Can design generate information to aid in technological innovation? An investigation using industry based case studies.

Michelle Hyams
Masters of Design

2008
Abstract

‘Can design generate information to aid in technological innovation? An investigation using industry based case studies.’

For the first time in the history of the Cooperative Research Centre (CRC) enterprise, design and design research was involved from the very beginning of a scientific research program. Within the CRC Wood Innovations, Project 2.3 was set up to research and develop innovative techniques for the production of bentwood components, including the use of microwave technology.

A Masters of Design (M.Des) project was included into the research program to contribute new and innovative ideas to assist in the design and development of a commercial bending technology. The aims of Project 2.3 that help to guide the outcomes of the design project were to develop innovative techniques for wood bending for the mass-production of bentwood components, to produce new designs and products and to develop a means for technology transfer.

A driving goal for this design project was to use existing parameters of industry partners and research constraints to produce furniture prototypes that utilise and test microwave bentwood components. Particular emphasis has been placed on technological, marketing and manufacturing parameters, while working with two Australian manufacturers, CDe Group and Jensen Jarrah.

The importance of producing physical embodiments of furniture using microwave bentwood components was that they allow the designer to test bentwood manufacturing techniques, component reliability and consistency, while also placing the technology into a simulated commercial production environment.

The objectives of the design project can be identified and divided into a number of elements. There was a need to identify collective needs and desires of the Australian Furniture Industry to give a strong information base to work from. Through a series of experiments and collaborative projects (case studies), furniture prototypes were created and the prototypes were used to stimulate discussion. The conversation generated information to assist in furthering the technological and product development of bentwood components in both scientific and manufacturing fields. The final stage consisted of an analysis of the information produced through the feedback generated by the prototypes.

The design project contained in this thesis was designed and completed to assist in the transition of a pre-commercial technology to a commercially viable manufacturing technique.
Acknowledgements

I would like to thank Dr Barbara Ozarska and Dr Deirdre Barron for their advice, patience and amazing inspiration during the research process and also for their ongoing support, advice and their assistance in overcoming many challenges.

This thesis would not have been possible without the continuing encouragement from my family and friends.

For Bruce, Jessica and Cassandra.

It is done.
Declaration

This thesis contains no material which has been accepted for the award to the candidate of any other degree or diploma, except where due reference is made in the text of the thesis. To the best of the candidate’s knowledge, this thesis contains no material previously published or written by another person except where due reference is made in the text of the document.

__________________________________
Michelle Hyams
# Table of contents

Title page

Abstract ii

Acknowledgements iii

Declaration iv

Table of contents v

List of illustrations viii

Chapter One

1.0 The beginning 1
1.1 What is the question? 2
1.2 Why was it done? 2
1.3 How was it done? 3

Chapter Two

2.0 Who, what and where 5
2.1 CRC Wood Innovations 5
2.1.1 Program 2 6
2.1.2 Project 2.3 – Innovative techniques in bending of wood components 6
2.1.3 Research projects with in Project 2.3 7
2.2 Who benefits from developing the technology? 8
2.3 Current status of Australian Furniture Industry 9
2.4 Use of Design in Australian Furniture Industry 10

Chapter Three

3.0 Chronological history of bentwood furniture and Technology 15
3.1 History of Bentwood Furniture 15
3.1.1 Windsor Chair 16
3.1.2 Samuel Gragg 17
3.1.3 Thonet 17
3.1.4 Jacob & Josef Kohn 21
3.1.5 Thonet-Kohn-Mundus 22
3.1.6 Decline of Bentwood Furniture 22
3.1.7 The place of plywood in the story of Bentwood Furniture 24
3.1.8 Examples of recent Bentwood Furniture 26
3.2 Bending Technologies 29
3.2.1 Steam Bending 30
## List of illustrations

