards, which were hit cross over with another board, which is also the reason of different brownish straight patch on boards no 3, 4 (see Appendix 2 and Appendix 3). It is in turn connected with the shortage of UV-radiation and richness of humidity the covered area had through 77 years. This area has also less splits and checks, because the drying rate after it got wet; boards had more time to dry due to shortage of sunlight, which usually accelerates the evaporation process.

Based on the results of previous studies (Walter Sonderegger, et al., 2015) the colour differences between recent and reclaimed wood were 95%, in contrast with this study where the ΔL (lightness) varied moderately 52% and the variation between colour areas ΔE were 76% (see Figure 29 and Appendix 10). The fact that the average lightness unit of this study for reclaimed wood were 40, 5 units and comparing it with recent spruce, which measurements was 83, 8 unit and the change of those have been only 52%, on this basis can be said that colour changes via ageing is time-consuming and lightness values can be decreased and colour changes can be increased through the ageing process (Matsuo, 2011).

The colour of reclaimed wood is a dot in a colour spectrum (Hrcka, 2008) and in this case it shows that the most important factor for spruce colour measuring is the decrease of the ΔL value, but the increase of Δa and Δb values had a smaller effect of colouring (V. Tarvainen, et al., 2004). As indicated in the graph of Figure 29 the reclaimed spruce received darker, redder and more saturated in colour when comparing it with recent wood (Keey, 2005)

According to the results of colour lightness measurements it can be seen that specimens of

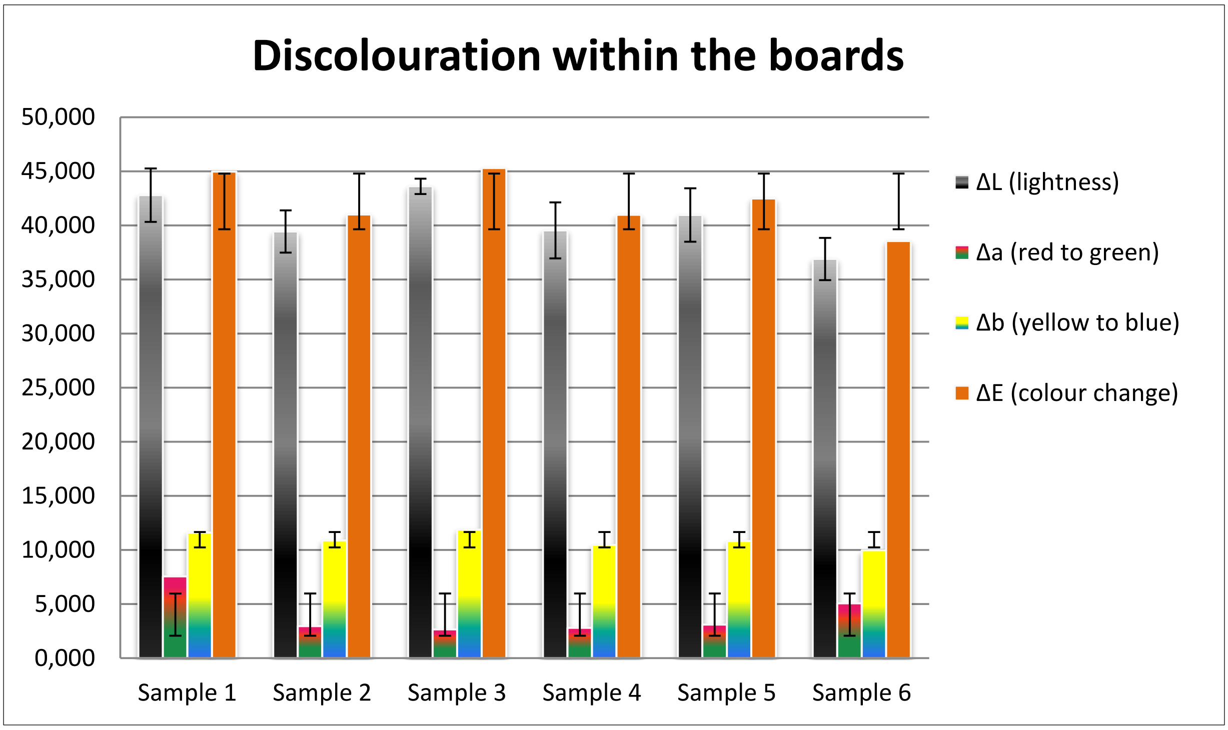


Figure 29. Discolouration within the reclaimed boards.

reclaimed spruce with greyish colour were more near to black than recent spruce pieces, which lightness unit were 84% with its creamy white colour. And as it can be seen from the graph (Figure 29), boards are mainly grey and their surface colour has only small variability. The differences between W. Sonderegger results are probably the amount of sunrise and moisture. The results of reclaimed wood through this study were mostly in the same areas irrespective of the specimen. Colour interval through boards can be seen from Appendix 11, which is depicted as vectors in the colour space.

As a result, boards had various colours from beige and light grey to darker brown and grey and in colour space it situates between black and white. The result of 77 years were in many different colours, because of decay, weathering and erosion. As an effect of weathering changes of the surface and discolouration will be accompanies. Some of the discolouration in boards were caused by decay fungi. On the authority of Sonderegger wood colour were influenced by wood species, different defects, conditions of illumination, effects of high temperature or radiation and chemical substances etc.

3.3. Cracking determination and its influence to wood

Every board of reclaimed wood had many cracks, which are mainly generated by weathering as well as colour changes. Likewise rapid drying causes cracking and splitting in wood structure. If through raining wooden board grains absorb water, after that exposed to the sun dries out fast. This process caused splitting and checking of the wood. Moreover cracks appeared better between earlywood latewood surfaces and in tangential surfaces, where cracks are deeper and more visible (Rowell, 2005).

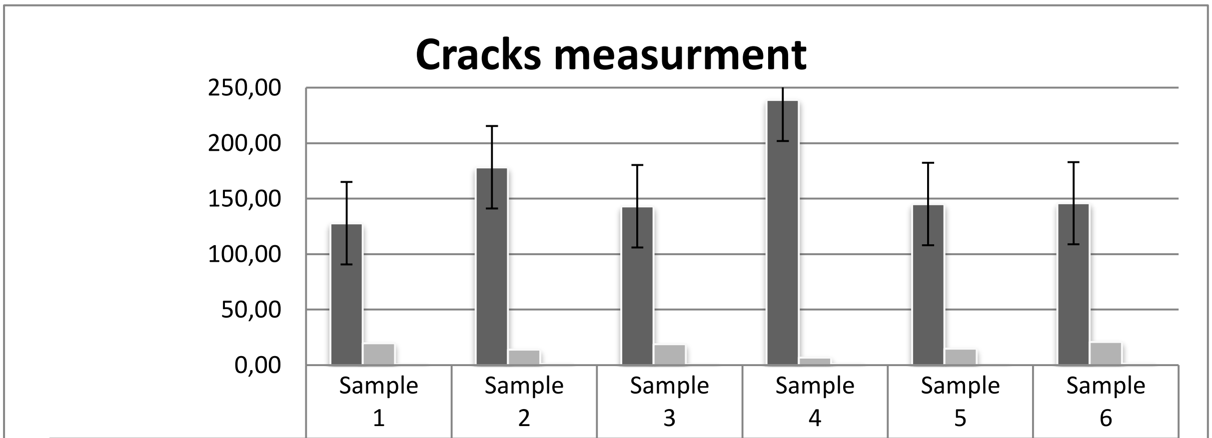
From earlier studies (Thaler, 2013) is found out that cracks arise during drying and wetting due to moisture gradient dimensional changes and tensile stress. From specimens can be seen that rainwater have absorbed into the surface and due to sunlight have evaporated again. In Estonia climate are high summer and winter temperature differences, what advances generating cracks among other things, for the reason that when wood absorbs water in it and weather temperature is below 0°C, water in the wood cells freezes and swells, furthermore it develops stresses in wood that causes cracking after temperature increases and water unfreezes.

Results of cracks assessment are outlined in Figure 30. Results showed that cracks were distinct from each and the average length, width and amount differed in every spruce plank.

Full measuring results can be seen from Appendix 13. Cracks and splits length varied between 32 to 600 mm, which width was at the mean 1 mm.

As can be seen from the Figure 30 the most of cracks, which were longer than 5 mm had test specimens 1 (Figure 35), 2 (Appendix 1) and 6 (Appendix 5). From board no 2 can be seen reclaimed wood boards and there are also taken out many distinguished cracks and splits. Most of them were small in thickness and depth, but some were big enough to affect wood fracture toughness.

When talking about crack depth, some of them have gone in the pith direction, which frequently reduces board’s strength, resistance properties quite a lot. Although sample 4



	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Total crack lenght	127,83	178,23	143,11	239,14	145,23	145,95
Amount of cracks	20	14	19	7	15	21
Average crack width	0,92	1,19	0,90	1,14	0,65	1,29

Figure 30. Total cracks lenght from six test specimens, total amount and width average.

(Appendix 3) had only 7 cracks, most of them were longer than 200 mm, which made it as the lowest resistance to bending, because of the cracks’ depth. Board no 4 must be used by pieces or should be strengthen with glue or refinement, otherwise will be a failure from overload or mechanical damage (Anthony R. W., 2007).

3.4. Determination of wood moisture content and density

The results of determination of reclaimed wood moisture content and density are given in Figure 31 and Figure 33. As can be seen test specimens of different boards varied in measurements. Moisture content of different board samples differed in 23%. It may be related to their different length (see Appendix 13), but most probable reason can be that part of the

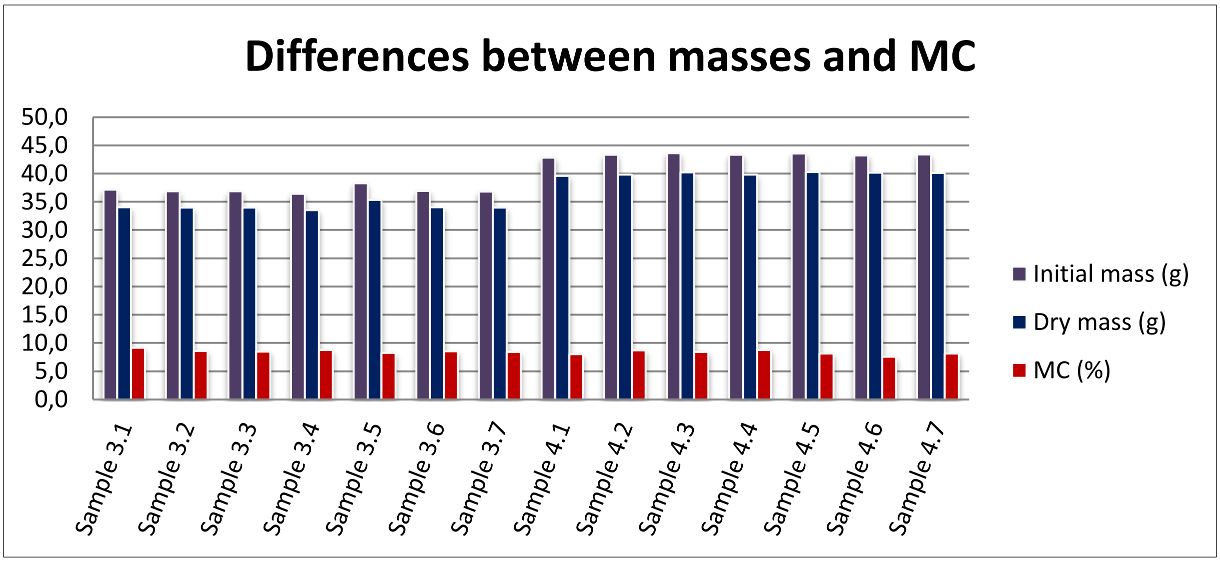


Figure 31. Reclaimed wood specimen no 3 and 4 mass and MC differences.

board no 4 (see Appendix 3) were covered with another cross direction board and as a result moisture gathered between those two boards.

