**MASTER OF SCIENCE BY RESEARCH**

# Charred Timber Cladding: Performance Investigation

White, Matthew

*Award date:*
2017

*Awarding institution:*
Coventry University

# Charred Timber Cladding

Performance Investigation

Masters by Research

Produced by

Matthew White

At

Coventry University

Faculty of Engineering, Environment and Computing

School of Energy, Construction and Environment

Director of Studies – Prof. Eshmaiel Ganjian

Supervisory Team – Paul Smith, Carl Mills, David Trujillo

2017

# ABSTRACT

Shou Sugi ban – or burnt timber cladding – is the Japanese method of charring the surface of timber to improve its durability characteristics and aesthetic appeal. In recent years, the popularity of charred timber cladding has grown steadily in both commercial and domestic construction projects. This rise in popularity has led to questions being asked as to the durability the treatment provides and longevity of the surface finish.

One of the advantages of using a charred finish over other types of surface finish is that the process doesn't involve any man made chemical compounds. Timber is burnt using either gas fired equipment or a tradition wood fuelled fire.

Until now there has been very little experimental research carried out in this, yet manufacturers of charred timber cladding make seemingly unsubstantiated performance claims. To this end, research has been carried out to ascertain the true properties of charred timber and to test manufacturer's claims against the tested performance.

This dissertation explores the findings of a 12 month research project. The testing includes accelerated UV weathering, freeze/thaw cycle testing, long term exposure testing and flame spread testing to ascertain the materials performance.

The primary aim of the research is to gather data that will be analysed with a view to test the claims made by users and manufacturers of charred timber cladding. The research will also aim to inform current teaching at Coventry University.

The main conclusions of the project are that the charring process has a beneficial effect on the durability of the surface finish of the timber, with improved performance in most areas of testing. The area that did not align with the current knowledge was the flame test result, where the charred sample performed significantly worse than the uncharred sample. The medium term exposure results show good durability, but long term durability has not been tested as part of this project.

Key words
Charred timber cladding, Shou sugi ban, accelerated weathering, material technology, material performance, technical performance, design performance.

# Contents

# Chapter 1 – Introduction

Historically, there is very little evidence of charred timber being used as a cladding material in the British Isles. More recently this has changed, as architects and designers look for more innovative materials and methods of constructing building envelopes. With the current drive for more sustainable construction methods and materials, designers are looking to use timber as well as timber products in the buildings they work on. To the authors knowledge there has been no laboratory based research carried out on charred timber cladding.

## 1.1 - Aims

Charred timber cladding has grown in popularity in recent years with a number of timber cladding manufacturers now producing charred timber products in one form or another.

Until now there has been very little experimental research carried out in this, yet manufacturers of charred timber cladding make seemingly unsubstantiated durability and fire performance claims. As a consequence this research project aims to perform limited experimental research into charred timber cladding durability and fire performance as well as providing recommendations to specifiers and installers of charred cladding products.

## 1.2 - Research objectives

The main objectives of this research project are as follows:-

- To review the literature surrounding charred timber cladding and traditional timber cladding products and how it is tested.
- To compare the manufacturing methods used to produce charred cladding products.
- To carry out appropriate comparative accelerated weathering tests to investigate the charred claddings resistance to the effects of the environment.
- To carry out comparative flame spread tests to assess the materials resistance to the spread of flame across its surface.
- To develop a set of recommendations that will help to inform building designer, specifiers and installers of charred cladding.

## 1.3 - Question of Research

The main questions that this project aims to answer is does charred timber meet the requirements of a building façade material and can manufacturers claims of performance be validated by testing.

## 1.4 - Limitations

There were some limitations associated with the types of tests that were carried out during the course of the project. The most prohibitive limitation was the cost of some of the test equipment that could have been used for the testing. Items such as a more powerful UV exposure lamp system were out of the projects allocated budget.

Another limitation of the testing was a lack of appropriate space for a long term exposure test site for the timber specimens. This could have provided some valuable in service comparative data to allow a larger sample size to be tested.

# Chapter 2 – Literature review

Timber has been used for building for the whole of human history. It is abundant, easy to work, renewable and aesthetically pleasing. With simple tools people have been able to use timber to create beautiful structures and facades that last for many years without huge amounts of maintenance.

In more recent years timber has enjoyed a resurgence in popularity among designers and end users of buildings - both large scale commercial and domestic. The main reasons for this increase in popularity are the recognition of timbers sustainable credentials and that timber as a building material can be both visually pleasing and tactile.

There is now widespread use of timber for cladding for domestic construction as well as for much larger and more prestigious buildings (TRADA, 2013). With careful selection of timber species and with good detailed design, timber can perform well as an external envelope material requiring little maintenance. The steps to achieve this are set in by TRADA (Timber Research and Development Association) in their technical documentation.

## 2.1 - Historical use of timber

In terms of use for external cladding, timber has been used for as long as people have been building structures for shelter. Timber external walls can be categorised into either load bearing or non-load bearing walls.

### 2.1.1 - Load bearing walls

One of the oldest examples of a structural timber wall in the United Kingdom is that of Greensted Church in Essex, UK. Built in approximately 1056, the walls are constructed of whole tree trucks that are split in half and arranged vertically to form the buildings structural wall as well as the weatherproof envelope. This type of construction method is known as a stave wall. Figure 1 Stave wall Greensted Church and Figure 2 Greensted Church show how this method is used in the building.

*Figure 1 Stave wall Greensted Church (Design, n.d.)*

In fact, it is thought that Greensted church is the oldest timber church in the world and is the only known building of its type in the UK. (Hewett, 1980)

*Figure 2 Greensted Church (Design, n.d.)*

### 2.1.2 - Non-load bearing walls

The most common form of historical timber wall in the UK is the non-load bearing type. This arrangement allows the use of a masonry or timber structural frame with a timber façade applied to the external face that provides protection from the elements.

A good example of cladding-on-frame construction in the historic context is Leigh Court Barn in Worcestershire, as pictured in Figure 3 Leigh Court Barn. The barn was built by the Pershore monastery to store and thresh grain and is the largest surviving cruck frame structure in the UK. (English Heritage, 2017). The cladding provides no structural support but protects the structural timber frame from the external environment. This particular barn is clad with Elm boards fixed horizontally to a structural frame.

*Figure 3 Leigh Court Barn*

## 2.2 - Contemporary use of timber

More recently timber has grown again in popularity as a material for building. Not only is timber light weight and easy to work with, it has good environmental credentials. As timber grows it absorbs carbon from the atmosphere and captures that carbon in the structure of the timber. This helps to reduce the amount of carbon in the atmosphere and may help reduce the effect that CO2 has on climate change.

Timber also uses a relatively low embodied energy in terms of production. Depending on how the timber is processed and dried, timber can have a very low carbon footprint.

### 2.2.1 - Modern cladding types

There are many issues that need to be considered before a specific cladding system is selected. Some of the main design criteria are listed below (TRADA, 2013).

- Visual or aesthetic appearance
- Durability requirements
- Building use
- End user requirements
- Cost

One of the biggest historical problems that has been associated with timber cladding is that of durability. Poorly designed fixing details and inappropriate timber species selection has made the problem more prevalent.

### 2.2.2 - Cladding orientation

Timber cladding can be installed in many different ways depending on the desired visual effect.

#### 2.2.2.1 - Vertical cladding

*Figure 4 Vertical cladding (Cromartie Ltd, 2010)*

Figure 4 Vertical cladding shows cladding fixed vertically in an arrangement that has 2 layers of timber. The first layer is fixed with a 50mm gap between each board then the second layer is fixed across that gap to cover the wall behind. This method allows for shrinkage and expansion due to varying moisture content.

This vertical arrangement also allows for any water to drain easily as there are no long horizontal surfaces to collect water.

### 2.2.2.2 - Horizontal cladding

Figure 5 Horizontal cladding show cladding fixed in a horizontal arrangement. This allows cladding to be fixed to vertical battens behind the walls surface. The advantage of a vertical batten is that there are no horizontal surfaces to allow water to accumulate behind the cladding. The disadvantage of this is that the boards themselves may allow water to collect on horizontal edges and joints unless the jointing system is very carefully designed.



*Figure 5 Horizontal cladding (Goodwins, 2018)*

## 2.2.2.3 - Diagonal cladding

Some materials have been removed from this thesis due to Third Party Copyright. Pages where material has been removed are clearly marked in the electronic version. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.

*Figure 6 Diagonal cladding (Woodtrend, 2018)*

The type of cladding shown in Figure 6 Diagonal cladding has boards arranged in a diagonal pattern. This method of installation overcomes some of the problems associated with horizontal cladding and prevents water from collecting on these horizontal surfaces. Arranging cladding diagonally can create some striking facades and allows designers to create very unique buildings.

The main issue with diagonally arranged cladding is that of the increased time and cost of installation. Because all of the cross cut ends of the boards are angled they are significantly more difficult to produce accurately. There is also more waste as the off cuts cannot always be used (TRADA, 2013).

## 2.2.3 - Shingles and Shakes

Some materials have been removed from this thesis due to Third Party Copyright. Pages where material has been removed are clearly marked in the electronic version. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.

*Figure 7 Shingles (Low impact, 2018)*

Shingles are essentially tiles made from wood. They are traditionally split or riven from solid timber and species such as cedar and chestnut are used in the UK. Shingles can produce a pleasing texture and allow for moisture induced movement easily. It is possible to fix shingles to almost any shaped building including tight curves. They can also be used as a roof covering allowing designers to match both wall and roof covering, as seen in Figure 7 Shingles

The main disadvantage is that shingles are very labour intensive to install as each shingle must be individually nailed.

## 2.2.4 - Panelised cladding

Various panelised cladding systems have appeared on the market in recent years. These utilize large manufactured timber panel products and apply them to the external face of a building. Some systems have exposed joints between panels and some cover joints with plastic or timber strips to conceal them.