<table>
<thead>
<tr>
<th>Illustration Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chapter Two</strong></td>
<td></td>
</tr>
<tr>
<td>Figure 1</td>
<td>Morrison sofa by Jasper Morrison for Vitra (<a href="http://www.vitra.com">www.vitra.com</a>)</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Optical mouse by Philippe Starck for Microsoft (<a href="http://www.microsoft.com">www.microsoft.com</a>)</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Louis Vuitton handbags (<a href="http://www.louisvuitton.com">www.louisvuitton.com</a>)</td>
</tr>
<tr>
<td>Figure 4</td>
<td>T4 Chair and Footstool for Company F (<a href="http://www.tessafurniture.com">www.tessafurniture.com</a>)</td>
</tr>
<tr>
<td><strong>Chapter Three</strong></td>
<td></td>
</tr>
<tr>
<td>Figure 5</td>
<td>Sackback Windsor chair (<a href="http://www.windsorchairresources.com">www.windsorchairresources.com</a>)</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Drilling for spindles - Windsor chair (<a href="http://www.windsorchairresources.com">www.windsorchairresources.com</a>)</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Wedge joint – Windsor chair (<a href="http://www.windsorchairresources.com">www.windsorchairresources.com</a>)</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Elastic chair, c.1808, Samuel Gagg (<a href="http://www.antiquesandfineart.com">www.antiquesandfineart.com</a>)</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Bent laminated wood, Michael Thonet, 1840-1843 (<a href="http://www.thonet.com">www.thonet.com</a>)</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Effect of steam bending on the neutral axis in a bend (W.C.Stevens)</td>
</tr>
<tr>
<td>Figure 11</td>
<td>Moulds for bending primary piece of chairs back rest (Simonikova)</td>
</tr>
<tr>
<td>Figure 12</td>
<td>Café chair #14, Gebrudër Thonet, 1859 (<a href="http://www.thonet.com">www.thonet.com</a>)</td>
</tr>
<tr>
<td>Figure 13</td>
<td>Chair, Otto Wagner for J&amp;J Kohn, 1905 (<a href="http://www.architonic.com">www.architonic.com</a>)</td>
</tr>
<tr>
<td>Figure 14</td>
<td>Wassily chair, Marcel Breuer, 1925-1927 (<a href="http://www.moma.org">www.moma.org</a>)</td>
</tr>
<tr>
<td>Figure 15</td>
<td>Cesna side chair, Marcel Breuer, 1928 (<a href="http://www.steelform.com">www.steelform.com</a>)</td>
</tr>
<tr>
<td>Figure 16</td>
<td>Vienna chair, August Thonet, 1904 (<a href="http://www.designmuseum.org">www.designmuseum.org</a>)</td>
</tr>
<tr>
<td>Figure 17</td>
<td>Paimio chair, Alvar Aalto, 1933 (<a href="http://www.moma.org">www.moma.org</a>)</td>
</tr>
<tr>
<td>Figure 18</td>
<td>LCW chair, Charles and Ray Eames for Herman Miller, 1945 (<a href="http://www.hermanmiller.com">www.hermanmiller.com</a>)</td>
</tr>
<tr>
<td>Figure 19</td>
<td>Hat trick chair, Frank Gehry for Knoll Inc., 1992 (<a href="http://www.knoll.com">www.knoll.com</a>)</td>
</tr>
<tr>
<td>Figure 20</td>
<td>Face Off table, Frank Gehry for Knoll Inc., 1992 (<a href="http://www.knoll.com">www.knoll.com</a>)</td>
</tr>
<tr>
<td>Figure 21</td>
<td>Body Raft, David Trubridge, 2000 (<a href="http://www.davidtrubridge.com">www.davidtrubridge.com</a>)</td>
</tr>
<tr>
<td>Figure 22</td>
<td>C3 Stacking chair, David Colwell, 1989 (<a href="http://www.trannon.com">www.trannon.com</a>)</td>
</tr>
<tr>
<td>Figure 23</td>
<td>C1 Reclining chair and footstool, David Colwell, 1981 (<a href="http://www.trannon.com">www.trannon.com</a>)</td>
</tr>
<tr>
<td>Figure 24</td>
<td>Wave bench, Carsten Schmidt &amp; Jens Bredsdorff for Allermuir (<a href="http://www.allermuir.com">www.allermuir.com</a>)</td>
</tr>
<tr>
<td>Figure 25</td>
<td>Capelli stool, Carol Catalano for Herman Miller, 2002 (<a href="http://www.hermanmiller.com">www.hermanmiller.com</a>)</td>
</tr>
<tr>
<td>Figure 26</td>
<td>Bending room at Thonet C1920, (Simonikova)</td>
</tr>
<tr>
<td>Figure 27</td>
<td>Bending at Jasienica Stock Corporation, 2004, (L.Juniper)</td>
</tr>
<tr>
<td>Figure 28</td>
<td>Soaking timber, Jasienica Stock Corporation, 2004 (L.Juniper)</td>
</tr>
<tr>
<td>Figure 29</td>
<td>Steam chambers, Jasienica Stock Corporation, 2004 (L.Juniper)</td>
</tr>
<tr>
<td>Figure 30</td>
<td>Machine bending, Jasienica Stock Corporation, 2004 (L.Juniper)</td>
</tr>
</tbody>
</table>
Figure 31 Components drying on metal straps, Jasienica Stock Corporation, 2004 (L.Juniper)
Figure 32 Stool, Jane Dillon for Mallinson Ltd, n.d. (www.mallinson.co.uk)
Figure 33 Compwood table, Dr Lyndon Anderson, 2004 (Dr.B.Ozarska)
Figure 34 Mountain ash bending after compression applied, Compwood, 2005 (Dr.B.Ozarska)
Figure 35 Size reduction visible after compression applied, Compwood, 2005 (Dr.B.Ozarska)

Chapter Four
Figure 36 Wood bending using Microwave Heating (Norimoto & Gril 1989)
Figure 37 SCM Record 110 CNC Machining Centre (www.scmgroup.com)
Figure 38 DMC Technosand 1350 Widebelt sander (www.machines4wood.com/mall/scottlandsargeant)
Figure 39 Dovetail joints
Figure 40 Halving cross joint
Figure 41 Variety of mortice and tenon joints
Figure 42 Bridle joint
Figure 43 Feathered (or Slip-Tongue) joint
Figure 44 A variety of Butt joints
Figure 45 Graph; the length of wood used for bent and/or machine shaped components (BFG Consulting)
Figure 46 Graph: preferred cross sectional areas (BFG Consulting)
Figure 47 Graph: Cross-sectional thicknesses and shapes using bent wood (BFG Consulting)
Figure 48 Timber blank prior and after manipulation by steam bending