Also when looking at Appendix 3, on board 4 is shown that one side of plank has more affects and cracks. Specimens for experiments from board no 4 were taken near the higher humidity area while board no 3 (Appendix 2) had entirely dry in same rate.

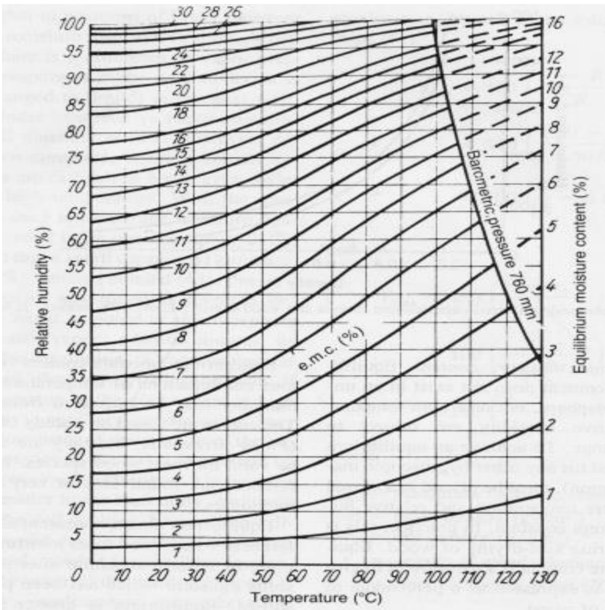


Figure 32. Determination of reclaimed wood equilibrium moisture content.

Since specimens average moisture content was 8%, relative humidity was 24% and room temperature was +22°C, equilibrium moisture content might be determined. According to Figure 32 equilibrium moisture content was 5-6%, which means that wood would not gain nor lose moisture. As a result when wood dries below the fiber saturation point, properties (strength, elastic) start to increase (Shmulsky, 2001). In contrast of this reclaimed oven dried wood specimens were more able to break than specimens, which were tried under normal room temperature.

When comparing results (Figure 33) with spruce average dried weight density of 405 kg/m^3 (Wood-Database), can be mentioned that reclaimed wood density was approximately the same as recent wood density. Reclaimed wood density varied between 391 to 418 kg/m^3. In that case no differences were noticed.

According to previous researches moisture content is related with many properties of wood, for instance if moisture content increases the strength and stiffness decreases (Gerhards, 1980). It was mentioned when reclaimed wood specimens were oven dry and capable to break under very low pressure. Shmulsky also took out that drying wood below EMC can have destructive effects on wood strength and surface roughness.

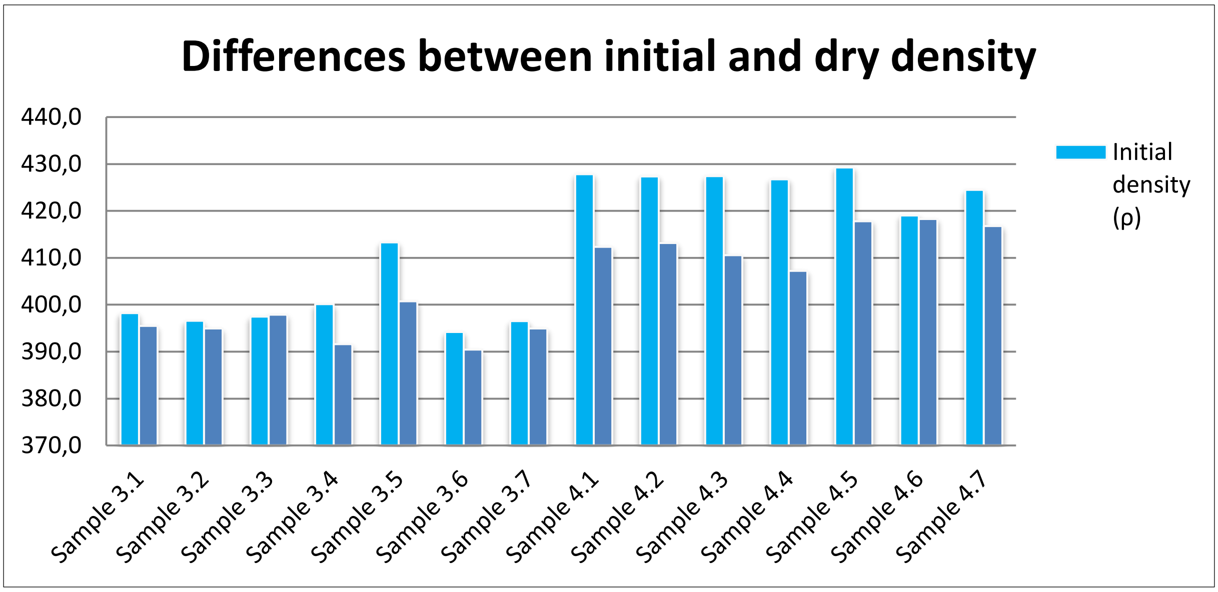


Figure 33. Differences between reclaimed wood specimens no 3 and 4 initial and dry density.

3.5. Natural durability of reclaimed spruce

Natural durability of reclaimed wood boards were mostly high, since boards have had insects in them, but they are all gone, left only insect trails and grinding gnaw. Those courses do not

Figure 34. Boards inner conditions with insects damages.

affect wood properties, but they offer more extra value to prospective furniture originality.

Insects damaged the most specimen no 4, maybe because of the lightest access under the bark or of preferable higher moisture content. As can be seen from Figure 34, some of the insects damages were made inside the boards and it affected the strength properties of wood, because

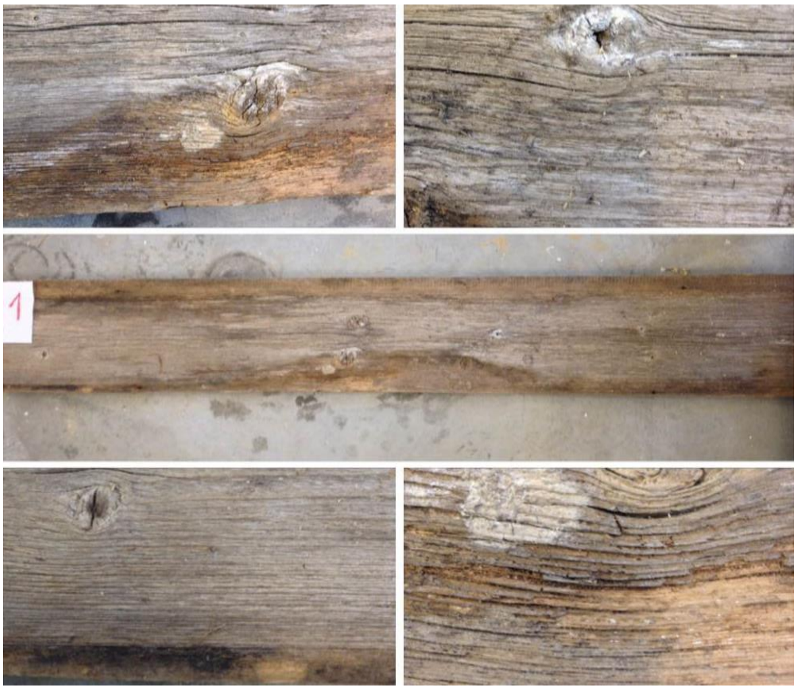


Figure 35. The outer, weathered side of a reclaimed wood board.

there were more free areas at the bending point.

Some of them were slightly damaged by brown fungi and different insects, at the same time some samples were barely affected through 77 years. In Figure 35 board no 1 had a slightly affected part by brown rot. Fungal attack was stopped and could the spores can be prosperously eliminated by sander to use it in furniture production. All of the boards had annual rings tightly in 1 cm and they were perfectly seen. This means that boards with more annual rings tightly side by side are more resistant to deterioration, resistant to different environmental impacts and breaking. Most boards had a lot of knots in various sizes that decreased resistance and strength properties. Boards, which were primarily barn walls, were all cut out in radial direction.

Some specimens (Appendix 4, board no 5) were partially covered with bird excrements, which also did not affect any property and in a matter of fact it can be cleaned and used in furniture production.

As can be seen from Figure 36, there is a slight mycelium damage. Probe were taken and sent

Figure 36. The inner, weathered side of a reclaimed wood.

to Tartu to laboratory, where was found out that it was spawn of basidiomycete *(Coniophora sp),* but the damage has been completely stopped and fungal hyphae are decomposed (Figure 37). It was not the only fungal attack boards had, test specimens 1 (Figure 35) and 6

(Appendix 5) had a slight brown rot fungi attack, where cellulose and hemicellulose on the surface layer were broken down, but lignin were destroyed slightly. Since boards had only initial phase of rot, it had almost no significant effect on wood density (M. Aleinikovas, et al., 2013) and had maintained its suitability for furniture.

If it is desired wood to be ready for furniture production, but it had some vestiges of fungal attack, it needs to be dried until approximately 8% of moisture content. Rather it should not be heat-treated under high temperature to avoid decrease of wood resilience (P. Navickas, et al., 2012). Fungi and insects would not attack wooden boards if wood have inappropriate conditions for them, which means wood must be dry and have sufficient environmental temperatures.

Figure 37. *Coniophora* sp decomposed hyphae.

Perceptible changes, but very limited in their intensity and their position or distribution: changes which only reveal themselves externally by superficial degradation, softening of the wood being the most common symptom. As a result of decay rating boards had a slight attack or no attack, depending of the area, because the intensity and distribution was limited. Only symptom board no 6 had was a superficial softening of wood surface.

As a one reason, reclaimed spruce high resistance is due to wood growth-rings density and closeness. Other reason can be almost perfect conditions to conserve boards, because after rain, sun could dry it again and defend boards from fungi in this way. Also if taking into account the fact those boards were from barn doors, which might not had preferable conditions for fungal attack.

3.6. Bending strength properties

Reclaimed wood is assumed to be stronger wood against recent wood (Hasek, 2014) , because of its weathered essence and tighter grain structure, but in this study it could not be mentioned.

Some previous researches have pointed out the fact that ageing causes a reduction of impact bending strength. According to previous studies on spruce is shown decrease strength values of aged spruce related with recent spruce. (Walter Sonderegger, et al., 2015)

Spruce bending strength is known to be 77 N/mm^2 (European Wood). Through this study bending test of recent wood was higher: 105 N/mm^2 (see results from Appendix 14 and Appendix 15). It could be higher, because of the moisture content or tighter growth rings. Aged wood bending strength test results (see Figures 38) were 22,6% lower than recent wood's. Average bending strength of reclaimed wood were 81,39 N/mm^2, while recent wood's bending strength were approximately 20 N/mm^2 higher. Comparing results with other researches (Walter Sonderegger, et al., 2015) outcomes, can be mentioned coincides with the earlier tendencies. As a result it means that recent wood withstands more force than reclaimed wood and as a matter of fact, recent wood is more resistant to make furniture, which has to sustain higher weights

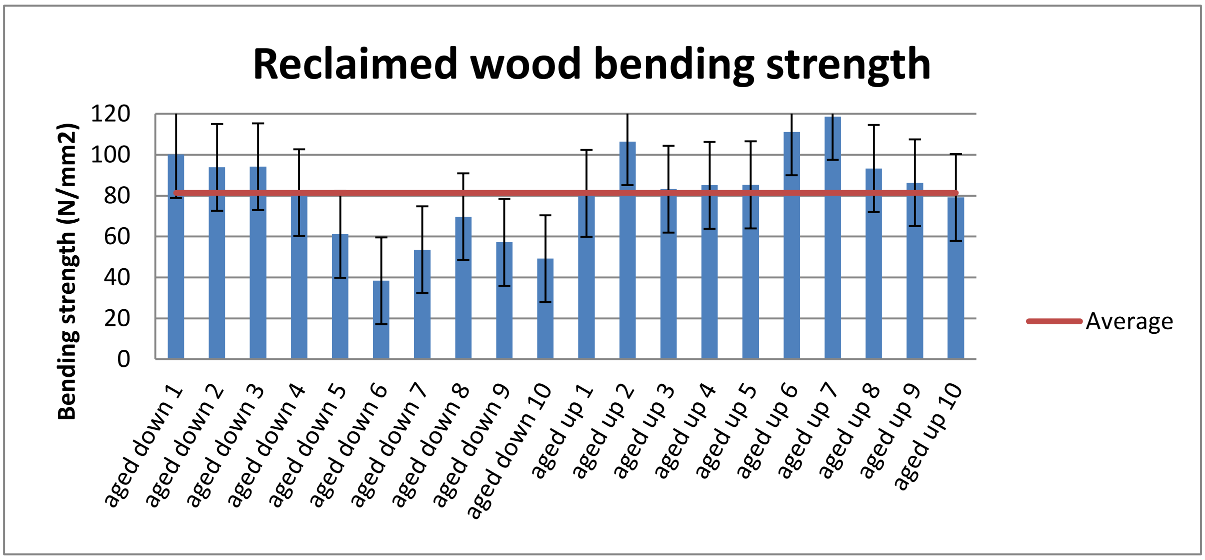


Figure 38. Reclaimed wood bending strength.