The main advantage of panelised cladding is the speed of installation. Large areas of wall as seen in Figure 8 Plywood cladding can be covered quickly and buildings can be finished sooner. Other advantages are that sheet material is usually more uniform in surface finish, thickness and is more dimensionally stable than natural timber products.

Some materials have been removed from this thesis due to Third Party Copyright. Pages where material has been removed are clearly marked in the electronic version. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.

*Figure 8 Plywood cladding (Carter Holt Harvey Group Limited, 2018)*

The main disadvantage of using this type of material is that the sheets rely on adhesives that need to be sufficiently durable to prevent the breakdown of the sheets structure over time due to water ingress into the panel. This will necessitate the specification of an external quality plywood manufactured with appropriate adhesive such as a Class 3 to BS EN 314-2. It is also recommended by TRADA that the surface timber is of a suitably durable species. (TRADA, 2013).

## 2.3 - Solar shading and louvered panels

Many building owners and designers are looking for simple ways to improve the energy efficiency of their buildings. One problem that is often overlooked is the effects of solar gain. Buildings with large glazed areas will often overheat in summer months if the orientation of the glazing is predominantly in a southerly direction. This overheating requires either a passive or active solution to prevent the internal environment becoming unacceptable. Active solutions cure a problem once it has occurred whereas passive solutions will prevent the problem occurring in the first place.

Active solutions include mechanical ventilation or some form of cooling or air conditioning. These systems use a significant amount of energy and will increase the buildings running and maintenance costs.

Passive solutions include careful planning and positioning of glazing and the orientation of the building in relation to the suns path. In the case of existing buildings, it is not possible to reposition the building so as its orientation is more favourable. Another passive solution is the inclusion of some form of shading for the building that will limit the amount of light into the building and reduce the amount of solar gain.

The two main types of solar shading systems are *brise soliel* as seen in Figure 9 Brise Soliel and louvres as seen in Figure 10 louvered panels . The systems comprise of vertical or horizontal elements that are positioned to prevent the maximum amount of solar radiation from entering the building at the suns maximum elevation in the sky, still allowing an adequate level of light into the building for natural daylighting.

Louvers and *brise soliel* can be manufactured from many different materials. Many buildings employ louvers and *brise soliel* made from timber as a consequence the same precautions must apply to these elements as to all types of external timber cladding.



*Figure 9 Brise Soliel (Bleck and Bleck Architects, 2017)*



*Figure 10 louvered panels (Cernadas, 2018)*

## 2.4 - Timber selection

Timber selection is an important process in the designing of any cladding system. The selection of any particular timber will affect the appearance of the building and the longevity of the façade.

### 2.4.1 - Environmental considerations

Timber is widely considered to be one of the most environmentally sustainable building materials available, provided it is sourced responsibly, but there are other important selection criteria to consider. These include appropriate species selection, how and where the timber was produced and processed and how the timber is going to be installed.

Another important consideration is how the material will be dealt with after the building has reached the end of its useful life. This consideration may become a problem depending on how the timber was processed and treated at the time of the claddings manufacture. Some types of chemical treatment pose a risk to health or environment, although this is a risk that is not yet fully understood. (Enviroment Agency, 2014)

### 2.4.2 - Durability

The dictionary definition of durability states:-

"Durability - the fact of something continuing to be used without getting damaged" (Cambridge University Press, 2018)

Timber is classified by durability testing as set out in BS EN 252 – Field test method for determining the relative protective effectiveness of wood preservative in ground contact.

The tests set out in BS EN 252 involve selecting an appropriate number of specimens of the timber to be tested and inserting the specimens into the ground and checking the condition of the timber regularly. Along with the specimens of the timber to be tested, control specimens of sap wood from scots pine are used as a control for the test. The specimens are tested for the prescribed period and given a durability rating from 0 to 4. Table 1 shows how the durability rating is calculated.

*Table 1 BS EN 252 wood classification rating system*

| Rating | Classification | Definition |
|---|---|---|
| 0 | No attack | No change perceptible by the means at the disposal of the inspector in the field. If only a change of colour is observed, It shall be rated 0. |
| 1 | Slight attack | 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. |
| 2 | Moderate attack | Clear changes: softening of the wood to a depth of at least 2 mm over a surface area covering at least 10 cm2, or softening to a depth of at least 5 mm over a surface area less than 1 cm2. |
| 3 | Severe attack | Severe changes: marked decay in the wood to a depth of at least 3 mm over a wider surface (covering at least 25 cm2), or softening to a depth of at least 10 mm over a more limited surface area. |
| 4 | Failure | Impact failure of the stake in the field. |

The required durability class of cladding depends on the desired service life of the cladding. Depending upon how the timber is treated or if there is a surface finish applied will affect the durability of the façade. The facades orientation and exposure will have an effect on the surface finish and may require more frequent maintenance or a reduction of service life than would have been anticipated.

## 2.5 – Origins of charred timber

As a method of finishing timber cladding, charring has been used for many hundreds, if not thousands of years. It has not been possible to find a firm date (or even an approximate date) of this methods first use.

*Figure 11 Charred cladding in Japan*

Japan has a great many building that employ charred timber as a cladding material but the author was unable to identify any written justification as to why this technique was adopted. Other articles, also unsubstantiated, claim some areas of Europe also used charred timber as a cladding material, especially in Switzerland (although no dates or details are given). It seems that the history of this technique has mostly been lost and forgotten. All that remains are some basic instructions of the original methods of producing charred timber, mostly in practical demonstrations posted in videos online. These films have been a useful resource, as they have provided a good starting point for the production of some cladding for testing purposes. Figure 11 shows a typical use of charred timber in Japan.

It is the author's opinion that the concept of charred cladding was initially conceived as a preservative technique but the aesthetic appeal may have also been a factor in the methods adoption. The reasons why charred timber is used for cladding and no other elements of the building is also unclear but probably for the perceived preservation properties of the char.

Figure 12 is taken from a video on YouTube that is fairly brief but shows the process of burning the face of the boards using the Japanese method. The video was accessed in 2017 and can be viewed at https://www.youtube.com/watch?v=yMDy745Mu2k



*Figure 12 Making charred cladding (Garden, 2017)*

Recently, this method of cladding treatment has had a modest revival among some innovative architects and house builders. Japanese architect, Terunobu Fujimori has produced various buildings in the last few years using this type of cladding. (Dezeen, n.d.)

The picture to the right shows one of Fujimori's Japanese tea houses. Although a modern design, this building features traditional Japanese style charred cladding. Fujimori has designed many tea houses across Japan and charred timber is common theme throughout his work. (Gillin, 2009)



*Figure 13 Japanese tea house (Gillin, 2009)*

## 2.5.1 - Case study - Parkside kiosk

Perhaps one of the most prominent buildings that employ charred timber as a cladding material is DSDHA (Deborah Saunt David Hills Architecture) Architects' Parkside Kiosk in central London.
Built in 2007, the building occupies a prominent location on a small site between City Hall and Tower Bridge on the Southbank. The scheme was part of the wider South bank redevelopment project and originally included a second kiosk, although this has been demolished to make way for a new apartment/office complex.
The building is overshadowed by the adjacent City Hall building and the More London office complex. With the development to the South the building feels dwarfed by its neighbours.

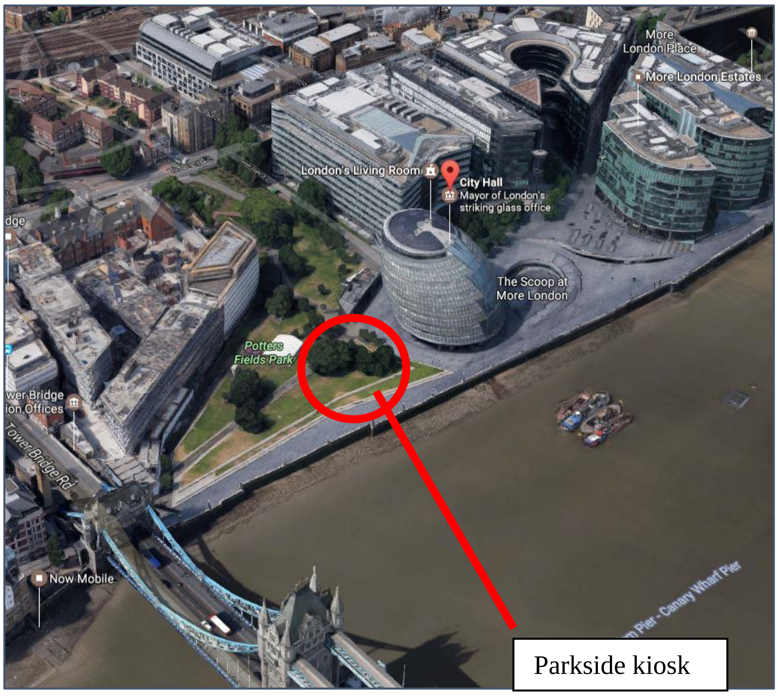



*Figure 14 Parkside Kiosk location (Google , 2017)*

The Parkside kiosk was primarily built as a storage building for the mobile access platform that is used to clean the windows on City Hall. The architects have incorporated a public toilet, ATM and coffee shop into the design to maximise the site's potential. (DSDHA, 2018)

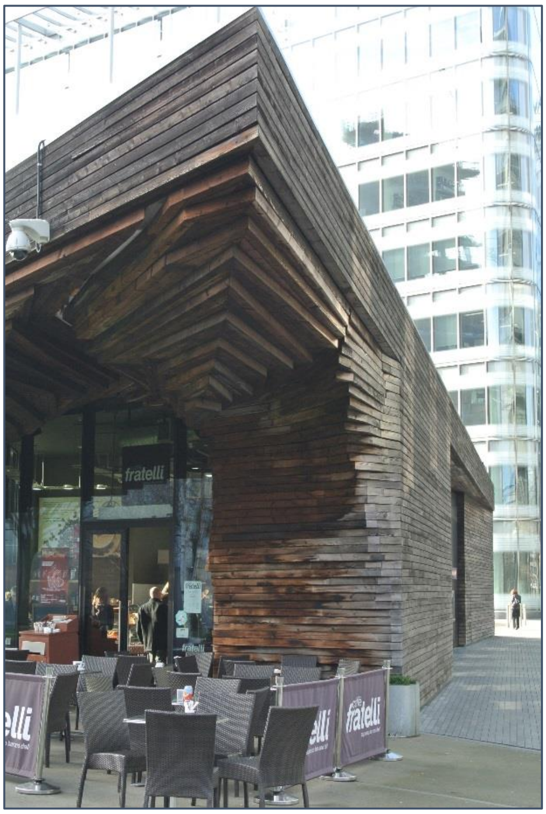



*Figure 15 Parkside kiosk front*

The building features charred Siberian larch rain screen cladding, manufactured in the UK by Martin Childs Limited. The geometry of the façade is complex in arrangement, with a large overhang forming a canopy to offer some protection to coffee shop patrons. The geometric design increases in size from bottom to top, creating an imposing effect to the seating area.