Chapter Five
Figure 49 Diagram of ‘generic’ product design cycle
Figure 50 Diagram of proposed product design cycle
Figure 51 Graphic representation of the design strategy

Chapter Six
Figure 52 Sketch of Rocking Horse
Figure 53 Rocking Horse prototype
Figure 54 Sketch of stool
Figure 55 Working on stool in workshop
Figure 56 Design of ‘Arch’ table
Figure 57 Design of metal strap to form arch
Figure 58 Asymmetrical bend for armchair
Figure 59 Extendable table with bent legs
Figure 60 Extendable table with bent legs and edges
Figure 61 Small couch flips into dining table
Figure 62 Bent legs turns side table into dining table
Figure 63 Extendable table
Figure 64 Extendable table
Figure 65 Extendable table
Figure 66 Table with adjustable legs
Figure 67 Table with adjustable legs
Figure 68 Mobile buffet extends to table
Figure 69 Mobile buffet extends to table
Figure 70 Long table with half-circle ends
Figure 71 Bentwood legs and table edges
Figure 72 Café table
Figure 73 Folding chair
Figure 74 ‘Wishbone’ legs made out of one piece of timber
Figure 75 ‘A’ chair
Figure 76 ‘Sling back’ bentwood chair
Figure 77 More chair sketches using bentwood components in a variety of ways
Figure 78 Original design of folding table with bent wood legs
Figure 79 Sketch of folding table
Figure 80 Exploded sketch of one half of table
Figure 81 Detail of leg
Figure 82 Folding action
Figure 83 CD stand designed and manufactured by Curvatura Fruilana
Figure 84 Section profile of table edge
Figure 85 Sketch of bending table with new former
Figure 86 Sketch of timber with slot and former
Figure 87 Carving and sanding to produce solid wood edged table
Figure 88 Table from Ton a.s. catalogue (2004)
Figure 89 Large tension failure
Figure 90 Small tension failure
Figure 91 Bending table with R300 former, metal strap and timber component
Figure 92 Experimental microwave softening unit
Figure 93 Bent component restrained with metal strap
Figure 94 Tension failure occurred during drying in conditioning chamber
Figure 95 Sketch of Café table #1
Figure 96 Exploded view of the components of the Café table #1
Figure 97 Section view of bentwood edge
Figure 98 Section view of MDF table top
Figure 99 Assembly section view of bentwood edge, table top and veneer
Figure 100  Colour of wenge stain
Figure 101  Table #2 stacking
Figure 102  Attaching leg to table edge
Figure 103  Restraining ends of table bentwood edges
Figure 104  Joint designs to hold edge ends and legs
Figure 105  Joint designs to hold edge ends and legs
Figure 106  Frame designs
Figure 107  Frame designs
Figure 108  3D line drawing defining materials and surface finishes
Figure 109  3D exploded view drawing
Figure 110  3D drawing of leg component
Figure 111  3D detail drawing of leg/frame assembly
Figure 112  3D drawing of leg/frame/edges
Figure 113  3D exploded view drawing of leg/frame/edges
Figure 114  Rocking Chair (2005)
Figure 115  Sawlog production forecast
Figure 116  10 tonne pneumatic press with double layer press-former
Figure 117  Drying rack
Figure 118  Tension failure
Figure 119  Collapse of timber surface
Figure 120  Microwave installations with box applicator for wood treatment
Figure 121  Bending former at the Jasienca Bentwood Furniture Company (L.Juniper)
Figure 122  Bending former at Curvatura Fruliana, Italy (L.Allnutt)
Figure 123  Drawing from Company E
Figure 124  Exploded view of press-former
Figure 125  Sketches for design of bending rack
Figure 126  Technical drawing for the manufacture of a press-former
Figure 127  Assembled bending jig
Figure 128  Soaking timber
Figure 129  Samples emerging from microwave tunnel after application of microwaves
Figure 130  Heated samples placed on base former
Figure 131  Side view of bending jig with timber pieces
Figure 132  Assembly of jig for pressing using pneumatic pump
Figure 133  Sketches of the original design for the Drying rack
Figure 134  Sketches of the original design for the Drying rack
Figure 135  Samples being assembled into drying rack
Figure 136  Assembled drying rack with spacers between assembled into drying rack samples to allow air flow
Figure 137  Sketch of assembled drying rack with spacers between
Figure 138  Sketch of assembled drying rack with reinforced ends
Figure 139  Sketch of transport equipment
Figure 140  Tested samples
Figure 141  Prototype of Rocking Chair with bentwood back slats
Figure 142  Assembly instructions for the Rocking Chair
Figure 143  Top view of slats assembled into base rail

Chapter Seven
Figure 144  Failures in bentwood component Trial #2
Figure 145  Tension failure occurred during drying
Figure 146  Lamination to create larger bent components
Figure 147  Prototype café Table #1
Figure 148  Edge detail, Table #1
Figure 149  Two bentwood pieces specified in drawing
Figure 150  Three pieces used in prototype
Figure 151  Components flair out at ends
Figure 152  Table #1: Section view of final table top assembly
Figure 153  Compression failures due to internal knot
Figure 154  Compression failures appear as small wrinkles
Figure 155  Modified frame
Figure 156  Modified frame and leg assembly
Figure 157  Bent components not R300 matched against fabricated jig
Figure 158  Rocking Chair with microwave bent back slats
Figure 159  Grade 2 tension failures
Figure 160  Detail images of microwave bentwood back slats
Figure 161  Detail of defect in back slat unaffected by microwave bending

Chapter Eight
Figure 162  Side view sketch of ‘Scoop’ chair
Figure 163  Detail drawing of chair frame
Figure 164  Scoop chair at Furnitex 2006
Figure 165  Detail drawing of leg assembly
Can design generate information to aid in technological innovation? An investigation using industry-based case studies.