Bending strength test results of reclaimed wood were probably lower due to more micro splits or higher brittleness (T. Volkmer, et al., 2013) comparing with recent wood. Specimens' strength properties are connected with their ability to stand against cracks. Another reason of strength decrease could be the photo degradation by sun, which made its surface weaker and damaged superficial grains. The more sun burns wood, the more grains it will affect and as a result strands are starting to break.

From Figure 39 and Figure 40 can be seen a difference between the bending sides of reclaimed wood. There is also a way to influence the bending strength. If a reclaimed wood is

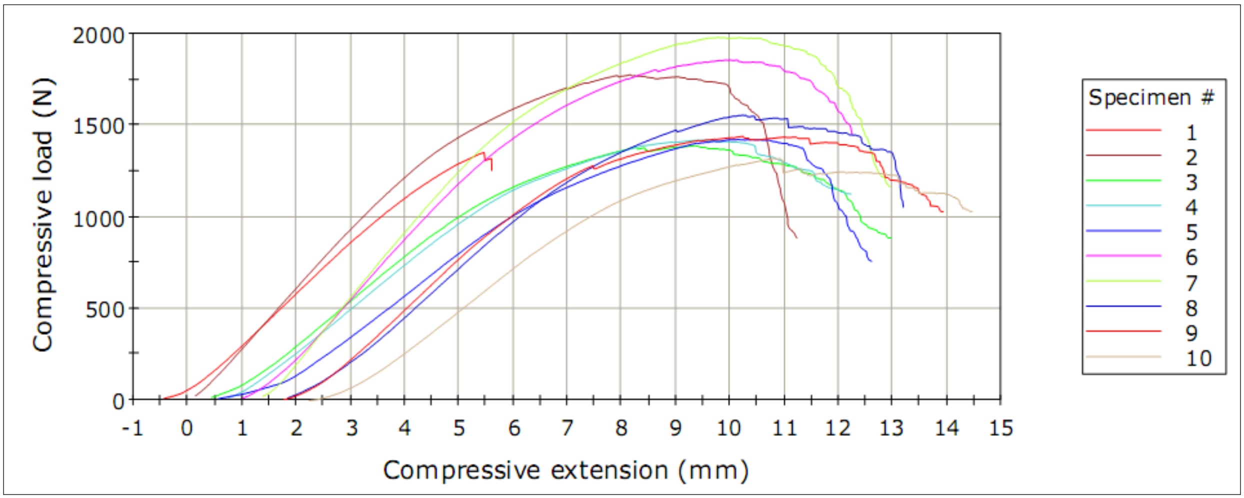


Figure 40. Compressive extension dependence of compressive load, aged side up.

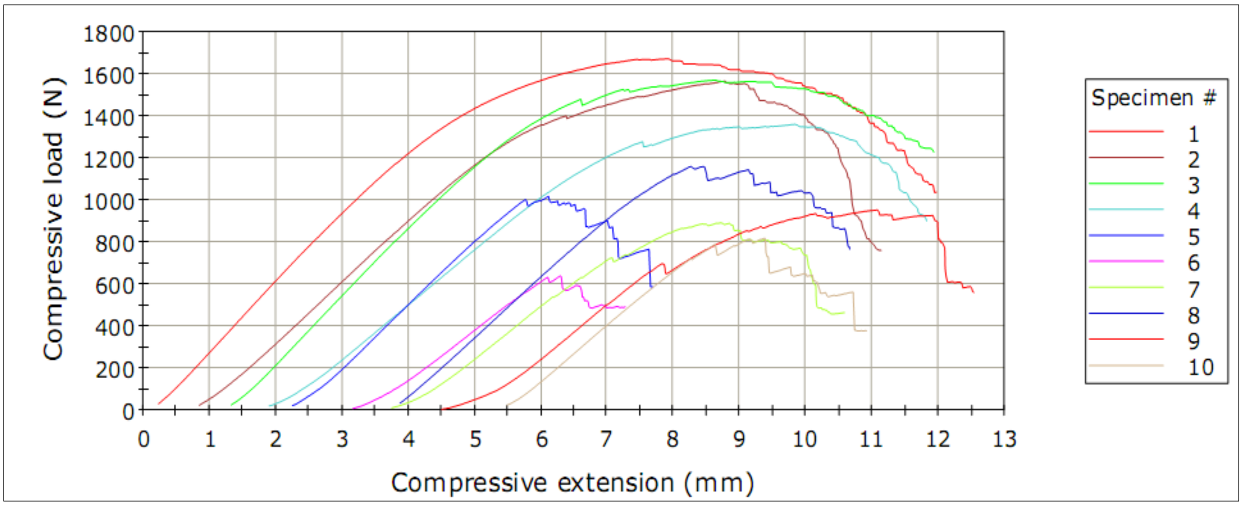


Figure 39. Compressive extension dependence of compressive load, aged side down.

bent aged face down then the bending strength will be lower than the aging while face up. It could be due to that case grains are connected slightly and can break easily. Based on the charts of Figure 39 and Figure 40 can be said that the more load is affecting wood, the more it will lengthen until the breaking point.

According to earlier studies, there were mentioned any increase of reclaimed wood elastic properties (Walter Sonderegger, et al., 2015). Analysing the test results the MoE values of reclaimed wood (Figure 41) and recent wood were both about 14 100±2634 N/mm^2. Relying on scientific data recent spruce MoE under bending is 12500 N/mm^2 (European Wood), but after adding standard deviation to MoE of recent wood of this study, the result 14 100±2634 N/mm^2 will be the same as scientific.

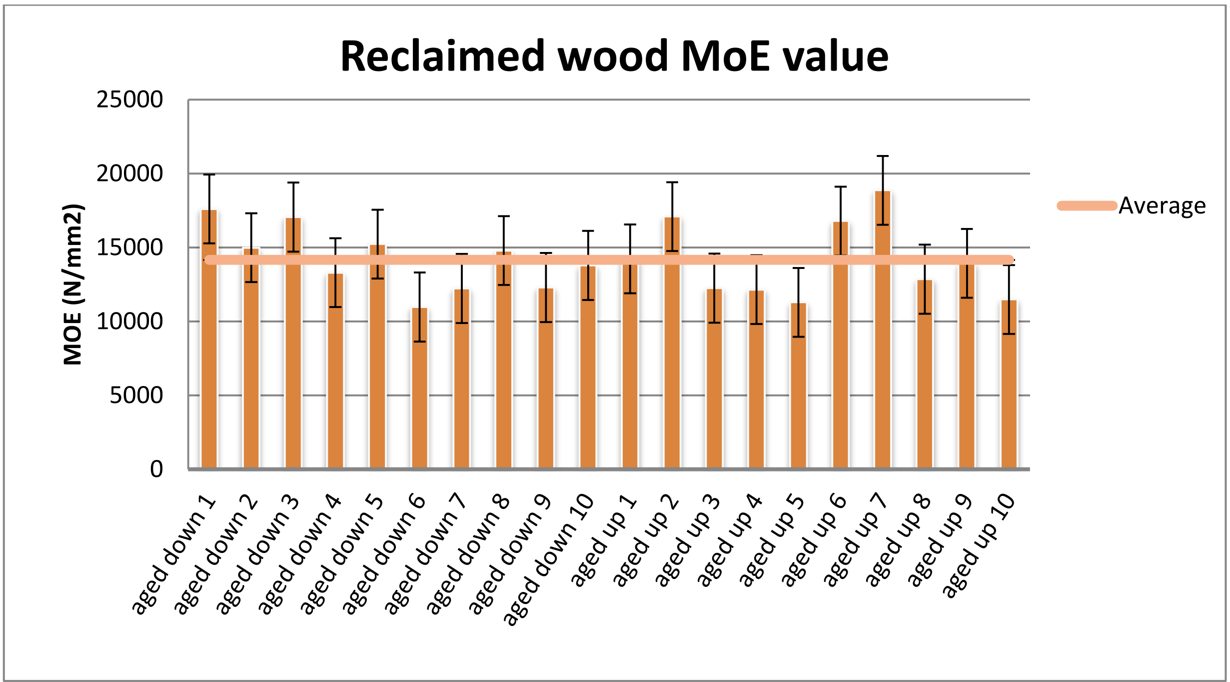


Figure 41. Reclaimed wood MoE results.

As a result of three-point bending test can be confirm an argument (Pemberton) that this method is not accurate to assess bending strength of wood, because the force applies only at one point in the material. The high standard deviation shows the natural variability of wooden boards, which in turn makes three-point bending test imprecise. To reduce bending test it is recommended to use four-point bending test to break material by shear forces.

3.7. Janka hardness of reclaimed spruce

Testing samples took place when the moisture content of wood was 9.7% (sample 1), 9.7% (sample 2) and 10.8% (sample 3), by reason of room moisture content. Janka hardness measuring can be seen from Figure 42.

Figure 42. Testing of Janka hardness.

As mentioned in the earlier paper (David W. Green et al., 2006) surface hardness of recent spruce is used to be 2,9 kN at 12% of moisture. Also is mentioned that reclaimed wood is up to 40 times harder than recent wood, because it comes from old-growth trees instead of first-generation forests (Wood V. R., 2013). In this study Janka hardness results are taken out as a graph on Figure 43. As can be seen it varied between 1,4 kN and 2,5 kN. The average

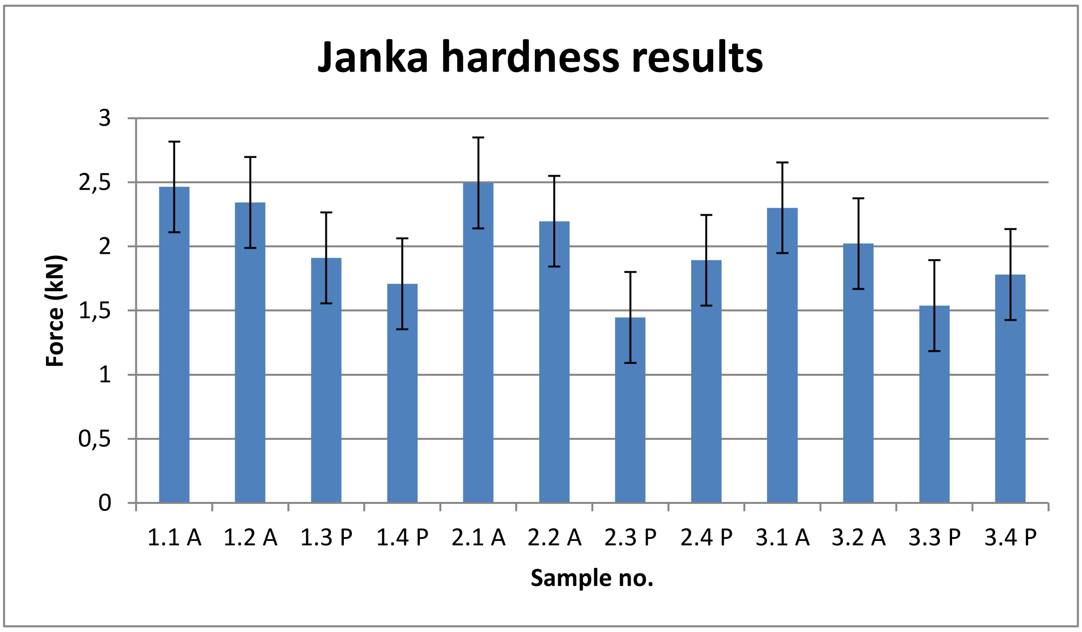


Figure 43. Results of Janka hardness tests.

hardness of reclaimed wood surface was 2kN, which is 31% smaller that hardness of recent spruce. The variability may be by the reason of surface erode. One of the highest force tolerance had sample no 1 and its surface is more stable than others aswell. The drop, which can be seen in Appendix 17, is in consequence of the fact that, specimen cracked near the testing point and stress dropped.