The cladding is well designed and detailed and acts as a rain screen cladding system that allows some of the driven rain and moisture to pass through and drain from the bottom of the façade. From available technical drawings the façade appears to be designed in line with TRADA's good design practice. (TRADA, 2013) The cladding strips are not interlocking and have a small gap between them to allow water to drain and dry out.



*Figure 16 Parkside kiosk detail (DSDHA, 2018)*

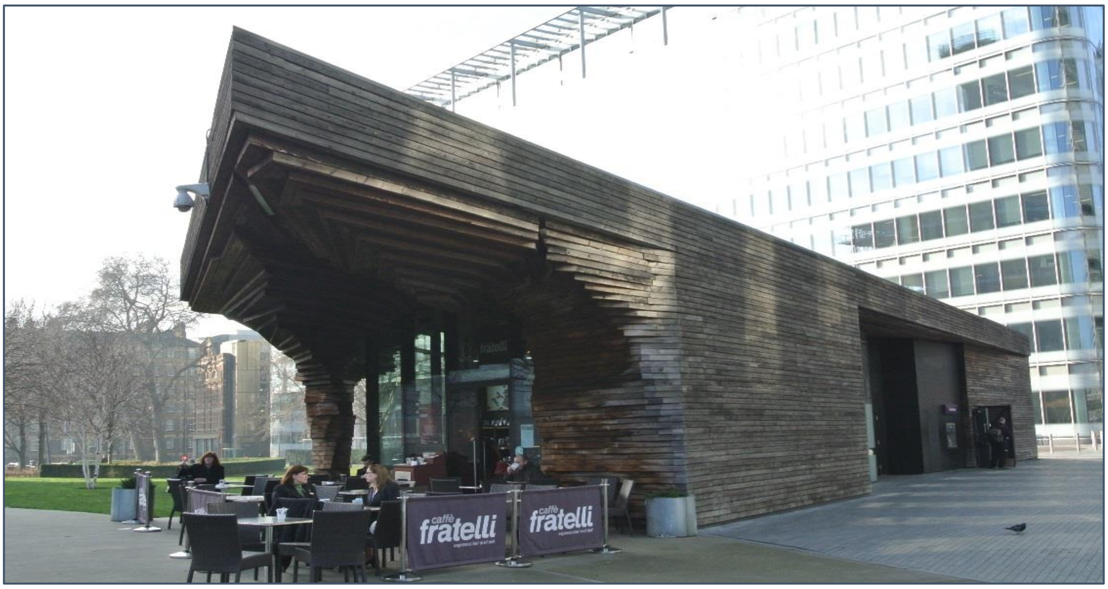



*Figure 17 Parkside Kiosk*

*Figure 18 Parkside Kiosk 2014*

Some materials have been removed from this thesis due to Third Party Copyright. Pages where material has been removed are clearly marked in the electronic version. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.

*Figure 19 Parkside Kiosk 2007 (DSDHA, 2018)*

Figure 19 Parkside Kiosk 2007 Figure 18 Parkside Kiosk 2014show a comparison of the façade when fitted in 2007 and the façade as photographed in January 2014. Over this period it can clearly be seen that the charred surface has faded and the timber has turned a sliver/grey colour. The silvering of the timber would be expected and poses no detrimental effect to the timber.

The pictures show a fairly good comparison of this type of cladding that has been exposed for a significant period, and it can be seen that the timber has weathered to the expected silver colour.

### 2.5.2 - Previous work on performance

During the course of this research project there has been very little previous research discovered that has been carried out to explore the performance of the cladding system. Some studies have been carried out by the Timber Research and Development Association (TRADA). In a bulletin published in 2016 by TRADA, various issues associated with the use of charred timber although the conclusions drawn in this document are not informed by any physical testing of charred timber (TRADA, 2013).

Some research and some testing has been carried out by Ivor Davies from Edinburgh Napier University. This work went towards the production of a paper and draft set of standards around timber cladding. As with the TRADA study, this paper has no evidence of testing on charred timber cladding. (Davies, 2015)

## 2.6 – Methods of manufacture - Introduction

Various methods of manufacturing charred timber cladding are described in varying levels of detail. By trialling the different methods described the author was able to make a judgement on the effectiveness of the methods tested.

These are two methods that are used to make charred timber cladding:-

- Japanese traditional method
- Western/Modern method

### 2.6.1- Japanese method

This technique is the ancient Japanese method of producing charred cladding. The details of this method are not fully documented but the process used for this project was developed from a video made by the aforementioned Japanese architect Terunobu Fujimori. (PAPER Magazine, 2018) The method involves tying 3 cladding boards together with wire to form a triangular tube. A small fire is lit either directly on the ground or in a small brazier and the boards are placed over the fire. The triangular tube acts as a chimney and the fire is drawn up the tube, charring the inside.
After a short time the tube is reversed and the fire is allowed to char the other end to ensure the entire internal surface is sufficiently charred.
This method has been recreated for the purposes of this project. The following steps describe the process used.

**Step 1** – Three boards are selected and the boards are wired together to form a triangular "chimney" as shown in Figure 20 Boards prepared for

*Figure 20 Boards prepared for charring*

**Step 2** – Figure 21 shows how the small brazier is prepared and a small fire is set inside. (A triangular brazier is used to allow the triangular chimney to sit easily on top)

*Figure 21 Brazier*

*Figure 22 Brazier top view*

**Step 3** – The fire is lit using waste timber and enough fuel is added to the brazier so as to achieve an appropriate amount of heat to ignite the inside of the timber chimney. As the method is not an exacting science there are no guidelines as to an appropriate amount of fuel. For this test approximately 10 25x25x200mm pieces of timber were used with a small amount of kindling to aid the initial ignition.

*Figure 23 Boards on brazier*

**Step 4** – The timber boards were placed over the fire and the flame is drawn up through the tube. The effect of this is 2 fold. Firstly, the chimney effect intensifies the fire, making it burn more quickly which speeds up the process. Secondly, flame and heat is distributed more evenly throughout the tube, making the charring more even. The boards are reversed and the fire allowed to char the tube from the other end. This ensures the entire internal surface is charred. This can be seen in figure 23 and figure 24.

*Figure 24 Fire lit in brazier*

*Figure 25 Boards after charring*

**Step 5** – Once the boards have reached the required level of charring, they are removed from the brazier and the wires holding them together are cut as shown in figure 25. At this point the flame on the boards is already extinguished, but the boards require cooling. This was done by spraying with a hosepipe but this could also be done by pouring buckets of water over the timber or submersing the boards in a tank of water. The required level of charring is completely subjective and varies on the desired surface finish.

*Figure 26 Surface of charred board*

Figures 26 and 27 are of the finished cladding. The charring has penetrated the surface relatively deeply compared to the western method of charring.

*Figure 27 Charred surface comparison*

Figure 27 shows a board with a 10 pence coin for scale. The cedar boards have resin pockets that heat up and pop when they are burnt causing part of the surface of the timber to become friable. For reference, a 10 pence coin has a diameter of 24.5mm.

*Figure 28 Charred surface coverage*

Figure 28 shows how some areas of the boards have not charred. As the flame is only on the inside of the chimney the edges that overlap slightly tend to not get charred at the same rate as the rest of the board leading to this unevenness.

## 2.6.1.1 - Japanese Method – Conclusions

The major advantage of this method is that it is very simple – low tech equipment and no expensive fuel and by using waste fuel it is making use of a resource that would otherwise be discarded.  The setup shown in this test was made form scrap material that was all waste and the fuel for the fire was from old pallets. Another advantage is that this method is relatively quick. Three boards are charred at the same time and it would be possible to set up several braziers to increase production rates.

The main disadvantage is the lack of control. It is difficult to see exactly what is happening inside the chimney, making it almost impossible to know when the cladding has reached the desired finish. It may be possible to use temperature monitoring equipment to measure the temperature of the boards on the outside of the chimney and by recording the level of char achieved against the temperature at which that charring was produced a system of control could be implemented. This was not implemented in this experiment.

There may also be an issue with water being trapped in the fissures left by the charring process. They are deep and will most certainly hold water. This would, over time, lead to decay.
Another problem can be seen in the last picture – uneven charring. This is not really a major issue as the uncharred areas could be charred after over the brazier but this is an extra process.

## 2.6.2 - Western/Modern Method

The modern method of production is now the most common way to make charred timber. (Charred Timber Ltd, 2017)
The timber is charred using a hand held gas blow torch or, for larger scale production, on a mechanized conveyor system where the timber is loaded onto a track which passes the timber under a row of gas burners that char the surface.

Boards are arranged on an appropriate surface and scorched with a propane gas blow torch.
To speed up the process the boards here are arranged in an L shape so as to contain the flame and char two boards at the same time as shown in figure 29.