1.0 The beginning

‘When the outcome drives the process we will only ever go to where we’ve already been. If process drives outcome we may not know where we’re going, but we will know we want to be there’ (Mau 1998).

This statement grasps quite simply the driving goal of the project executed and documented in this thesis. The process, a new bending technology using microwaves, and its capabilities determined many of the parameters of the project, yet through the involvement of ‘design’ the perceived boundaries were expanded. It was essential for the products produced during the course of the project to harness the strengths of the pre-commercial technology and assist development into a commercially viable manufacturing process.

A project titled ‘Design in Technology Research’, sponsored by the Design Council and EPSRC in the United Kingdom, created six case studies that teamed designers and researchers together and completed over a three month period. The findings were that it was an extremely successful experiment. ‘The researchers were mostly surprised at how broad a contribution design could make. Even though the project was short, the designers’ input exceeded their expectations. The researchers went into the project with the belief that design was mainly focused on shaping or styling industrial products. Instead, through the project, design input gave the researchers a clearer idea of the commercialisation process and fresh insight into potential applications. It also gave them a way to get their ideas across to others and it provided insight into users’ needs and the value of market testing’ (Design Council UK 2005).

A similar strategy was independently formed and applied into a Cooperative Research Centre (CRC) environment in Australia. The outcomes of the project demonstrated that design can assist with scientific research, and in the end the manufacturing industry, and not just in ways generally considered or employed by these two different businesses.

The inclusion of design in the CRC Wood Innovations project, and more specifically the wood bending project, created a conduit through which the new technology can be streamlined to suit mainstream manufacturing methods in the Australian furniture industry. A link was formed between the scientists and industry through the use of an experimental design process and the production of prototypes.

The primary goal of the project was to create a strategy where design would contribute to the development of a pre-commercial technology into a commercially viable manufacturing method. The next goal to achieve was to use design as a tool to create a ‘common language’. This was
necessary to allow a comfortable flow of information between a multidisciplinary research team, industry investors and academic institutions; all of whom work in different ways with a unique ‘language’ of their own. Through the implementation of the project strategy, the involved factions could understand each other and contribute as equals.

To avoid further confusion of the reader at this early point of the document, it must be stated that the field of design employed in this project was Industrial Design. A fundamental requirement in this profession is to have a great appreciation and understanding of all areas relating to the research and development (R&D) process for new products. This skill, to appreciate the many differing influences that affect the development and application of a new technology, identified an opportunity to introduce a project strategy that can contribute and complement the existing research goals.

1.1 What is the question?
A research strategy was created for this project, where ‘design’ was able to constructively contribute to the development of a new technology within a CRC setting. The strategy had to integrate smoothly into the overall aims of the CRC Wood Innovations (CRCWI), complementing the existing research programs as well as identifying new areas for research.

Within the situation of the CRCWI, Project 2.3 ‘Innovative Wood Bending Techniques’ originated due to the need for further information on the bending abilities of Australian hardwoods and to also develop a new technique for wood bending utilising microwave energy. The strategy used in this project aimed to identify and address major opportunities within the bending project where design input could generate appropriate commercial outcomes. The project title reflects on the issue of whether design, therefore the design and development of new products, can assist in the research development of a new technology. The requirements and parameters established by the multiple factions involved in the CRCWI are explained thoroughly in Chapter Two.

1.2 Why was it done?
The primary objective of Project 2.3 is to develop innovative techniques to produce bentwood components through using microwave technology. Project 2.3 is primarily looking at using the microwave bending technology with Australian hardwoods, first within the furniture industry. The issue of the growing import market is one stimulus behind pursuing the chosen avenue of research.

Another motivation behind the proposed design strategy in this part of Project 2.3 was to work directly with furniture manufacturers, developing collaborative projects and creating opportunities to generate, collect and analyse information to feed back into the research program.
The very nature of the industrial design profession is to consider the manufacturing and production issues which furniture manufacturers face daily, while working within existing technology parameters. A primary consideration while creating the design strategy was to use the existing parameters (technological, marketing and manufacturing) to produce furniture prototypes, using and testing the microwave bent wood components. These parameters were fixed as the starting point for all research work in Project 2.3.

A thorough investigation into the history of bentwood furniture was included as part of the research into bentwood technologies; past, current and future. Chapters Three and Four document the information required to develop a suitable strategy and to understand the methods for designing furniture for mass-manufacture.

1.3 How was it done?
The placement of an industrial designer into the project team introduced a totally different approach to research into Project 2.3, not always with the most favourable outcomes. The focus of the design project was positioned to concentrate on the fundamental requirements of the end user, identified for the purposes of the project as the furniture manufacturer and as an extension, the consumer. Including the design strategy in these early stages of the R&D project, assisted in directing the commercialisation of the new technology.