A small hardness difference is between inner and outer surfaces. Bottom side of the board, which were aged by weathering process sustained higher force rate, than inner sides. This is related with the fact that weathered wood carry on more.

In this experiment the condition of material surface is important to get fair results in comparing with virgin wood. As tests were accomplished with unmanufactured boards (Figure 44), test specimens surfaces were left weathered and because off it, surfaces of reclaimed wood withstanded less force than recent wood. Reclaimed spuce inner wood could have been more stronger to the impact of forces than recent wood.

As a result if reclaimed wood surface is wanted to be preserved, it should be reckon that its surface is not as hard as unaged spruce surface.

Figure 44. Spruce wood surface after testing Janka hardness.

CONCLUSION

As a result of decades of the weathering, the surface of samples were greyish in colour and rough due to grain rise. Also many cracks occurred in the samples. The weathering process has affected mainly the samples surface and significantly has reduced the aesthetics and performance of wood. In spite of weathering damage, samples of aged wood can be still used to make furniture due to its unique look and the importance of recycling.

Drilling resistance showed reclaimed wood inner stability after decades of weathering. Nearly all of the testing samples were free of serious rotting damage. Natural durability of wood boards were mostly high, however most of the samples showed damage by different insects. Some of the boards were slightly attacked by brown rot, but fungal attack has stopped and the spores can be prosperously eliminated by sander to use it in furniture production.

Discolouration results were compared with recent wood. Reclaimed wood became much nearer to black colour as decrease of ΔL value, but the increase of Δa and Δb had a minor effect of colouring. Discolouration assessment resulted that colour differences between recent and reclaimed wood were 80% and the contrast were caused due to decay, weathering and surface erosion.

The most of the cracks in the samples were small in thickness and depth, but some were big enough to affect wood fracture toughness. Although cracks cause reduction of wood strength, boards should be used in different ways, where danger of cracks expansion to surface fracture is reduced.

Reclaimed wood density (391-418kg/m^3) was practically the same as recent wood (405kg/m^3) and no differences in properties were noticed. Yet it was mentioned that oven dry reclaimed wood specimens had higher capacity to break under very low pressure and confirmed an earlier assertion that drying wood below EMC 5-6% can have destructive effects on wood strength and surface roughness.

Reclaimed wood showed 22,6% lower bending strength and surface hardness than recent wood. However, some of the studies has reclaimed that aged wood is harder than recent wood, but this did not get approval from this study.

As a result reclaimed wood can be dealt with as same as recent wood when producing furniture, although there could not be a mass production, by a reason of material scarcity. However, to gain more from quality, time and resources, materials recycling should be improved to enhance the effectiveness of production.

SUMMARY

Nowadays, world consumption of goods has gone so far, that people live in a consumer society. Novel products are bought, because unconventional counts, but at the same time recycling is one of the modern possibilities for it. Therefore sharing knowledge about eco design and its importance is a growing trend, where wood has an enormous part as well.

Reclaimed wood is a wood that was harvested tens or hundreds of years ago, and used as a construction material until it was torn down. After that, it can be used in a second round. In a matter of fact, there are many obstacles, when using reclaimed wood. The life cycle of wood is influenced by diverse factors, both wood-inherent (extractives, species) and environmental factors (climate, location, rain) (G. Alfredsen, et al., 2012).

The aim of this paper is to understand and determine reclaimed wood, its properties and use in the furniture production. During the work many experiments were accomplished and compared with recent wood results.

At the first, properties, sources and main ageing factors of reclaimed wood were described. In technology part was mentioned that the hardest part of producing furniture from reclaimed wood was foreign bodies and old refinement removal, because some of substances can be hidden and refinements may not be detectable.

Many experimental tests were accomplished. As a material was used an old barn wall boards, which were made of spruce and were without any refinements. Most of the specimens were prepared according to the standard EN 326 and conditioned after EN 325. Results were gathered by the best practice from literature to find out aged wood properties, which are essential and characteristic, when dealing reclaimed wood.

After determining the inner conditions of recycled wood, revealed that test specimens had withstand various ageing factors and boards could have been successfully used as a raw material in furniture manufacturing. Test was done by drilling the specimens with RESISTOGRAPH® in radial and tangential directions to determine damages of ageing, for instance decay. Also was ascertain reclaimed wood approximate age, which was more than 66 years. Discolouration assessment took out that colour differences between recent and

reclaimed wood were 80% and the contrast were due to decay, weathering and surface erosion.

Reclaimed wood is said to be (All-Recycling-Facts, 2014) more durable and stronger than recent wood, but this fact did not get any confirmation, because bending test, which was done according to the standard EN 310 showed that reclaimed wood broke under lower force at 81,39 N/mm^2 and Janka hardness pointed out that some of the specimens got cracked during the test and other withstand less force because of the eroded surface. Despite the fact that Janka hardness could have been influenced by reclaimed wood surface, which is times more brittle than the inner part. Even though three-point bending test have been used by researchers for long-time, its result is not accurate, because force affects only one point in the material.

This study concentrated on reclaimed wood and its suitability to use it in the furniture production. Thesis performed all of the established aims. As a result can be said that reclaimed wood can be used as a material in furniture manufacture, even though it could not be as strong as recent wood. Instead furniture is original, historical and more time-lasting, because of ages of weathering and other influential factors.

RESÜMEE

Üle maailma on üha enam hakatud tarbima erinevaid tooteid, mistõttu öeldakse, et tänapäeval tarbimisajastuga. Tingituna soovist eristuda võib ühiskond oma tarbimisega liiga teha järgnevatele põlvkondadele. Selle vältimiseks on ka taaskasutus üks võimalustest originaalsena näida. Ka puit on oluline osa ökodisainist ja materjalide taaskasutamisest, mis muutub aastate jooksul üha olulisemaks.

Puitmaterjal on saetud kümneid või sadu aastaid tagasi hoonete ehitusmaterjaliks. Aastaid hiljem vanad hooned lammutatakse ja vana puit saab uue elu taaskasutuse näol. Materjal on aastate jooksul nii loomuliku protsessina kui ka ilmastiku ja muude keskkonnamõjude kaasabil teinud läbi suure muutuse, mille tulemused võivad vanast puitmaterjalist mööblitootmisel takistuseks olla. Töö eesmärgiks oligi hinnata puitmaterjalide omadusi, mis oli erinevate tegurite tulemiks ning mida võrreldi värske kuusepuidu omadustega.

Töö esimeses osas kirjeldati vanandatud puidu omadusi, leiduvust ja põhilisi vanandamise tegureid. Tehnoloogia osas toodi keerulisema etapina välja vanas puidus leiduvate võõrkehade ja endise viimistluse hindamine ning nende eemaldamine.

Magistritöö käigus tehti mitmeid katseid, kus materjalina kasutati vanadest viimistlemata kuurilaudadest standardi EN 326 järgi valmistatud ning EN 325 järgi säilitatud katsekehasid. Tulemusena toodi vana puidu võrdluses värskega välja vanale puitmaterjalile iseloomulikud ja olulised omadused.

Peale puidu sisemiste omaduste hindamist ilmnes, et katseteks varutud vanandatud puitmaterjal sobib edukalt ka mööblitootmises kasutamiseks, sest puit oli sisemiselt kahjustamata. Värvimuutuse katse tuvastas, et võrreldes värske puiduga on materjali värvuste erinevus ~80%.

Varasemalt väidetud fakt, et vanandatud puit on palju vastupidavam kui värske, ei saanud kinnitust. Standardist EN 310 lähtudes sooritatud paindekatse tulemusena, purunesid puidukiud madalama raskuse all võrreldes värske puiduga. Janka kõvaduse katse tõi välja, et vana puidu pinnale katse käigus tekkinud pragude ja varasemate pinna ebaühtluste tõttu oli vana puit madalama pinnakõvadusega kui värske kuusepuit.

Töö keskendus vana puitmaterjali omadustele ja puidu sobivusele mööblitootmise tarbeks. Uurimuses täideti töö alguses püstitatud eesmärgid ning leiti ei vanandatud puitmaterjal sobib mööblitootmiseks, kuigi tegu ei pruugi olla värskest puidust tugevama materjaliga, on selle originaalsus ja ajalugu väärtustatud.

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APPENDIX 1. OVERVIEW OF RECLAIMED WOOD TEST SAMPLE NO 2

Figure 1. Sample no 2 inner side.

Figure 2. Sample no 2 outer side.

APPENDIX 2. OVERVIEW OF RECLAIMED WOOD TEST SAMPLE NO 3

Figure 3. Sample no 3 inner side.

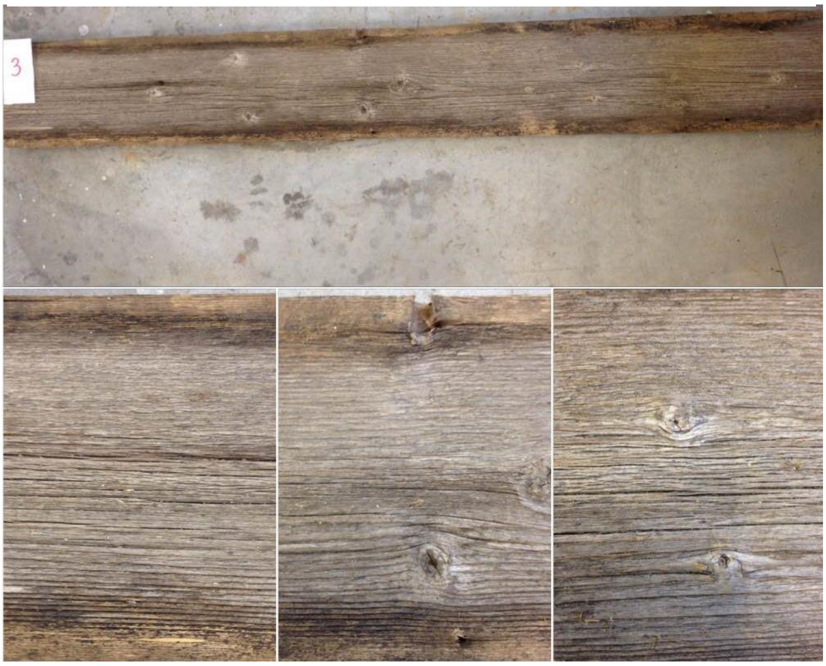

Figure 4. Sample no 3 outer side.

APPENDIX 3. OVERVIEW OF RECLAIMED WOOD TEST SAMPLE NO 4

Figure 5. Sample no 4 inner side.

Figure 6. Sample no 4 outer side.