*Figure 29 Charring with propane torch*

### 2.6.2.1 - Western/Modern method - Conclusions

The main advantage of this method of production is the level of control over the finish. As the surface being treated is visible throughout the charring process, a more consistent finish can be achieved across the whole board.
The biggest disadvantage is that the equipment required to char the cladding is relatively expensive compared to the equipment used for the Japanese method. The gas used to fuel the torch is also expensive and relies on fossil fuels, making the process more carbon intensive.

Figure 30 shows the finished cladding. This is a specimen made for testing in both the environmental test chamber and long term external weathering testing. It shows how even the charring is compared to the traditional method of production.

*Figure 30 Specimens after charring*

# Chapter 3 – Testing methodology – Introduction

As set out in the research objectives it is the aim of this study to ascertain the validity of manufacturers claims of the performance of charred timber cladding.

The areas of interest in terms of performance of charred timber cladding that need to be considered are as follows:-

- Resistance to UV fading
- Freeze/thaw cyclic behaviour
- Flame resisting properties
- Exposure testing

These three areas were chosen as they are either the important qualities that any external cladding must have a reasonable level of resistance to, or they are claims that are made by various manufactures of charred cladding that are without thorough testing to substantiate this claim. Manufacturers such as Exterior Solutions claim that the process protects timber from UV degradation and improves fire resistance (Exterior Solutions, 2018)

The case study of the Parkside Kiosk shows how a timber façade can be effected by environmental conditions. The three areas of testing chosen will aim to replicate some of the conditions timber facades are subjected to. The areas chosen also align well with Coventry Universities' lab testing capabilities.

## 3.1 – Resistance to UV fading

All buildings are exposed to UV radiation during their life. The UV radiation emitted by the sun ranges from 1,412 $Wm^{-2}$ in January to 1,321$Wm^{-2}$ in July in the UK (Beckers, 2013). This must be taken into account when designing a surface finish as a material with poor resistance to UV light will reduce the life of the envelope and increase the need for regular maintenance. This is usually undesirable for a building owner as it will increase operational costs and devalue the building as a whole.

For timber this will not only degrade the visual appearance but will also cause mechanical failure of the timber structure. (Bingnan Yuan, 2019)

### 3.1.1 – UV light

To go into the great detail as to the radiometric power of light in the UV spectrum is beyond the scope of this work but a basic understanding of how UV light effects materials is important to understand the significance of this test. The UV light that reaches the earth's surface is only 10% of that emitted by the sun as the majority is filtered out by the earth's atmosphere. In addition to these three categories above there are the Vacuum UV and Deep UV. It is the light that is in the UVB wavelength range that causes the most damage to not only materials that are installed on the outside of buildings but also to human tissues. (Beckers, 2013)

UV light can be categorized by wavelength into three general categories

- UVA – 315-400nm
- UVB – 280-315nm
- UVC – 200-280nm

The UV light that falls onto building facades causing fading to paints and finishes that require continual maintenance and repair.

## 3.1.2 – UV light exposure test

It was decided to expose samples of charred timber and uncharred timber to a UV light source to simulate prolonged exposure of an external cladding system.

The test procedure decided on was broadly in line with BS EN ISO 4892-3-2016 Plastics – Method of exposure to laboratory light sources. This particular standard was chosen as it was designed to prematurely age plastics by exposure to UV light and, in certain circumstances, the use of water spray or condensation producing apparatus. BS EN ISO 4892-3-2016 can be seen in appendix 3.

The main differences to the test procedures in BS EN ISO 4892-3-2016 and the chosen test procedure for this project are as follows:-

- Test equipment – the standard refers to manufacturer's equipment. This type of testing equipment was unavailable due to the high purchasing cost and rental cost. The tests carried out used a simple UV florescent lamp with a custom built enclosure.
- Spray and condensation testing – The standard also refers to using water spray generating apparatus to spray the samples under test on a cyclical basis. The apparatus that was used for this project did not have the capability to produce water spray. It was decided that spray cycling would be omitted and Method B from Table 4 of the standard would be used as this method has no use of spray equipment.
- Test sample size and mounting – As the standard is designed for guidance on testing polymer samples there is no advice or guidance given as to the size of samples made of other materials. Therefore it was decided to use a convenient size as described in the test procedure.

## 3.1.3 Test procedure

The test was carried out using the following apparatus that was constructed in the lab at Coventry University. Figure 31 shows an exploded image of the apparatus.

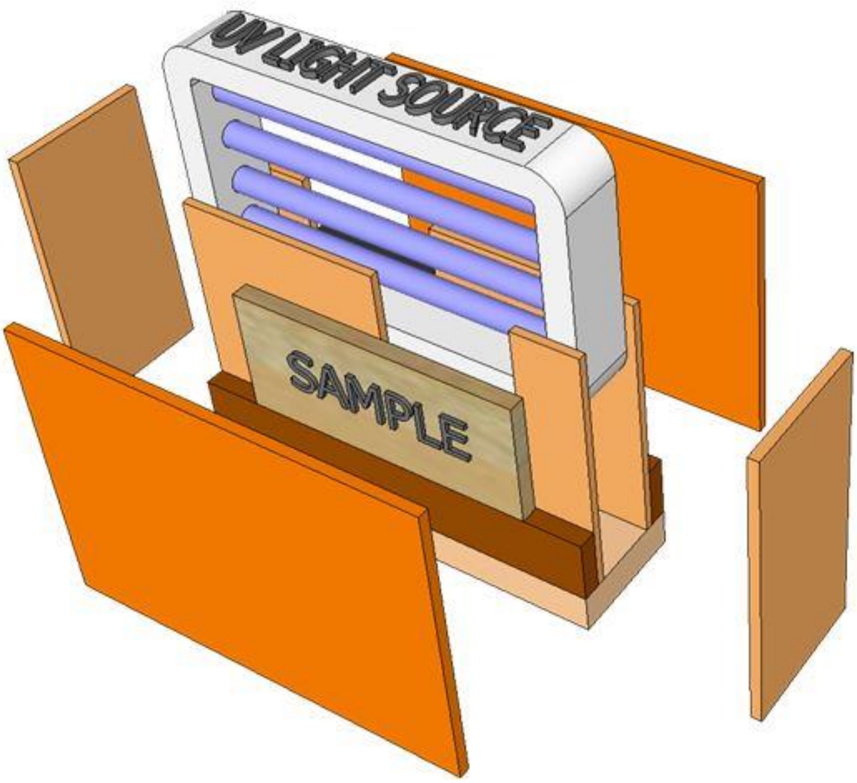



Figure 31 UV exposure test equipment

The light fitting chosen for this test consists of a simple twin tube ultra-violate florescent fitting. This type of lamp fitting was chosen because it was readily available and could be easily modified to enable the mounting of the test specimens in front of it thus exposing them to UV light.

The enclosure that is built around the lamp is constructed of plywood and MDF (medium density fibreboard). This not only encloses the ultra-violate light that is emitted that could be harmful to others in the lab, but also acts as the mounting structure that supports the sample. One half of the sample is exposed to the light while the other is shielded completely to allow for a direct comparison of the effect of the ultra-violate light has on the surface. The specimen was mounted at a distance of 25mm from the lamp surface.

The apparatus allows a specimen to be mounted on either side of the light source so as to test two specimen simultaneously. To allow a comparison of both the charred and uncharred timber, one of each type of timber specimen was tested at the same time. This would allow for any variation in the ultra-violate light output from the lamps to be mitigated as both specimens would be subjected to the same amount of variation. The average power output of the ultra-violate lamp was measured using a UV light meter at various positions within the apparatus. The lamps tend to take approximately 5 minutes to reach the maximum output of 0.69MW/cm2. However this output was not maintained throughout the test as when the lamps are left on for a prolonged test period the power level dropped to 0.03MW/cm2.

This value is significantly lower than the output of commercially available lamps that are specifically designed for accelerated UV testing. This type of equipment presents difficulties relating to the safety of the testing. The high levels of UV radiation that they emit need to be controlled using specialist screens to protect user’s eyes and skin and excessive heat is emitted with temperatures reaching 300°C. This type of equipment is necessary in a commercial testing laboratory as the time constraints are much greater than those of an academic project. The high power outputs allow samples to be exposed to high levels of UV light in a very short time period.

Therefore it was decided that given the relatively low output of the available apparatus, the specimen exposure period was extended to a period of 1500 hours. The testing was carried out in the laboratory of Coventry Universities Sir John Laing building from 20/12/2016 to 20/02/2017. This period was convenient as the labs were generally quiet over the Christmas and New Year period and the testing could be carried out without the risk of effecting other lab activities. No formal risk assessment was carried out on this test as the lights power output is relatively low. The test apparatus were monitored every week throughout the test period.

The timber specification for this test is as follows:-

- Length 300mm
- Width 150mm
- Thickness 20mm
- Timber species Siberian larch

As this test was carried out over a very long period, only 2 specimens were tested.

## 3.1.4 UV Test sample comparison

After the test period specified above the specimens were removed from the apparatus and the two specimens compared against each other for signs of fading due to UV light exposure. Due to the low power of the lamp used and the time constraints of the test period, only one board of each type was tested.

Figure 32 shows the two specimens immediately after removal from the test apparatus.