Chapter Five describes the design theories applied during the development of the strategy and the relevance of these theories to the desired and final outcomes. This chapter also clearly states the position taken by the author with relation to how industrial design should be placed in the scheme of a R&D project, commercial or not.

The primary motive behind the proposed research strategy was to involve industry partners early into the research program for a number of reasons. The first and most important reason for involving furniture manufacturers in the design strategy was to gain in-depth insight into how they foresee the use of and what are their most significant concerns relating to the developing technology. The second reason was to work into an existing market and use a modern manufacturing resource to develop prototypes in the collaborative projects. The third and final reason was to continue to promote the developing technology of the CRC into the furniture industry so that industry remains aware of innovative technology when developing new products.

The method selected for testing the design methodology was to produce furniture components using the new microwave bending technology and using those components in 3-dimensional prototypes. The purpose of these prototypes was two-fold. One, as stated earlier, was to create a ‘common language’. Another was to create a method for the designer to test the reliability and
consistency of the technology, and also to place the outcomes of the technology into a simulated commercial production environment. Collaborative projects were created with industry partners, giving the author an appreciation of current market fashions and requirements.

The findings of the case studies, by placing the microwave bending process into the everyday production of furniture, demonstrate that the microwave bending process does have a place in furniture manufacturing industry. A detailed commentary of the actual design process completed for this project makes up Chapter Six. It leads the reader through the whole design process of this project; from conceptual sketching to the manufacturing of furniture prototypes using microwave bentwood components.

The work undertaken for this project can be condensed into the following points:

- Identifying collective needs and desires of Australian furniture manufacturers, with a direct focus on bentwood components
- Creating of collaborative projects (case studies) developing furniture prototypes, concentrating on existing market segments of the project partners
- Developing prototypes to stimulate discussion, opinion and generate further product development using bentwood components
- Revising and reflecting on feedback generated by the prototypes to assist in the transition of a pre-commercial technology to a commercially viable manufacturing technique.

Chapter Seven gives the reader an analysis of the project outcomes, from the subjective viewpoint of the author. It also summarises what information was collected from the work produced during the course of the project, such as giving suggestions about how the production of bentwood components would best suit the furniture manufacturing industry.

To conclude, Chapter Eight contains the author’s reflections about the project; working in an interdisciplinary team with people who originally did not know what ‘design’ was, the overall response to the project and suggesting future areas for research after concluding of this project.

Buchanan (1992) observes that ‘design eludes reduction and remains a surprisingly flexible activity.’ Coming from a long career in ‘practice,’ it was with difficulty that the author was able to separate and identify the differences between ‘design research’ and ‘design practice’, because both fields are so dependent on each other. The project contained in these pages has attempted to take into account the external requirements, technological parameters and end user requirements to produce outcomes that push the pre-commercial technology into a commercially viable manufacturing method.
Can design generate information to aid in technological innovation? An investigation using industry-based case studies.

1.0 The beginning

‘When the outcome drives the process we will only ever go to where we’ve already been. If process drives outcome we may not know where we’re going, but we will know we want to be there’ (Mau 1998).

This statement grasps quite simply the driving goal of the project executed and documented in this thesis. The process, a new bending technology using microwaves, and its capabilities determined many of the parameters of the project, yet through the involvement of ‘design’ the perceived boundaries were expanded. It was essential for the products produced during the course of the project to harness the strengths of the pre-commercial technology and assist development into a commercially viable manufacturing process.

A project titled ‘Design in Technology Research’, sponsored by the Design Council and EPSRC in the United Kingdom, created six case studies that teamed designers and researchers together and completed over a three month period. The findings were that it was an extremely successful experiment. ‘The researchers were mostly surprised at how broad a contribution design could make. Even though the project was short, the designers’ input exceeded their expectations. The researchers went into the project with the belief that design was mainly focused on shaping or styling industrial products. Instead, through the project, design input gave the researchers a clearer idea of the commercialisation process and fresh insight into potential applications. It also gave them a way to get their ideas across to others and it provided insight into users’ needs and the value of market testing’ (Design Council UK 2005).

A similar strategy was independently formed and applied into a Cooperative Research Centre (CRC) environment in Australia. The outcomes of the project demonstrated that design can assist with scientific research, and in the end the manufacturing industry, and not just in ways generally considered or employed by these two different businesses.

The inclusion of design in the CRC Wood Innovations project, and more specifically the wood bending project, created a conduit through which the new technology can be streamlined to suit mainstream manufacturing methods in the Australian furniture industry. A link was formed between the scientists and industry through the use of an experimental design process and the production of prototypes.

The primary goal of the project was to create a strategy where design would contribute to the development of a pre-commercial technology into a commercially viable manufacturing method. The next goal to achieve was to use design as a tool to create a ‘common language’. This was
necessary to allow a comfortable flow of information between a multidisciplinary research team, industry investors and academic institutions; all of whom work in different ways with a unique ‘language’ of their own. Through the implementation of the project strategy, the involved factions could understand each other and contribute as equals.