APPENDIX 4. OVERVIEW OF RECLAIMED WOOD TEST SAMPLE NO 5

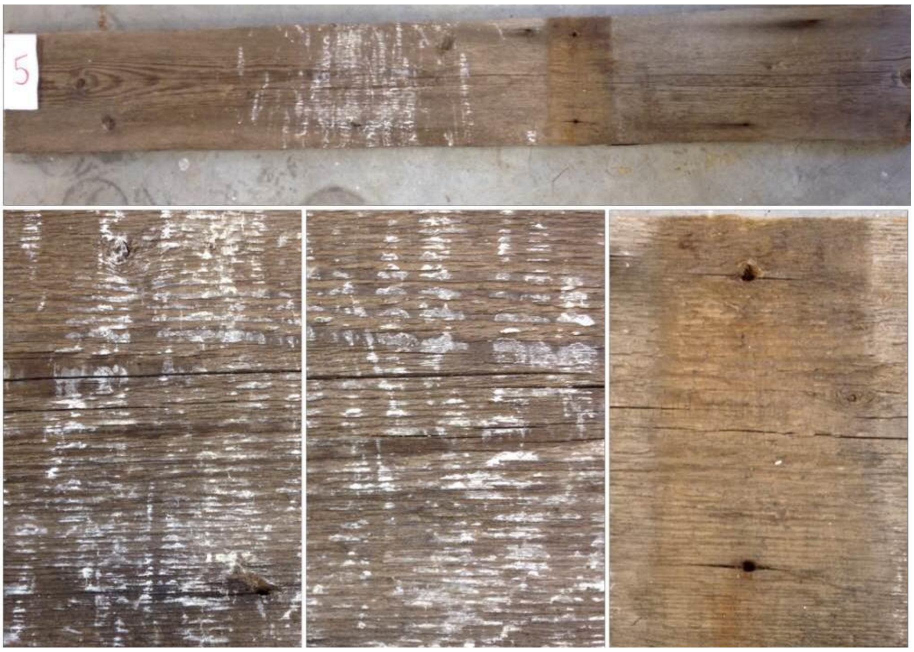

Figure 7. Sample no 5 inner side.

Figure 8. Sample no 5 outer side.

APPENDIX 5. OVERVIEW OF RECLAIMED WOOD TEST SAMPLE NO 6

Figure 9. Sample no 6 inner side.

Figure 10. Sample no 6 outer side.

APPENDIX 6. INTERVIEW WITH CAROLINE METZELAAR, RIVIÈRA MAISON

All questions concerned reclaimed wood/driftwood, their properties and technology by Caroline Metzelaar, furniture product trainer in Rivièra Maison furniture and interior company from Denmark.

• What is the origin of your material?

Our Driftwood furniture has been a resounding success for several years; the table-top in this series is made from the North American Elm, which was used at the beginning of last century to make front doors. We took those old front doors and had them converted into furniture.

• What are the main types of wood your are using? Do you sort them somehow? What do you

prefer?

Mostly Old Elm, that's the type of wood we prefer. The old doors are collected locally, scrubbed clean and sanded down, and then sawed into the size of wood needed for the furniture. Untouched is what the factory calls it, and that's exactly what it is.

• As I have been comparing reclaimed and driftwood, I wanted to ask whether I have understood the following correctly: reclaimed is already used but driftwood is mainly old wood from beaches and forests. Correct?

That's not correct. We use the name "driftwood" in our furniture series we named this series of tables 'Driftwood' because the weathered glow of the table-tops makes it look like it has been worn and weathered by the sea. Reclaimed wood and driftwood are both old reclaimed wood but in different atmospheres.

• What makes reclaimed/driftwood such a valuable material? What are its main advantages?

The untreated wood of these doors is recycled , so no trees put down that's a big advantage and this preserves the original quality of the timber.

• Is this kind of wood more timeless than regular furniture made of solid wood or different wooden panels?

Because we use the old used doors and reconstruct the doors to new furniture all the details, for instance; Where the hinges once entered the wood, there are now holes; where the doors were cracked, cracks still remain in the table-top or cabinet door, and a door that has always been battered by rain has a different colour than a door that usually stayed dry and/or caught the full force of the sun's rays. Pure and natural, these tables are authentically aged. So that makes the tables time proof. So other woods for example mango wood tables give a whole different atmosphere and less lived appearance, even after a longer time.

• How is the disinsectization done? And dried? How can all the insects and termites be removed?

The old doors are treated with a water-based insecticide spray. That's the first treatment before the old doors are manufactured to table tops. When the tables are dried in drying sheds. And stayed there for a week and undergo a drying treatment with temperature ranging from 0 to 70 degrees. After this drying period the tables/ furniture is rapped for transport. When the furniture is put in the transport containers. The furniture is still in the sealed container in a special gas to combat the last termites etc.

• What kind of varnishes are the best for surface finishing?

There are no varnishes on our untouched old elm furniture and we don't recommend this. We like the weathered look and give the customer only the advice to clean the table tops with a dry or wet cloth.

• What are prospects of reclaimed/driftwood in your opinion?

Because we are revitalizing old recycled wood are the predictions that this product current very plausible. Especially at this time.

APPENDIX 7. INTERVIEW WITH MERIKE ERKMAA, MUINASMÖÖBEL OÜ EXECUTIVE DIRECTOR

- Mis on põhilised puuliigid, mida Eestis taaskasutatakse? Kas puitu tuleks kuidagi liigiti või muudmoodi sorteerida?

  Palkmajad tehakse põhiliselt kuusest. Võimalik on kasutada kõiki puuliike.

- Kui palju kasutatakse ühe toote puhul mitme puuliigi detaile?

  Tavaliselt tehakse tooted ühest puust.

- Kuidas kuivatada kogutud materjal?

  Kuivatuskambris või õhu käes. Õhu käes kuivatades tislerikuiva materjali ei saa. Väga tihti seisavad vanad palgid väljas ja on läbi vettinud. Ütleme nii, et kuiva materjali saamine on probleem.

- Kuidas eemaldada võõrkehad (nt naelad) ?

  Mehhaaniliselt

- Kindlasti olete kokku puutunud ka seente/mädanike ja putukatega, mida nende rikete ilmnemisel ette võtta? Kuidas eemaldada?

  Kamberkuivatus aitab. Võib ka puitu külmutada. Mädanikuga puit on targem välja sorteerida.

- Kuidas teha kindlaks vana viimistlus ning see ilma puidu pinda kahjustamata eemaldada (st säiliks vanandatud puidu pinnastruktuur)?

  Me kasutame viimistlemata puitu. Vana viimistluse eemaldamine on restaureerimisega seotud. On mehhaaniline (harjadega eemaldamine) ja keemiline eemaldamine.

- Millega puitu viimistleda, et saada parim välimus, pikaaegne mööbliese?

  Viimistlusvahendeid on väga erinevaid. Looduslikud vahendid on tungaõli, LeTonkinois paadilakk, tõrvaõli. Osmo tooted on head sisetingimustes.

- Kuidas vana puitu konserveerida, et vananemist peatada?

  Mädapuitu ei ole vaja kasutada. Tugeval tervel puul ei ole vaja ekstra vananemist peatada.

- Milliseid variante on puidu tugevusomaduste parandamiseks?

  Me ei tugevda puitu.

- Kuidas teada saada vana puitmaterjali vanus?

  Vana materjal on seotud hoonega ja inimestega. Siit tuleb hakata jälgi ajama.

APPENDIX 8. IVARI MAAR, MEMBER OF MTÜ VIVENDI, RESTORER

- Kuidas vana puidu kasutamine eseme kauem kestvamaks muudab (sisetingimustes)?

Kuna see puit ei ole ilmastiku meelevallas, toas ikkagi hoitakse seda. Materjalina ta ongi nagu puit ja käitub nagu puit.

- Milliseid konserveerimise meetodeid soovitate?

Tuleb meeles pidada, et puit on hügroskoopne materjal, mis tähendab, et tema tahab olla sellise niiskusega nagu on tema ümbritsev keskkond. Lakk seob poorid ära ja see oleneb sellest, kuidas puit hingab. Konserveerimise osas tagavad kauakestva mööbli ühtlased tingimused. Lakid ja keemia on liigsed. Nt muuseumi eksponantide seas on kindlasti neid, millele lakiga ei tohi lähedalegi minna. Puit kestab, kui tal on ühesugused tingimused.

- Kuidas kõige parem on puitu kuivatada?

Oleneb, mida sellest puidust teha, kui aknaid, uksi, siis puidu niiskus on ~12 %, kui aga toamööblit, siis 8%. Väga madala niiskussisaldusega puit on tegelikult prahtpuit, sest sellega ei saa peaaegu, et midagi teha: töödelda, liimida, tappida. Kõige ideaalsem on õues 7-10 aastat vihma eest varjatuna. Sundkuivatuse puhul tulevad igaljuhul pinged sisse ja puit hakkab oma elu elama. Kiire asi ei saa kunagi hea olla, aga elutempo on paraku selline, et peab saama kiirelt kuivatatud. Kiirkuivatist tulnud puidu puhul, nt palgi algusest, tuleb vähemalt pool meetrit ära vistata, sest tekivad praod.

- Kuidas vana viimistlus kindlaks teha? Kuidas eemaldada?

Ainult vaatlus, keemikud osakavad ilmselt ka muul moel. Saab ka ajastute järgi paika panna (mõisa või talumööbel). Õlid ja vahad pole need, mida tööstused kasutaksid, väikesed ettevõtted kasutavad. Need on olnud taludes alati olemas, kas siis mesilasvaha või linaõli näol, lakk oli rohkem mõisa asi. Uut viimistlust vana peale igaljuhul panna ei saa.

Parim eemaldus on kindlasti mehaaniline. Puidu pinda ei tohiks kindlasti põletata, ei kuuma õhu, ei infrapunaga. Kõige parem on maha lihvida ja kui see ei sobi, tuleks kasutada mõnda värvieemaldusvahendit, tõmmata kaabitsaga üle, seejärel lihvida maha ja hiljem uuesti viimistleda - üle lakkida, vahatada. Kuuma õhuga pigem mitte.

Kui on u. 100 aastat vana põrand, siis sealt viimistlust maha lihvida ei saa. Selleks on nn infrapuna värvieemalduskarbid. See on parem, kui kuuma õhuga, sest sealt eralduvad ikkagi gaasid. Vana aknakitt ei tulegi näiteks ilma kuuma õhuta maha, pigem puruneb klaas.

- Kas söögisooda ja äädikaga oleks ka kuidagi võimalik?

Sooda on nüüd ainult puhastamiseks. Äädikas teeb ta vanaks tagasi, teeb veidi hallikamaks. Soodaga teeb vana puidu valgemaks ja samamoodi saab ka seebikiviga vanad asjad valgemaks, värskemaks teha, kuid loomulikult on näha, et ta on vana. Seebikivi on mürgine, kuid restauraatorid kasutavad seda siiski, just pesemiseks. Ka terrassipuhastajaga saab laua heledamaks. See on natuke kangem, kui tava mööblipuhastuvahendid. Seal ongi seebikivi sees. Kanda puidule, oodata u 15 minutit, pesta veega maha, seejärel lihvida ja pind ongi heledam. Ta annab pinnale värskema mulje. Kui 20%-lises äädika ja raua lahuses sees hoida paar päeva nt terasvilla või naelaga ja seda puru pärast sinna peale lihvida, hoida seda kuskil 1-2 päeva ja eemaldada, siis saab uuesti rohkem hallikama, vanema ilme tagasi. Otse äädikat pinnale panna ei tohiks. Kui kauem hoida, tõmbab ta mustaks – seda tehnikat nimetatakse ka eboniseerimiseks ehk teisisõnu tavapuidust eebenipuu tegemine, puidu tumendamine.

- Kuidas parasiite ja muid putukaid eemaldada?

Mööblipoest putukamürki. Väiksed asjad (lauad, toolid, riiulid) viia saunalavale 80 ^{o}C kätte.

Mädanike ja seente puhul võtta maha ikkagi selle ala ümbert 50-70cm osa.

- Kuidas eemaldada võõrkehad (nt. naelad)?

Saekaatritel ilmselt ongi magnetid, sest puud, mis maha võetakse sõjaajast kui ka jahimeestest kuule täis.

- Millega puidu pinda viimistled, et jätta kauem kestvam välimus sisetingimustes?

Vahad, õlid. Läbi õli ja vaha hakkab mööbel elama. Lakk teeb ta minu arvates pigem võõrkehaks.

- Milliseid masinaid ja tööriistu kasutada? Kas on mingeid erilisi töötlusviise ka?