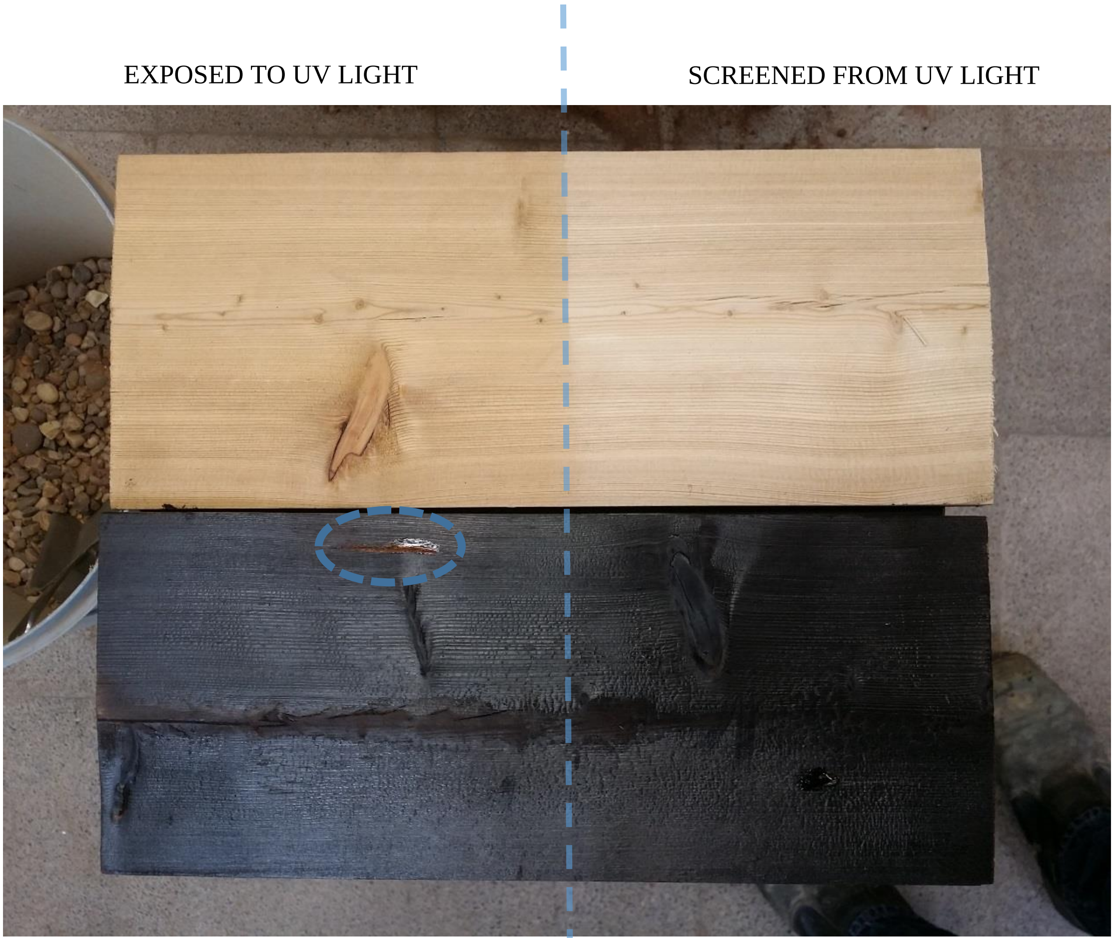



*Figure 32 UV exposure comparison*

a significant level of change in surface colour whereas the charred specimen shows no detectable change in surface colour. The only notable change that was observed in the charred timber sample was that there was a small amount of resin that had leached from a small resin pocket on the timber surface (this is circled on the image above).

## 3.2 Resistance to flame testing

During the research carried out for this project, it has been noticed that more than one manufacturer claims that charring the timber improves its resistance to fire. One manufacturer, QTD group, claim *“Combined with the charring/burning process the boards become highly fire resistant.”* (QTG group, 2017) While another manufacturer, Charred Timber Ltd, claims *“Charring hardens and protects the wood at a cellular level”* (Charred Timber Ltd, 2017). On further investigation it appears that no scientific research has been carried out to substantiate these claims.

### 3.2.1 Test procedure

Comparative testing between charred and un-charred cladding would be carried out in line with BS 8414-1:2015 Fire performance of external cladding systems. This standard has been developed to enable manufacturers of timber cladding to test their products in an approved way to ensure that they react in a certain way when they are subjected to fire.

There were some changes made to the recommended test procedures that are outlined in the standard. The standard recommends having test specimens of 6m in height. This was not practical or possible for the test that was carried out for this project due to a lack of a suitable place to erect the test apparatus to a height of 6m. The other major change from the test standard was that the thermistors were emitted as the type required for this high temperature type of testing were not available.

It was decided that a 2m high panel of cladding was sufficient to allow a fair comparison of the charred and un-charred samples. Figure 33 shows the un-charred cladding panel before it was subjected to the test.

The arrangement of the board for the spread of flame test was that of the hit-and-miss style of cladding. The arrangement and construction method can be seen in figure 35. In simple terms this style of cladding involves a board being installed onto the substrate vertically with a gap between the next board of approximately half the width of the board. The gap is then covered with the next layer of cladding boards.

This method allows for expansion and contraction of the timber as the joint between the boards has a large overlap to accommodate this movement without causing gaps in the façade.

The specification for this test was developed from the British standard and through development with other research colleagues at Coventry University. The crib fir arrangement was chosen for its simplicity and to enable repeatability for other tests during this research project and by others if required.

*Figure 33 Flame spread test setup*

Figure 33 shows how the panel was set up. The cladding is fixed to a softwood frame in a “hit and miss” pattern. This type of cladding arrangement has become popular over recent years as the boards don’t need any special edge mouldings and as the boards are installed vertically they have a good geometric resistance to trapping water, increasing their durability. The boards have a graduated scale in increments of 0.5m marked on the side of the sample to help with the analysis during and after the testing is completed. The charred cladding panel was set up in exactly the same way.

Each test was recorded in its entirety with video as described in the test standards. In addition to this, the test was also recorded with the use of a thermal imaging camera and a still camera. This enabled the test results to be analysed in different ways – the visual spread of flame across the surface and the progression of heat across the test panel. This was deemed an appropriate substitute for the thermistors that were omitted from the test that form part of the standard test for this type of cladding.

The source of the fire is a small crib type fire that was constructed of square kiln dried pine. The timber for the fire had the flowing specifications:-

- Size - 30mmX30mmX150mm Siberian Larch
- Quantity – 17 off
- Arrangement – Timber is stacked in 6 layers. The bottom layer has 2 pieces of timber the other 5 layers have 3 pieces laid perpendicular to the previous layer. The gap between the piece s in each layer is 25mm.

The pieces of timber for the fire were all cut from one board that was kiln dried and then cut into the required size for the fire. The pieces were then left for 28 days to normalize the pieces moisture content. The same number of pieces were used for the fire in both tests. Figure 34 shows the crib arrangement immediately before starting the test.

*Figure 34 Fire crib*

The purpose of this crib type fire arrangement is to mimic a situation where a fire starts at the base of a wall that is clad with a combustible material. The crib arrangement allows the fire to spread rapidly and easily. The resulting flames then spread from the crib fire up to the cladding.

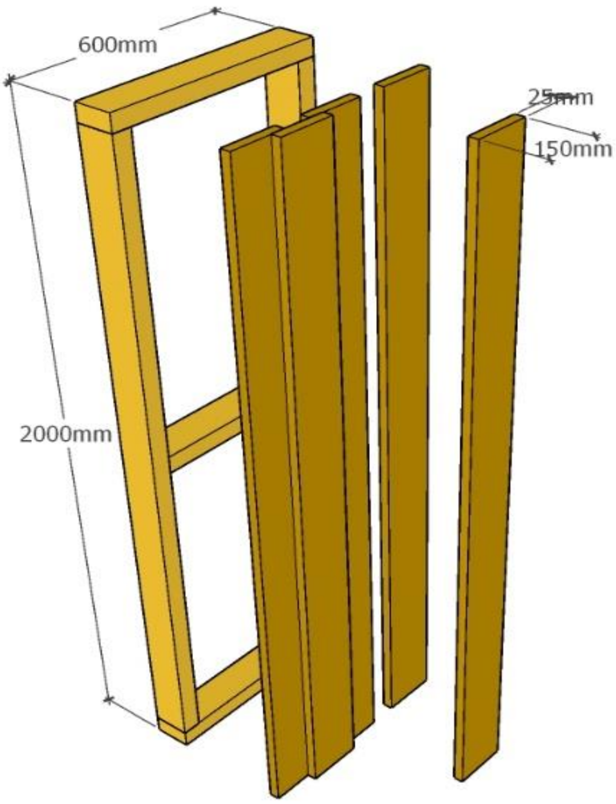



*Figure 35 Exploded detail of panel*

Figure 35 shows the test panel in an exploded view. The image shows the arrangement of the hit and miss style of vertical cladding chosen for this particular test. Figure 36 shows the crib dimensions and general arrangement used for the test

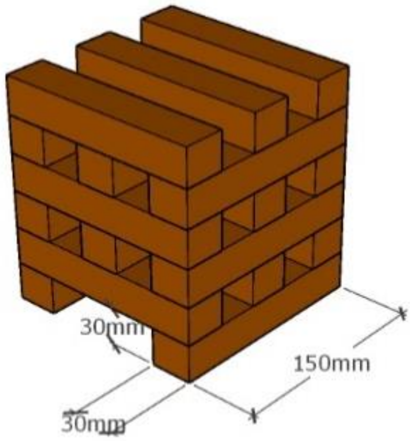



*Figure 36 Crib timber arrangement*

### 3.2.2 Thermal imaging results

During the testing a thermal imaging camera was used to measure the progression of the heat spread over the panel. This enabled some more accurate measurements to be made in lieu of thermocouples. The equipment used was a Testo t870-2 thermal imaging camera. The camera was set to auto adjust to different temperature ranges, allowing the difference in temperature to be displayed in relation to the surrounding temperatures.

The following images show the infrared image alongside the standard camera image taken from the same angle with the camera. Figures 37 to 39 show the uncharred cladding test.