To avoid further confusion of the reader at this early point of the document, it must be stated that the field of design employed in this project was Industrial Design. A fundamental requirement in this profession is to have a great appreciation and understanding of all areas relating to the research and development (R&D) process for new products. This skill, to appreciate the many differing influences that affect the development and application of a new technology, identified an opportunity to introduce a project strategy that can contribute and complement the existing research goals.

1.1 What is the question?
A research strategy was created for this project, where ‘design’ was able to constructively contribute to the development of a new technology within a CRC setting. The strategy had to integrate smoothly into the overall aims of the CRC Wood Innovations (CRCWI), complementing the existing research programs as well as identifying new areas for research.

Within the situation of the CRCWI, Project 2.3 ‘Innovative Wood Bending Techniques’ originated due to the need for further information on the bending abilities of Australian hardwoods and to also develop a new technique for wood bending utilising microwave energy. The strategy used in this project aimed to identify and address major opportunities within the bending project where design input could generate appropriate commercial outcomes. The project title reflects on the issue of whether design, therefore the design and development of new products, can assist in the research development of a new technology. The requirements and parameters established by the multiple factions involved in the CRCWI are explained thoroughly in Chapter Two.

1.2 Why was it done?
The primary objective of Project 2.3 is to develop innovative techniques to produce bentwood components through using microwave technology. Project 2.3 is primarily looking at using the microwave bending technology with Australian hardwoods, first within the furniture industry. The issue of the growing import market is one stimulus behind pursuing the chosen avenue of research.

Another motivation behind the proposed design strategy in this part of Project 2.3 was to work directly with furniture manufacturers, developing collaborative projects and creating opportunities to generate, collect and analyse information to feed back into the research program.
The very nature of the industrial design profession is to consider the manufacturing and production issues which furniture manufacturers face daily, while working within existing technology parameters. A primary consideration while creating the design strategy was to use the existing parameters (technological, marketing and manufacturing) to produce furniture prototypes, using and testing the microwave bent wood components. These parameters were fixed as the starting point for all research work in Project 2.3.

A thorough investigation into the history of bentwood furniture was included as part of the research into bentwood technologies; past, current and future. Chapters Three and Four document the information required to develop a suitable strategy and to understand the methods for designing furniture for mass-manufacture.

1.3 How was it done?

The placement of an industrial designer into the project team introduced a totally different approach to research into Project 2.3, not always with the most favourable outcomes. The focus of the design project was positioned to concentrate on the fundamental requirements of the end user, identified for the purposes of the project as the furniture manufacturer and as an extension, the consumer. Including the design strategy in these early stages of the R&D project, assisted in directing the commercialisation of the new technology.

Chapter Five describes the design theories applied during the development of the strategy and the relevance of these theories to the desired and final outcomes. This chapter also clearly states the position taken by the author with relation to how industrial design should be placed in the scheme of a R&D project, commercial or not.

The primary motive behind the proposed research strategy was to involve industry partners early into the research program for a number of reasons. The first and most important reason for involving furniture manufacturers in the design strategy was to gain in-depth insight into how they foresee the use of and what are their most significant concerns relating to the developing technology. The second reason was to work into an existing market and use a modern manufacturing resource to develop prototypes in the collaborative projects. The third and final reason was to continue to promote the developing technology of the CRC into the furniture industry so that industry remains aware of innovative technology when developing new products.

The method selected for testing the design methodology was to produce furniture components using the new microwave bending technology and using those components in 3-dimensional prototypes. The purpose of these prototypes was two-fold. One, as stated earlier, was to create a ‘common language’. Another was to create a method for the designer to test the reliability and
consistency of the technology, and also to place the outcomes of the technology into a simulated commercial production environment. Collaborative projects were created with industry partners, giving the author an appreciation of current market fashions and requirements.

The findings of the case studies, by placing the microwave bending process into the everyday production of furniture, demonstrate that the microwave bending process does have a place in furniture manufacturing industry. A detailed commentary of the actual design process completed for this project makes up Chapter Six. It leads the reader through the whole design process of this project; from conceptual sketching to the manufacturing of furniture prototypes using microwave bentwood components.

The work undertaken for this project can be condensed into the following points:

- Identifying collective needs and desires of Australian furniture manufacturers, with a direct focus on bentwood components
- Creating of collaborative projects (case studies) developing furniture prototypes, concentrating on existing market segments of the project partners
- Developing prototypes to stimulate discussion, opinion and generate further product development using bentwood components
- Revising and reflecting on feedback generated by the prototypes to assist in the transition of a pre-commercial technology to a commercially viable manufacturing technique.

Chapter Seven gives the reader an analysis of the project outcomes, from the subjective viewpoint of the author. It also summarises what information was collected from the work produced during the course of the project, such as giving suggestions about how the production of bentwood components would best suit the furniture manufacturing industry.

To conclude, Chapter Eight contains the author’s reflections about the project; working in an interdisciplinary team with people who originally did not know what ‘design’ was, the overall response to the project and suggesting future areas for research after concluding of this project. Buchanan (1992) observes that ‘design eludes reduction and remains a surprisingly flexible activity.’ Coming from a long career in ‘practice,’ it was with difficulty that the author was able to separate and identify the differences between ‘design research’ and ‘design practice’, because both fields are so dependant on each other. The project contained in these pages has attempted to take into account the external requirements, technological parameters and end user requirements to produce outcomes that push the pre-commercial technology into a commercially viable manufacturing method.
2.0  Who, what and where?
There were a number of factors which influenced the direction and outcomes of this research. The goal of the work contained in this document had always been to produce designs that would assist in directing the development of a pre-commercial microwave bending technology which could be easily implemented into the commercial realities of furniture manufacture. However, the background and separate aims of the interested parties must first be discussed to gain an understanding of why this project took its particular form and direction.