Restauraatoritöö pinkides on enamus siiski sama. Võib-olla siis harilihvmasin, mida ilmselt tava puidutöökondades ei kasutata. Sellega saab tegelikult ka vana värvi näiteks maha võtta.

Kindlasti on erinevaid protsesse nt proteesid, eri tapid jne.

- Kuidas puidu pinda parandada, plommida?

Vaha ja õli on natuke lihtsam hooldada. Vaha ja õli puhul pole näha, kus on parandus tehtud, laki puhul pigem on. Kriidi ja linaõli seguga saab paigata kuni 5mm ava, sest see segu hakkab hiljem pragunema.

- Kuidas toimida hilisema hoolduse puhul?

Tava hooldusvahendid, sh looduslikud.

- Mis on vana puitmööbli plussid ja miinused?

Minu arvates on sellel ainult üks pluss: vana asja ei saa enam teha, mis kunagi tehti, see on ja selle eest hoolitsedes saab pikendada mööbli eluiga. Miinuseks võib olla nt inimtegevus, hoolitsematus.

Also were interviewed:

Kermo Jürmann and Gerda Kättmann - Säästvad Ehitusmaterjalid and Since Design

Kalle Pilt - expert in moisture and biodamages

APPENDIX 9. DRILLING RESISTANCE

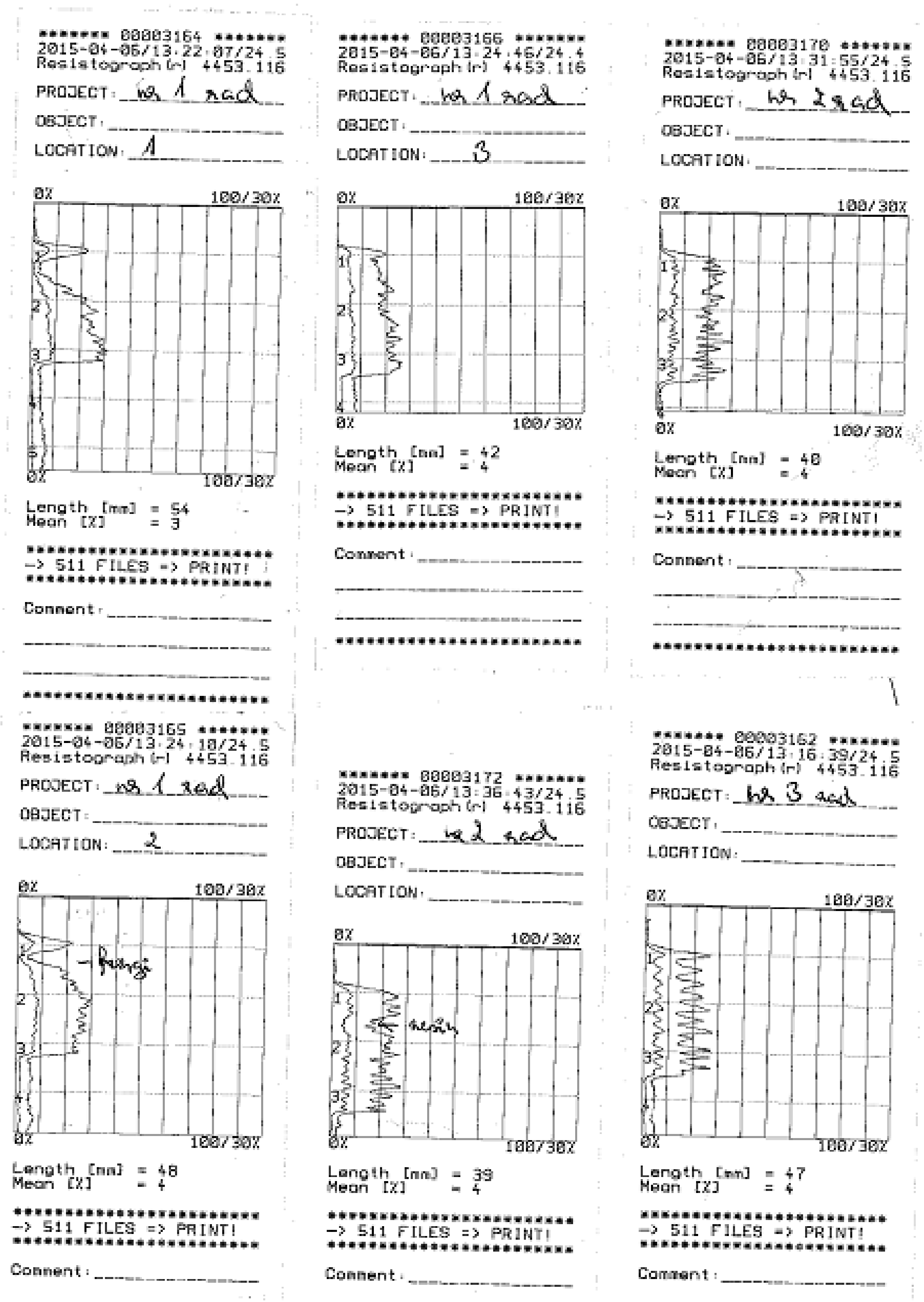

Figure 11. Results from radial drilling of sample 1, 2 and 3

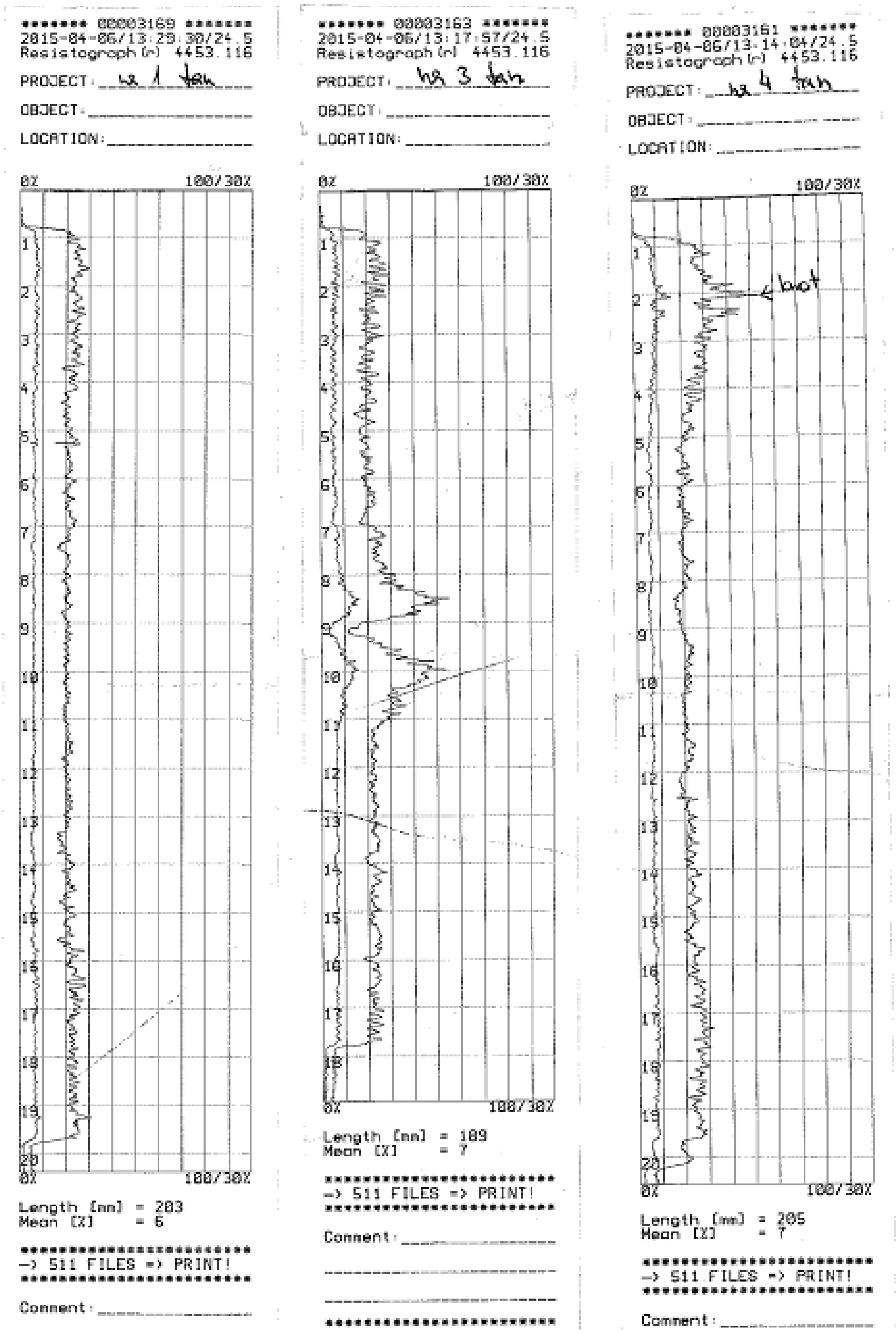

Figure 12. Results from tangential drilling of sample 1, 3 and 5.

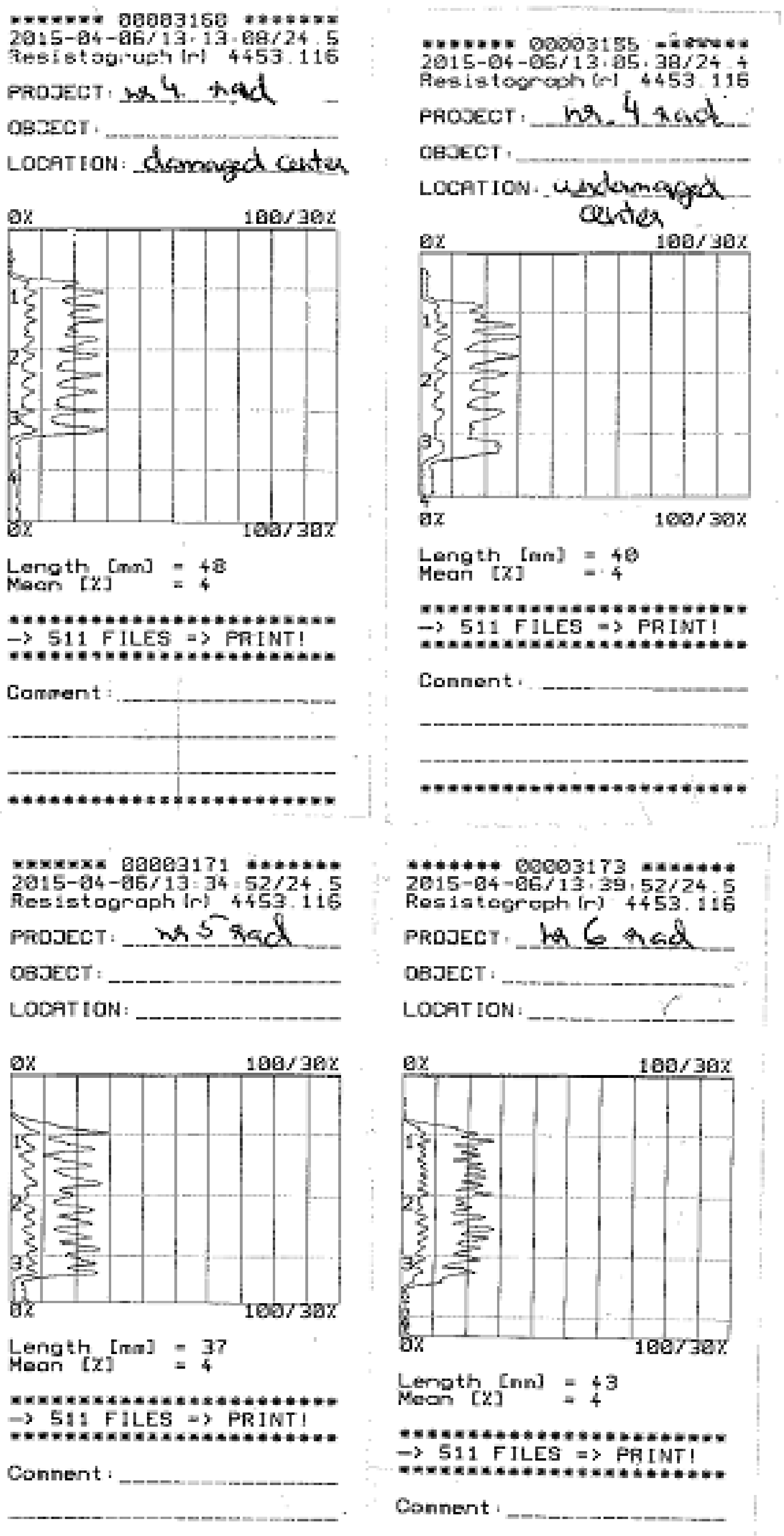

Figure 13. Results from radial drilling of samples 4, 5 and 6.