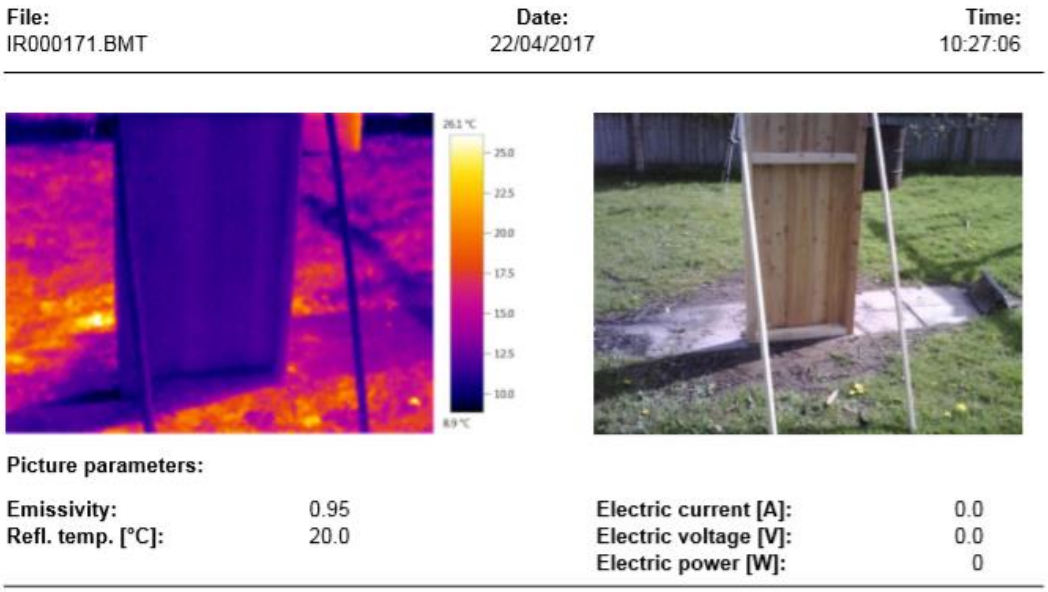
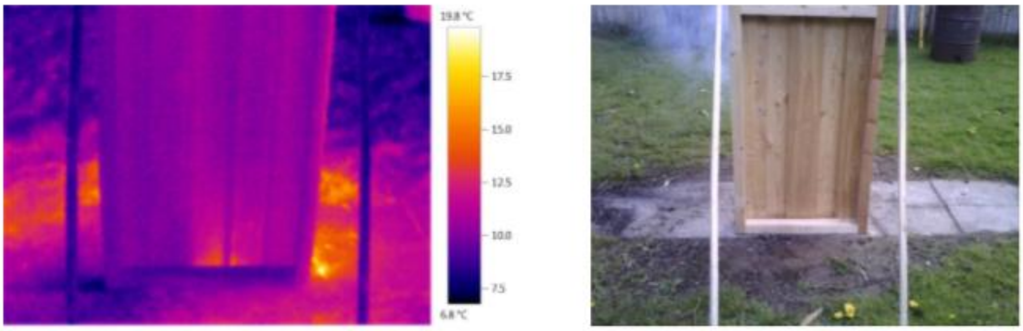



*Figure 37 Thermal image comparison*

Figure 37 shows the surface temperature of the rear of the test panel immediately before the start of the test. The surface temperature of the boards is approximately 11ºC.

*Figure 38 Thermal image comparison*

| File: | Date: | Time: |
|---|---|---|
| IR000178.BMT | 22/04/2017 | 10:34:06 |

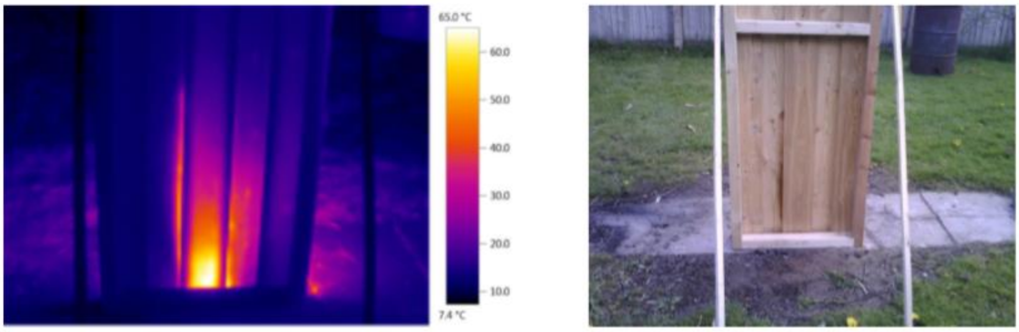



**Picture parameters:**

| | | | |
|---|---|---|---|
| **Emissivity:** | 0.95 | **Electric current [A]:** | 0.0 |
| **Refl. temp. [°C]:** | 20.0 | **Electric voltage [V]:** | 0.0 |
| | | **Electric power [W]:** | 0 |

Figure 38 shows the rear of the panel 7 minutes into the test. The standard image shows no signs of any damage due to the fire. The surface temperature has risen to approximately 13.5ºC. This is not a significant rise in temperature as it appears that the timber is having a significant insulating effect.

| File: | Date: | Time: |
|---|---|---|
| IR000191.BMT | 22/04/2017 | 10:41:16 |



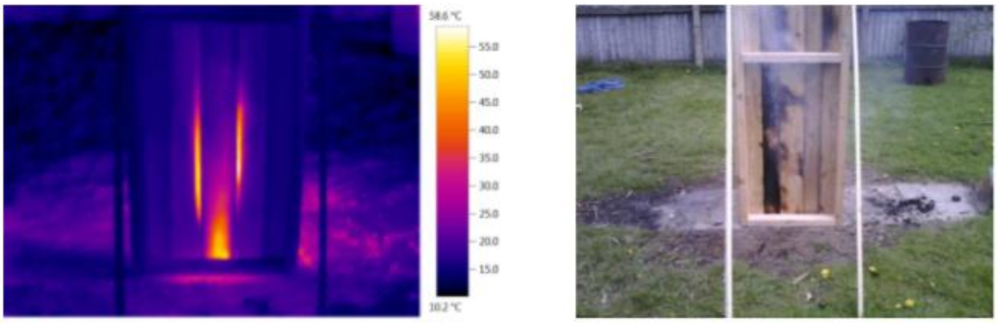

**Picture parameters:**

| | | | |
|---|---|---|---|
| **Emissivity:** | 0.95 | **Electric current [A]:** | 0.0 |
| **Refl. temp. [°C]:** | 20.0 | **Electric voltage [V]:** | 0.0 |
| | | **Electric power [W]:** | 0 |

*Figure 39 Thermal image comparison*

In figure 39 it can be seen that the flames have started to penetrate the boards at the overlapping joints. This occurred 14 minutes into the test. The temperature at the surface of the timber directly behind the crib fire reached approximately 65ºC at the time the fire breached the timber cladding boards.
Figures 40 and 41 show the thermal imaging test comparison for the charred cladding panel.

| File: | Date: | Time: |
|---|---|---|
| IR000233.BMT | 22/04/2017 | 12:08:24 |



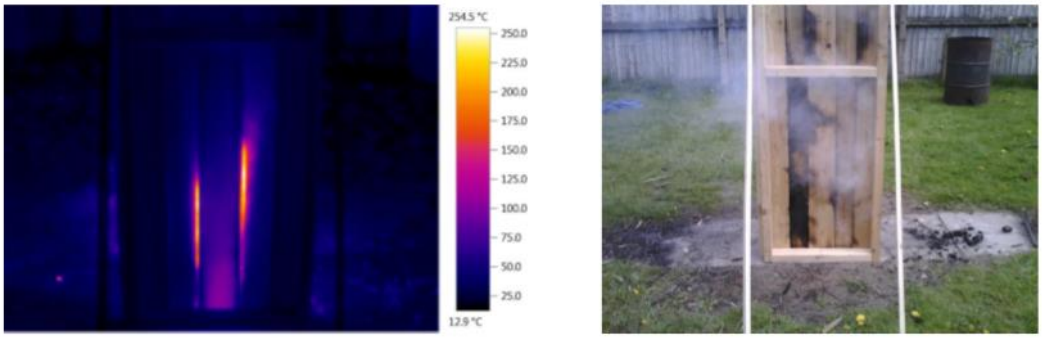

**Picture parameters:**

| | | | |
|---|---|---|---|
| **Emissivity:** | 0.95 | **Electric current [A]:** | 0.0 |
| **Refl. temp. [°C]:** | 20.0 | **Electric voltage [V]:** | 0.0 |
| | | **Electric power [W]:** | 0 |

*Figure 40 Thermal image comparison*

Figure 40 shows the rear of the charred panel after 7 minutes of flame testing. The thermal image shows that the panel has heated up much more quickly and the extent of the heat spread is significantly larger than the uncharred panel. The temperature has reached approximately 58.6ºC, over 4 times the temperature at the same stage in the uncharred panel test.

| File: | Date: | Time: |
|---|---|---|
| IR000246.BMT | 22/04/2017 | 12:15:12 |




**Picture parameters:**

| | | | |
|---|---|---|---|
| **Emissivity:** | 0.95 | **Electric current [A]:** | 0.0 |
| **Refl. temp. [°C]:** | 20.0 | **Electric voltage [V]:** | 0.0 |
| | | **Electric power [W]:** | 0 |

*Figure 41 Thermal imaging comparison*

Figure 41 shows the infrared images 14 minutes after the start of the test. The image shows that the heat has spread higher up the panel than the uncharred panel at the same point in the test.

The test was continued until the fuel from the fire was exhausted and the fire extinguished naturally. The complete thermal imaging report can be found in the appendix.

### 3.2.3 Flame test sample comparison

Figure 42 is a comparison of the samples immediately after the test was finished.