2.1 CRC Wood Innovations
The CRC Wood Innovations (CRCWI) is a Cooperative Research Centre focused on the development and commercialisation of new technologies to establish wood as the sustainable material of choice. The overall CRC program was initiated and sponsored by the Australian Government to generate and promote the importance of collaborative arrangements, therefore maximising the benefits of research through an enhanced process of utilisation, commercialisation and technology transfer, (CRC Australia 2004). Funding for the CRCWI will total AU$60 million over a period of seven years, including AU$16.3 million from the Australian Government and substantial backing from the timber industry (CRC Wood Innovations 2001). The proposed area of study generated much external interest in the Australian timber industry and the CRCWI has since received substantial backing from the private sector. Commercialisation is a Government mandate concerning the sponsorship of the CRC program and therefore a major issue of consideration for all the research programs in the CRCWI.

The CRCWI introduced the novel application of an existing process (microwave) into a divergent field of research (timber technology), resulting in the production of internationally patented technologies applying to the microwave modification of wood. Subsequently two major interrelated and mutually dependent programs have been formed, which are Program 1: Microwave Processing of Wood and Program 2: High Value-Added Wood Products. These research programs provide a strong platform to generate groundbreaking investigative projects, which in turn have the potential to create new intellectual property and revolutionise the wood products industry in Australia.

The CRCWI research programs include the areas of wood drying, modified wood materials, wood preservation, wood bending, and improved surface coatings for wood products (InnovaWood 2005). The expected outcomes of these numerous projects are to develop various new technologies and consequentially design complete working prototypes around these technologies into on-line equipment. The final objective is to successfully deliver these commercially viable technologies into the wood processing and furniture industries.

A multidisciplinary team was assembled from research centres and universities around the country to collaborate on these projects, which are aimed at developing innovative techniques
and methods for the design and manufacture of superior wood products and thereby to give to
the Australian forestry and furniture industries a competitive advantage in local and international
markets.

2.1.1 Program 2
Program 2 was established to ‘…develop innovative techniques and methods for the design and
manufacture of high quality and high performance furniture and other high value-added wood
products to ensure their competitiveness on international markets’ (CRC Wood Innovations
2005). Program 2 has been divided into four separate projects, with each segment of the
program somewhat overlapping and focussed strongly on the global marketplace. Research
within this program includes the design and development of new products using solid timber,
microwave modified wood and other related materials.

Australian hardwoods have many good qualities; however, they also have characteristic defects
or properties that create problems when used in the production of furniture. Program 2 is
currently addressing a number of issues through various research projects, such as the difficulty
of gluing certain species, the difficulty in bending Australian timbers using existing technologies
and methods to reduce material waste during production. New problems and issues are being
identified regularly as part of the initial research program and future research projects are
constantly being developed under the CRCWI umbrella.

2.1.2 Project 2.3 - Innovative techniques in bending of wood components
Project 2.3 was established in Program 2 to research and develop innovative techniques for the
design and manufacture of bentwood components. The technologies being investigated are
microwave softening of timber and technical parameters during bending and microwave drying
of bent components, as well as a steam-bending technique which is being investigated in order
to compare the two methods. The program is particularly focused on the investigation of the
development of a microwave bending technique using Australian furniture grade hardwoods.
The project is concentrating on developing a method to supply a reliable manufacturing source
for bentwood components that are functional, consistent in quality and readily available to
Australian furniture manufacturers at the present time.

The grounds for Project 2.3 and its research program being developed were based on many
factors. These factors included: the bending wood manufacturing technique has not changed
significantly since the nineteenth century, successful bending is limited to a small range of wood
species, and there is a decreasing supply of good bending quality hardwoods. More pertinent to
this project is the fact that many Australian hardwoods are not being bent in commercial quantities
by using existing bending processes, because of the high failure rate (Ozarska 2005).
The initial scientific goals of the research project were to find out the optimal parameters for microwave-treated timber and the minimum radius achievable. Much of this 'background' research is still being completed, as the data required is detailed and at times laborious to document. There have been a number of delays due to equipment problems, material supply and limited human resources.

One of the major issues concerning local industry and the world in general is how mass-manufacturing can be environmentally friendly while still producing the economic profits desired by business. The CRCWI is approaching this issue with the notion that timber is a renewable resource that can be replaced time and again, and therefore methods should be developed to assist in promoting the use of timber through new technology and material development.

The fact that timber is a sustainable material, unlike plastic or metal, makes a strong argument to persist with the development of a new technology such as microwave bending. One of the great benefits of this technology is the reduction of material waste during the manufacturing process. Manufacturers purchase quantities of timber by the pallet and often face losses of up to 30 to 35 per cent (Ozarska 2005) of the initial purchase through the sawing, shaping and sanding processes. The bending of timber minimises material waste and promotes a more environmentally friendly method of producing wooden forms. The continuous grain in bent timber gives it a strength advantage over timber that is sawn to produce a given shape. Ultimately, the furniture buyer is rewarded by use of this process, as products are more economical to produce, resulting in a lower purchase price.