APPENDIX 10. DISCOLOURATION MEASURMENTS OF RECENT SPRUCE WOOD

Table 1. Results of dicolouration of recent wood.

	ΔL	**Δa**	**Δb**	**ΔE**
Solid wood sample 1	81, 83	0, 27	20, 80	10, 09
Solid wood sample 2	84, 87	0, 33	16, 50	10, 10
Solid wood sample 3	84, 73	-0, 33	16, 23	10, 05
Mean	83, 81	0, 09	17, 84	10, 08
Stanndard deviation	1, 71	0, 37	2, 56	0, 03

APPENDIX 11. COLOUR INTERVALS THROUGH SIX RECLAIMED WOOD SPECIMENS

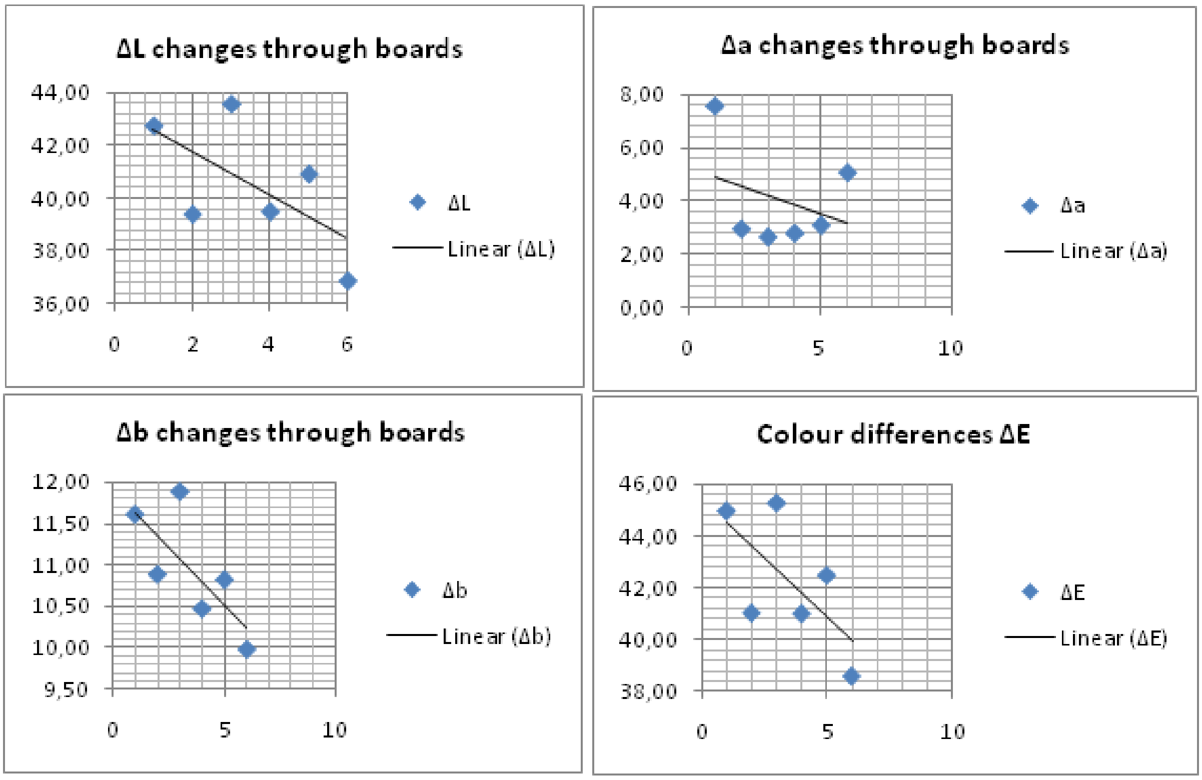

Figure 14. Colour intervals of reclaimed wood boards.

APPENDIX 12. CRACKS ASSESSMENT RESULTS

Table 2. Results of cracks measurements.

Specimen ID	Total crack length	# cracks	Average crack width
Sample 1 in	130	1	0, 5
	156	1	0, 5
	103	1	1
	88	1	1
	260	1	0, 5
	137	1	0, 5
	120	1	0, 5
	123	1	0, 5
	65	1	1
Sample 1 up	76	1	1, 5
	146	1	1
	170	1	0, 5
	87	3	1
	63	1	1, 5
	110	1	1
	187	1	1, 5
	127	1	1, 5
	153	1	1
Sample 2 in	104	1	1, 5
	110	1	0, 5
	290	1	1
	124	1	1
	328	1	1
	286	1	0, 5
Sample 2 up	100	2	1, 5
	115	1	2
	195	1	2
	130	1	1
	123	1	0, 5
	240	1	1, 5
	172	1	1, 5

Specimen ID	Total crack length	# cracks	Average crack width
Sample 3 in	77	1	0, 5
	32	1	0, 5
	130	1	1
	127	1	0, 5
	93	1	0, 5
	440	1	1
	102	1	0, 5
Sample 3 up	86	2	0, 5
	42	1	1
	135	1	1
	83	1	1
	344	1	1, 75
	78	1	0, 5
	68	1	0, 5
	149	1	1, 5
	70	1	1, 5
	270	1	1
	250	1	1, 5
Sample 4 In	360	1	1, 5
	70	1	1
	95	1	0, 5
	600	1	1
Sample 4 up	246	1	1, 5
	140	1	1, 5
	163	1	1
Sample 5 in	297	1	1
	115	1	0, 5
	243	1	1
	445	1	1
	95	1	0, 5
	50	1	0, 5

Specimen ID	Total crack length	# cracks	Average crack width
Sample 5 up	100	1	1
	76	3	0, 5
	92	1	0, 5
	60	1	0, 5
	80	1	0, 5
	120	1	0, 5
	115	1	0, 5
Sample 6 in	205	1	1
	146	1	0, 5
	143	1	0, 5
	157	1	7
	102	1	0, 5
	300	1	1
	182	1	0, 5
	43	1	1
	87	1	2
	33	1	0, 5
Sample 6 up	125	1	1, 5
	90	1	1, 5
	81	1	1
	276	1	1
	100	1	0, 5
	105	1	0, 5
	285	1	1, 5
	182	1	1, 5
	157	1	1
	146	1	1, 5
	120	1	1
Mean	163, 25	1, 07	1, 02
Standard Deviation	37, 12	0, 056	0, 21

APPENDIX 13. RESULTS OF AGED WOOD MC MEASUREMENTS

Table 3. Aged wood MC measurements.

	Initial mass (g)	Lenght (mm)	Average width (mm)	Dry mass (g)	Lenght (mm)	Average width (mm)	MC (%)	Initial density (ρ)	Dry density (ρ)
Sample 3.1	37,2	170	27,4	34,0	164	26,3	9,2	398,2	395,5
Sample 3.2	36,9	170	27,4	34,0	163	26,4	8,6	396,5	394,9
Sample 3.3	36,9	170	27,3	34,0	163	26,2	8,5	397,5	397,9
Sample 3.4	36,5	168	27,1	33,5	161	26,6	8,8	400,1	391,5
Sample 3.5	38,3	170	27,3	35,4	165	26,8	8,3	413,2	400,7
Sample 3.6	37,0	170	27,6	34,0	163	26,7	8,5	394,2	390,4
Sample 3.7	36,9	170	27,3	34,0	163	26,4	8,4	396,5	394,9
Sample 4.1	42,8	187	26,8	39,6	182	26,4	8,1	427,8	412,3
Sample 4.2	43,3	187	27,1	39,9	182	26,5	8,7	427,4	413,1
Sample 4.3	43,6	188	27,1	40,2	184	26,6	8,5	427,4	410,5
Sample 4.4	43,3	188	27,0	39,8	185	26,5	8,8	426,7	407,2
Sample 4.5	43,6	188	27,0	40,3	183	26,3	8,2	429,2	417,8
Sample 4.6	43,2	189	27,3	40,9	185	26,5	5,6	419,0	418,2
Sample 4.7	43,4	188	27,2	40,1	183	26,3	8,2	424,5	416,7
Average:	43,3	187,9	27,1	40,1	183,4	26,4	8,0	426,0	413,7
Standard deviation:	0,27	0,69	0,18	0,43	1,18	0,11	1,08	3,39	4,10

APPENDIX 14. RESULTS OF BENDING STRENGTH OF RECENT SPRUCE, UPPER SIDE

Table 4. . Bending strength of recent wood, abradised side up.

	Modulus of elasticity (MOE) (N/mm2)	Maximum Compressive load (N)	Compressive extension at max, compressive load (mm)	Bending strength (N/mm2)
1	18178,21	1913,96	7,75	114,8376
2	13669,65	1537,64	8,29	92,2584
3	15762,95	1658,39	7,16	99,5034
4	18186,97	1868,82	7,68	112,1292
5	16397,42	1546,25	5,95	92,775
6	13561,38	1424,87	7,38	85,4922
Mean	16049	1658,32	7,37	99,4993
Standard deviation	2332	195,59	0,79	11,74

APPENDIX 15. RESULTS OF BENDING STRENGTH OF RECENT SPRUCE, LOWER SIDE

Table 5. Bending strength of recent spruce, rough side up.

	Modulus of elasticity (MOE) (N/mm2)	Max compressive load (N)	Compressive extension at max compressive load (mm)	Bending strength (N/mm2)
1	19156,79	1825,84	6,94	109,5504
2	17768,58	1901,29	6,87	114,0774
3	16828,38	1829,56	7,28	109,7736
4	17852,6	1960,05	8,48	117,603
5	16865,64	1817,08	7,79	109,0248
6	16653,51	1739,86	8,4	104,3916
Mean	17521	1845,61	7,63	110,7368
Standard deviation	950	75,95	0,71	4,56

APPENDIX 16. JANKA HARDNESS RESULTS

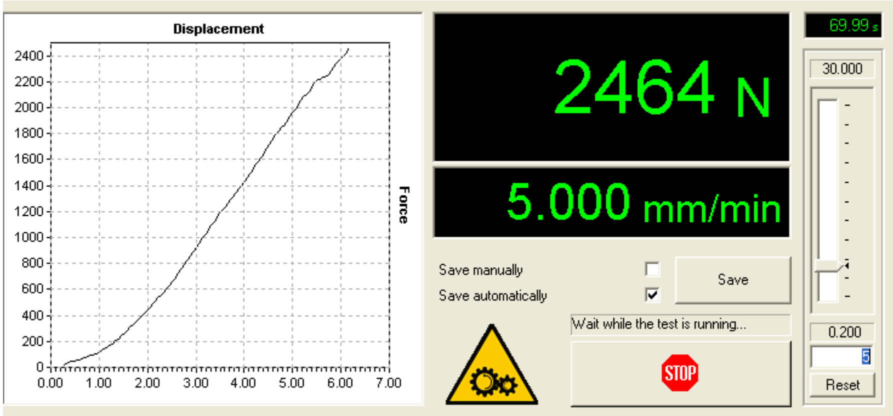

Figure 15. Test 1.1 A.

Figure 16. Test 1.2 A.