*Figure 42 Flame spread test comparison*

Figure 42 shows how the resulting fire has burnt the through the panel. It can be seen very clearly that the charred samples on the left of the image have burnt to a much greater extent than the uncharred sample. The charred sample burnt through to a height of 750mm from the base while the uncharred sample burnt through to a height of 575mm. It can also be seen that the width of the burnt area is larger on the charred sample. This equates to an increase of approximately 6 times the area burnt through the panel.

## 3.3 Environmental test chamber testing

The purpose of testing in the environmental test chamber is to recreate certain environmental conditions that the timber would be subjected to in service. The test chambers allows the user to accurately control temperature and humidity and set a pre-determined cycle of environmental conditions. This allows specimens to be subjected to rapid changes in temperature and humidity and a greater number of cyclical changes than would be possible if a specimen was simply exposed to the elements.

The environmental test chamber used for this test was a Weiss WKL 64. This particular model of environmental test chamber is programmed either with an integrated control panel or linked PC. For this particular test the chamber was controlled using the integrated control panel due to the linked PC being unavailable.

This type of freeze/thaw testing is usually carried out on masonry and concrete based materials. With this in mind it must be noted that there is no specific benchmark for a freeze/thaw test in timber and the masonry benchmark is unsuitable. These types of materials are damaged by freezing to a greater extent than timber. The reason this test was introduced into this project was that the char layer may exhibit different characteristics in freeze/thaw testing than uncharred timber. To understand charred timbers performance, it was deemed necessary to ascertain how the char layer would perform under these conditions. This type of freeze thaw testing is usually referred to as cyclical freeze/thaw testing.

### 3.3.1 Test procedure

The test parameters outlined in figure 43:-

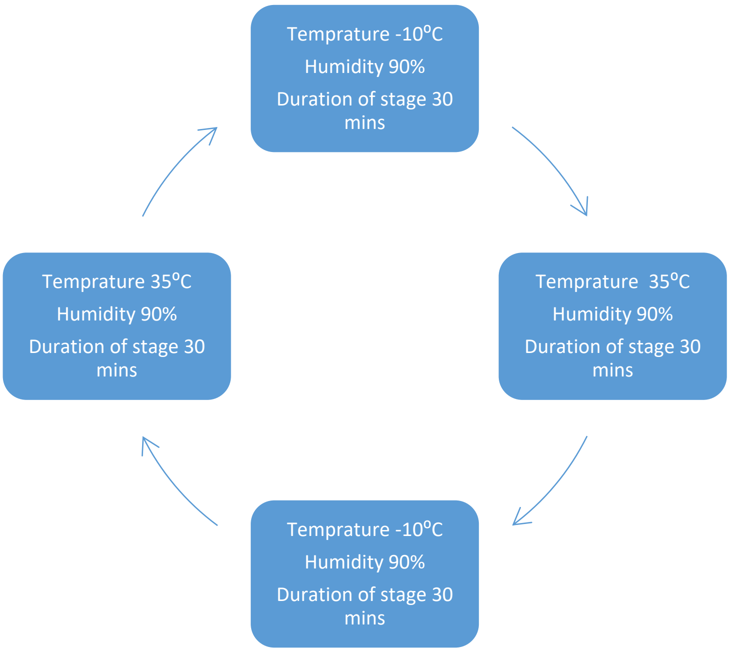



*Figure 43 Environmental test cycle*

The set points for this cyclic testing were based on the UK average temperature data from the Met Office. The temperature are the average maximums and minimums that the cladding could potential be subjected to in service conditions on a building façade.

Frost can be categorized as follows:-

- Air frost – when the air temperature at 1.25m above ground level falls below 0ºC
- Ground frost – when the temperature falls below 0ºC on a grass surface.

There are between 40 to 60 days of air frost per year and between 100 to 125 days of ground frost per year. This is the approximate number of frost days for the Midlands region of the UK. (Met Office, 2018)

The test cycle was repeated for 30 cycles. This was chosen to represent the upper maximum of 60 air frost days per year and allowed a year of frost events to be simulated in approximately 3 days.

As cladding would not be installed at grass/ground level, it was decided that 60 simulated freeze/thaw cycles would give a good representation of one year's exposure.

The timber specification for this test is as follows:-

- Length 400mm
- Width 150mm
- Thickness 20mm
- Timber species Siberian larch

For this particular test there is no specific benchmark test for freeze/thaw testing on timber samples as timber is not usually effected by cyclical freeze/thaw action, due to its inherent flexibility. This test was devised to test the effects of water absorption into the char layer and subsequent freezing of that water.

### 3.3.2 Environmental test chamber specimen comparison

*Figure 44 Uncharred specimen*

Figure 44 shows the uncharred specimens immediately after the test was completed. There is little visual difference to the boards apart from a small amount of black staining to the surface of the boards, although this is localized.

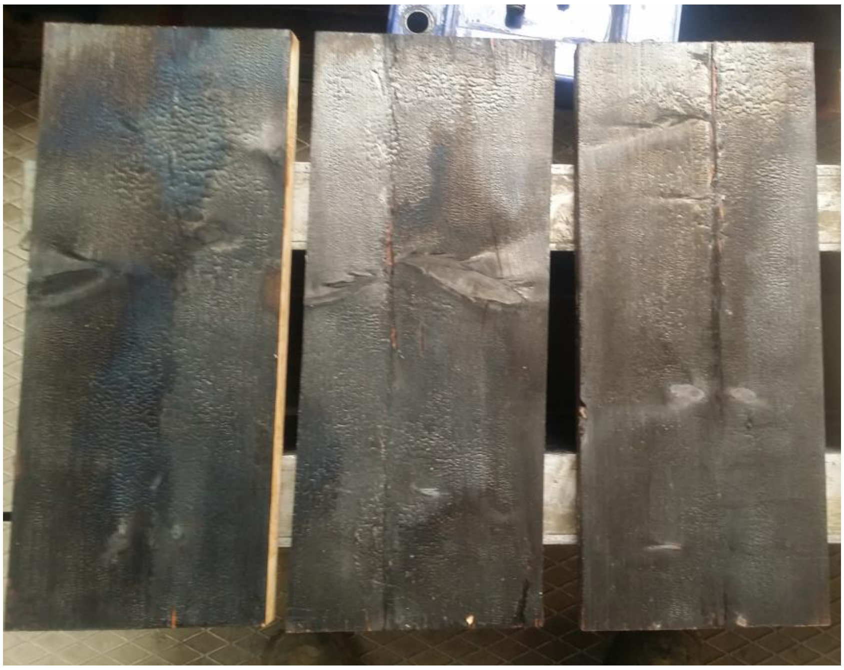


*Figure 45 charred specimen*

Figure 45 shows the charred specimens immediately after testing. The surface shows no signs of degradation. There is a fairly prominent area of what appears to be oil based staining over approximately 50% of one of the boards. This stain appears to be from the natural oils contained in the timber. This has migrated to the surface and spread across the char layer.

## 3.4 Exposure testing

From the beginning of this project it was decided that some short to medium term external exposure testing would be a desirable way to ascertain the way cladding will be affected by the elements.

Therefore, a small sample of test specimens were tested for a period of 496 days.

The timber specification for this test is as follows:-

- Length 300mm 4 off and 400mm 4 off
- Width 150mm
- Thickness 20mm
- Timber species Siberian larch

### 3.4.1 Test procedure

The test was carried out using a sample of 8 specimens – 4 charred and 4 uncharred. The specimens were fixed to a timber batten and mounted vertically. This arrangement best simulates the conditions that vertically fixed cladding will be subjected to in service.

It is usually advisable to use stainless steel fixings for Siberian Larch cladding (Hislop, et al., 2013). This is necessary to prevent staining to the surface of the timber from steel fixing corroding.

It was decided that galvanised steel fixings would be used for the test as this would subject the specimens to undesirable conditions, allowing a measure of the claddings resistance to staining. To accelerate the process of oxidization the specimens were treated with a saline solution of 10 parts water to 1 part ordinary salt. This was applied to the face of the specimens after they were fixed. Figure 46 shows the specimens immediately after installation and application of the saline solution.

*Figure 46 pre exposure test image*

It can be seen in figure 46 that the saline solution has left a white stain on the face of the charred boards. This is the salt after the water from the saline solution has evaporated. There did not appear to be any significant staining on the uncharred boards.

### 3.4.2 Exposure testing comparison

Figure 47 shows the test specimens after the test period. It can be seen that the boards have discoloured significantly. In general, the charred sample has discoloured the least with less significant stains.

The saline solution that was applied at the start of the test has caused significant corrosion to the screws and this in turn has caused staining around the screw head. This is only apparent on the uncharred sample as the charred sample shows little to no signs of staining around the screw heads.

*Figure 47 post exposure test image*

# Chapter 4 – Test results and Discussion

## 4.1 - UV test conclusions

The results that were obtained from the accelerated UV exposure testing were broadly in line with what was expected. All timber when left untreated will start to show signs of discolouration due to many different factors including UV light.

The unexpected element of the results were the lack of change to the surface colour of the charred timber sample. It was expected that there would be some minimal change to the colour but there was no visible change at all. The only detectable effect of the UV light was the leeching of the sap from fissures on the timber surface. As the species of timber used was Siberian Larch it is possible that the sap would leech from the surface regardless of surface treatment although this is pure conjecture. The leeching was most probably caused by the heat from the UV light source or from the heat during the charring process.

The UV light exposure testing could be improved by employing the following:-

- Higher powered UV light source would reduce the duration of the testing.
- Varying the wavelength of the UV light may obtain different result outcomes.
- Using moisture generating apparatus or commercial UV light exposure equipment may increase the weathering effect.

In direct comparison it can be seen that the charred sample showed improved UV resistance to fading compared to the uncharred sample.

## 4.2 - Flame test conclusions

The flame spread experiment was an important part of the testing for this material. It allowed the researcher to explore some of the claims made by manufacturers of charred cladding. The main claim in terms of fire performance is that the charring process makes the timber have improved resistance to fire.

The tests show that there is no appreciable increase in fire resistance, either in ignition or resistance to the propagation of flame spread across the surface. In fact the charred sample shows a faster rate of ignition and an increase in damage from the fire than in the uncharred sample.

To improve the accuracy of the results of this test the following points should be considered:-

- Increase the size of the panel
- Use thermocouples for the temperature sensing
- Carry out the test in a controlled, in-door fire test facility
- Monitor the temperature of the crib fire to ensure comparative heat output

These points will help to improve the data that is collected, although the results for the experiment that was carried out give a good indication of the performance of the cladding. By comparing the two identically arranged panels it can be seen that the charred panel exhibited less resistance to fire.

Although limited to only one panel of each type of cladding this test still shows a significant difference in burn times and flame spread. This could be improved by increasing the number of specimens. The test procedure allows for repeatability as it is a simple test that is relatively low risk.

## 4.3 - Environmental test chamber conclusions

The principle behind this test was to ascertain the charred timber claddings performance when subjected to freeze/thaw cyclic conditions. Timber in general is relatively resistant to the damaging effects of freezing due to its inherent flexibility.

This resistance to freeze/thaw damage was in line with the results of the freeze/thaw testing. None of the charred layer was damaged in the freeze/thaw testing. No spalling or degradation was viable. It appears that even when the timber has a moisture content over 90% the timber has enough flexibility to retain the charred layer.

## 4.4 - Exposure testing conclusions

Overall the exposure test was successful and provided valuable results. The charred specimens showed only a small amount of discolouration and very little staining around the steel fixings. The uncharred specimens shows significant staining around the steel fixings and a significant discoloration of the timbers surface. This form of weathering is in line with expectations and widely accepted as normal.

The charred specimens shows a significant improvement in performance in this test with a marked reduction in discoloration. The charred specimens did begin to discolour as the exposure has weathered some of the charred layer away, revealing uncharred timber below.

Therefore it could be concluded that eventually the timber would discolour to the same colour as the uncharred specimens, but the charring would slow down the process by offering some medium term protection. This set of conclusions is in line with the observations made of the Parkside kiosk. The cladding used on the case study building also showed signs of discolouration.

The effect of the chosen test on the cladding is that the visual measured performance has been altered. This visual measure is a direct comparison and is quantified as such. There are no numerical scales to compare the discolouration of the test specimen against.

# Chapter 5 - Conclusions and Recommendations

## Summary

During the course of this topic, a few of charred cladding performance have been investigated. This has been carried out with both case study data and from laboratory testing. Overall it has been found that charred timber cladding has more favourable in service performance than uncharred cladding of the same species, with the exception of resistance to the spread of flame.

## Conclusions

It is the author's opinion that charring is a useful surface finish for external timber cladding but should not be used in lieu of industry recommended detailing of timber façade systems, or as a solution to fire protection and improved durability. From a timber cladding specification viewpoint, charring should be treated as a decorative finish.

In relation to the aims and objectives of this project, it has been shown throughout the testing carried out, that the manufacturers claims of improved fire resistance is unfounded and in fact the opposite of these claims has been observed. Not only does charring not protect the timber cladding against the effects of fire but it actually reduced the claddings performance in the test carried out, compared to the uncharred panel.

It has also been observed that the claims made about char being a protective finish for weathering effects has some validity with the exposure testing showing some reasonably good results in favour of the charred specimens.

## Recommendations

One of the project aims was to produce a set of recommendations that helps to inform specifiers and designers as to the performance of charred timber cladding. It is the author's recommendation that charred timber be only used as a decorative finish and should not be used to replace careful detailing, correct timber selection, appropriate fixing grade or fire prevention methods.

## Further work

This project has highlighted some areas that could be explored further – both from an academic and commercial point of view. As mentioned, charred cladding manufacturers make unsubstantiated claims of the performance of their products and this could be tested to industry standards to help develop a guide for specifiers. There is also scope to process the research on charred timber further at a post graduate level of study – perhaps PhD.

Some of the areas that require further investigation are listed below:-

- Long term exposure tests
- Higher powered UV exposure tests
- Water absorption tests
- Resistance to fungal growth and subsequent decay

The tests mentioned in the list could be carried out as part of an industry sponsored project or a PhD research project.

# References


Beckers, B., 2013. *Solar Energy at Urban Scale.* s.l.:John Wiley and Sons.

Bingnan Yuan, X. J. T. T. N. Z. H. M. G., 2019. UV protection of wood services by graphitic carbon nitride nanosheets. *Applied Surface Science,* 467-468(1), pp. 1070-1075.

Bleck and Bleck Architects, 2017. *Brise Soliel.* [Online] Available at: https://bleckarchitects.com/shade-structures/brise-soleil/ [Accessed 6 October 2018].

Cambridge University Press, 2018. *Cambridge Dictionary.* [Online] Available at: https://dictionary.cambridge.org/dictionary/english/durability [Accessed 24 November 2018].

Carter Holt Harvey Group Limited, 2018. *Shadow clad.* [Online] Available at: https://www.chhwoodproducts.co.nz/shadowclad-structural-natural-texture/ [Accessed 6 October 2018].

Cernadas, A., 2018. *filt3rs.* [Online] Available at: http://filt3rs.net/case/timber-louvers-barcelona-biomedical-research-park-367 [Accessed 6 October 2018].

Charred Timber Ltd, 2017. *Charred Timber Ltd.* [Online] Available at: http://charredtimber.co.uk/ [Accessed 13 October 2017].

Coates, K., 2013. *epz.* [Online] Available at: https://www.ephotozine.com/user/rambler-85348/blog/day-81--greensted-church-7452 [Accessed 6 October 2018].

Cromartie Ltd, 2010. *Cromartie Timber.* [Online] Available at: https://cromartietimber.co.uk/ [Accessed 6 October 2018].

Davies, I., 2015. *Development of performance-based standards for external timber.* s.l., Elsevier.

Design, C., n.d. *Greensted church.* [Online] Available at: http://www.greenstedchurch.org.uk/ [Accessed 6 October 2018].

Dezeen, n.d. *Terunobu Fujimori.* [Online] Available at: https://www.dezeen.com/tag/terunobu-fujimori/ [Accessed 25 September 2018].

DSDHA, 2018. *Potters Field Park Pavilions.* [Online] Available at: http://www.dsdha.co.uk/projects/51c43fefc3fc7a000200000f/Potters-Fields-Park-Pavilions
[Accessed 25 November 2018].

English Heritage, 2017. *Leigh Court Barn.* [Online] Available at: http://www.english-heritage.org.uk/visit/places/leigh-court-barn/ [Accessed 06 November 2017].

Enviroment Agency, 2014. *Briefing on Regulation of Wood,* Newcastle: Enviroment Agency.

Exterior Solutions, 2018. *Exterior Solutions.* [Online] Available at: https://exterior.supplies/charred-timber-cladding/ [Accessed 1 December 2018].

Garden, I., 2017. *YouTube.* [Online] Available at: https://www.youtube.com/watch?v=yMDy745Mu2k [Accessed 14 November 2017].

Gillin, J., 2009. *dwell.* [Online] Available at: https://www.dwell.com/article/terunobu-fujimori-e123c0fa [Accessed 25 November 2018].

Goodwins, 2018. *Goodwins timber and DIY products.* [Online] Available at: https://www.goodwins.ie/timber-cladding/c-1381.html [Accessed 6 October 2018].

Google , 2017. *Google maps.* [Online] Available at: www.googlemaps.com [Accessed 20 November 2017].

Hewett, C. A., 1980. *English Historic Carpentry.* 1st ed. Fresno, California: Linden publishing.

Hislop, P., Kaczmar, P. & Taylor, L., 2013. *External Timber Cladding.* 3rd ed. High Wycombe: BM TRADA.

Low impact, 2018. *Low impact.* [Online] Available at: https://www.lowimpact.org/lowimpact-topic/roof-shingles/ [Accessed 6 October 2018].
Met Office, 2018. *Regional Climates: midlands.* [Online] Available at: https://www.metoffice.gov.uk/climate/uk/regional-climates/mi#temperature [Accessed 18 October 2018].
Monday, 2017. *Good report,* Cov: CU.
PAPER Magazine, 2018. *YouTube.* [Online] Available at: https://www.youtube.com/watch?v=T_BBBSLDhGw [Accessed 25 September 2018].
QTG group, 2017. *Charred/Burnt cladding.* [Online] Available at: https://www.qtdgroup.com/thermowood-charred-cladding [Accessed 13 October 2017].
TRADA, 2013. *External timber cladding.* 3rd ed. High Wycombe: BM TRADA.
Weijnen, P., 2014. *Pintrest.* [Online] Available at: http://www.pinterest.com/pin/43910165089807994/ [Accessed march 2014].
Woodtrend, 2018. *Woodtrend.* [Online] Available at: https://www.woodtrend.co.uk/alison-brooks-architects [Accessed 6 October 2018].

# Table of figures

# Appendix

## Appendix 1 Thermal image report – charred panel

**Charred cladding testing - charred panel**

Coventry University

| | | | |
|---|---|---|---|
| **Company** | Coventry University - John Laing | | |
| **Device** | t870-2 | Serial No.: | 2919915 |
| | | Lens: | Standard 34° |
| **Customer** | | Measuring Site: | |
| **Task** | | | |

Page 1/47

## Appendix 2 – Thermal image report – uncharred panel

# Charred cladding testing - uncharred panel

**Company** Coventry University - John Laing

| | | | |
|---|---|---|---|
| **Device** | t870-2 | Serial No.: | 2919915 |
| | | Lens: | Standard 34° |

**Customer**

Measuring Site:

**Task**

Page 1/49

## Appendix 3 - BS EN ISO 4892-3-2016

**BS EN ISO 4892-3:2016**

BSI Standards Publication

# Plastics — Methods of exposure to laboratory light sources

Part 3: Fluorescent UV lamps



...making excellence a habit.™