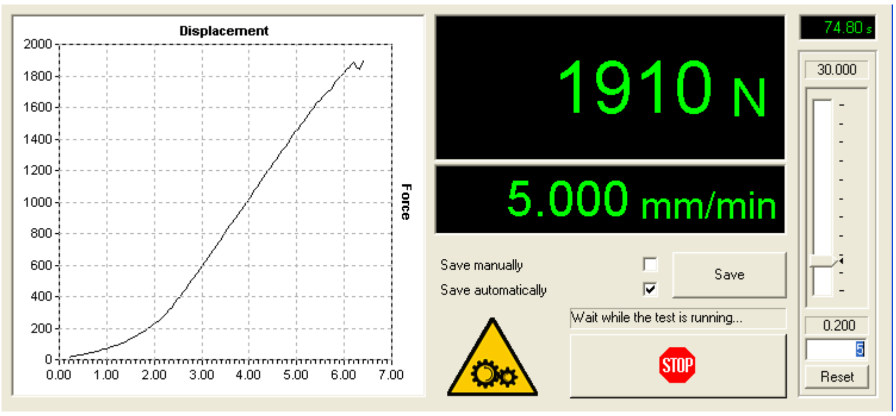

Figure 17. Test 1.3 P.

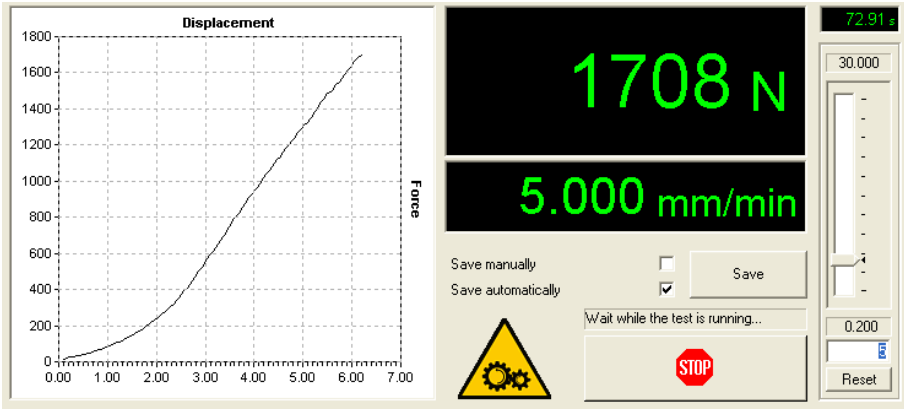

Figure 18. Test 1.4 P.

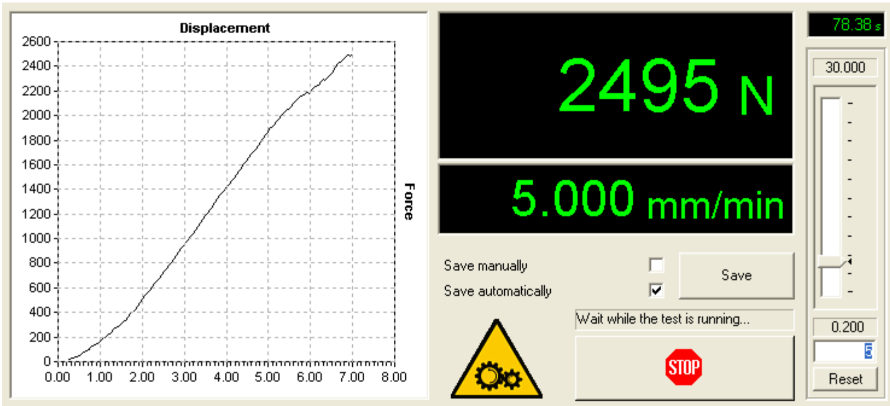

Figure 19. Test 2.1 A.

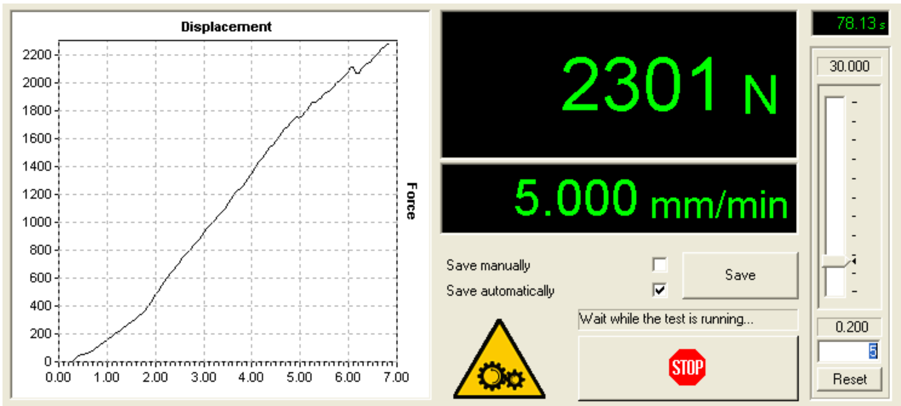

Figure 20. Test 2.2 A.

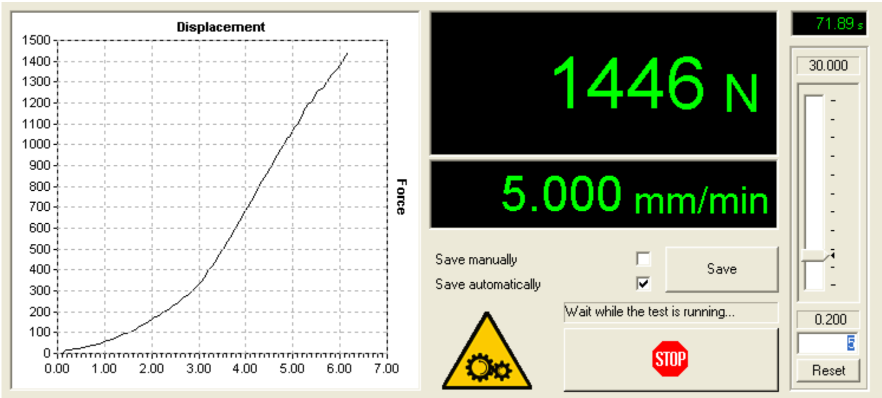

Figure 21. Test 2.3 P.

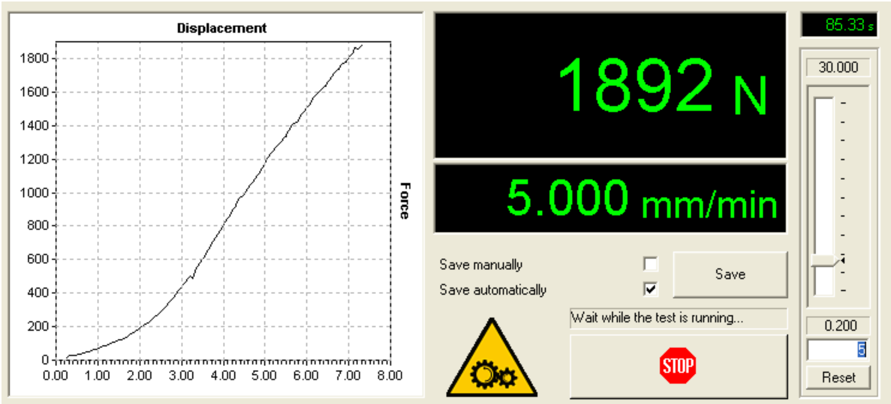

Figure 22. Test 2.4 P.

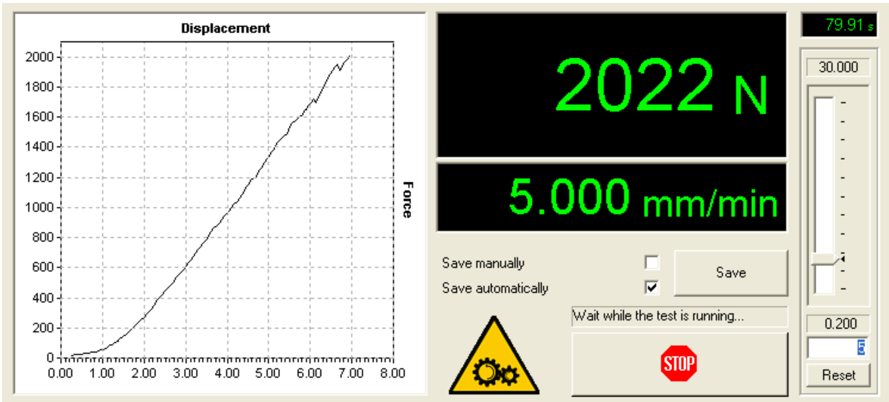

Figure 23. Test 3.1 A.

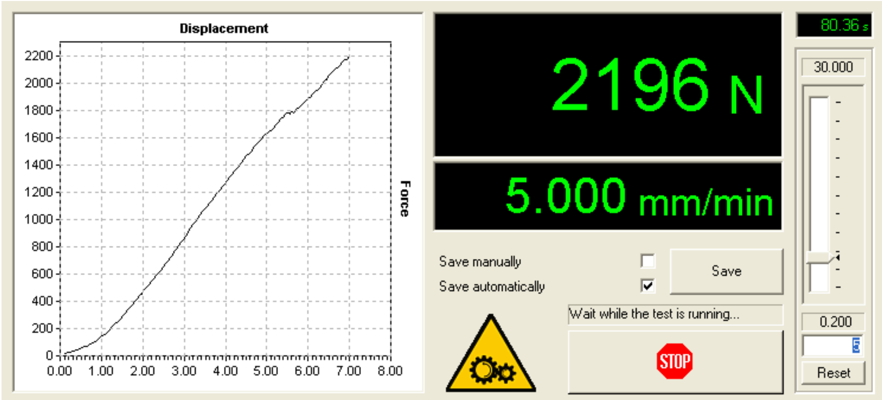

Figure 24. Test 3.2 A.

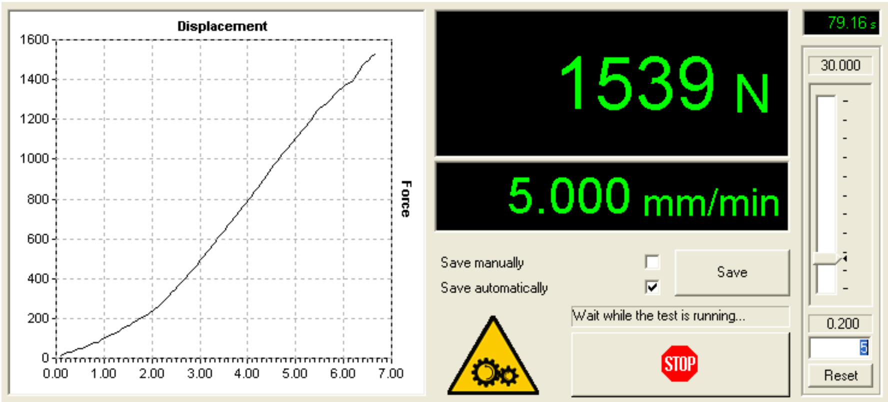

Figure 25. Test 3.3 P.

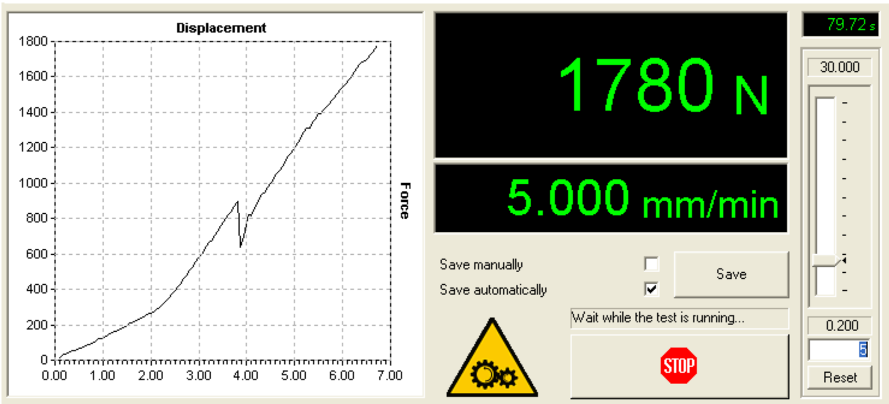

Figure 26. Test 3.4 P.