In Australia, timber as a resource is supplied from a number of places such as mature, regrowth and plantation forests. Specific to the research program is Mountain ash (Eucalyptus regnans), which was selected as the primary research timber. It is being used in the initial testing of the new microwave bending technology due to it being the most common timber used in the furniture industry in south-east Australia and it is currently available in large quantities. Other timber species are being investigated for reasons that are explained in detail later in this thesis.

2.1.3 Research projects within Project 2.3
Within Project 2.3 there are a series of other research projects being completed by other members of the research team. Below is a summary of the individual projects:

- Determination of optimal parameters for softening solid wood using microwave irradiation, in particular, focussing on the moisture content and temperature distribution within a wood sample during MW heating, time of moisture and temperature loss and moisture transfer
- Use of microwave heating for final drying and stabilisation of bent components
- Comparison of structural changes in wood heated by steaming and microwave irradiation
• Property and structural changes in wood during microwave softening and bending, looking at the cellulose crystallinity in wood
• Mechanical behaviour of wood during microwave bending; concentrating on the shear, compression and tension properties of wood to determine the ultimate strains/strength for various moisture contents, optimal temperature and bending conditions, performing an experimental strain analysis during a bending operation and determining empirical relationships for end force and bending force
• Comparison of optimal wood parameters and the mechanism of heating in wood during steam and microwave softening
• And at the core of this thesis is the following project focus, the design and development of new products utilising the new bending technology.

2.2 Who benefits from developing the technology?
The Australian furniture industry as a whole should benefit from the microwave bending technology. When proved viable, this new bending technology can be introduced into other businesses that use a large quantity of timber, such as building and construction. Initially microwave bending will be introduced to the solid timber furniture manufacturing companies in Victoria as the majority of the research is being done in this State. The benefits offered by this technology will become apparent and will then filter into the mainstream furniture industry. Once the technology is accepted as a feasible and reliable method of manufacture, it is predicted that the bending technology will spread from the small to medium sized residential manufacturers and will be adopted by larger commercial furniture manufacturers such as Sebel, Schiavello and other companies.

The CRCWI has always intended to commercialise this technology, to offer the furniture industry a reliable method of producing bentwood components. The question to this point has been how and where these components should be manufactured; will an offshoot company be created from the CRC offering a specialised bending service or will the technology be sold to individual companies to make their own bentwood components in-house? The initial plan was to engage in the design and construction of a bending facility, not only proving the viability of the new technology, but also placing the technology in a production environment. Later it is intended to sell this manufacturing process as a package to independent companies, both locally and overseas.

A new company, ‘Wood Shapes Pty Ltd’, has been created through a partnership between the CRCWI and a medium-size Victorian hardwood mill. The bending facility will be located on site due to the easy availability and access to suitable timbers. A Science, Technology and Industry (STI) Grant valued at AU$1.1 million, and in-kind contributions from the mill (AU$562,000 for
shed, timber and staff) and the CRCWI (AU$504,000 for R&D expertise and staff) are supporting and funding the design and construction of the bending facility.

2.3 Current status of Australian furniture industry

An awareness of the current status of the Australian furniture industry is required at this point to appreciate why there is a necessity for the research and development of a new technology. When discussing the future of a company, or the industry on a whole, most furniture manufacturers raise the same topic time and again. During interviews with furniture manufacturers conducted for this project, all commented about how furniture being imported from Asia is undermining the local Australian industry.

The overwhelming concern about this key issue is based on the continued growth of imported products in the Australian furniture market. The easing of tariff protection (30 per cent in 1988 to 15 per cent in 1993) and at present 5 per cent (IBISWorld 2003) and the sourcing of low cost imports from Asian manufacturers have seen import share of the domestic market increase from 6.2 per cent in 1990-91 to an estimated 21.8 per cent in 2002-2003 (IBISWorld 2003). Australian manufacturers commented on the quality and sales cost of locally made furniture in comparison to imports, with local furniture being of a better quality overall. However, this appears to be less of a concern to consumers in Australia's retail market as the demand for imports is steadily increasing.

The 'Australian Furnishing Industry Action Agenda' was created concurrent with the development of Program 2, adopting the vision of many Australian furniture manufacturers who believe that the industry has to develop as a competitive and innovative supplier of goods to combat the growth of import products. There is good reason for this concern. In 1999 the sale of imported furniture gained 14.6 per cent of apparent consumption in Australian furniture sales, which is a growth of over 4 per cent since 1995 (CSIL Milano 2005). Conversely, Australian furniture exports in 1999 were over US$70 million, showing an increase of 34 per cent compared to the previous year (CSIL Milano 2005).

Over the past five years Australian exports in the furniture sector have remained more or less constant, while imports have risen steeply... Imports rose because local producers were not capable of satisfying the demand from the domestic market at prices and qualitative standards that were acceptable to consumers.

Many local Australian furniture manufacturers claim that the reason they are not able to satisfy domestic market demands in competition to the imported furniture from Asia is based on two critical factors; labour and material costs.
To combat these industry-wide problems, an approach was taken to develop a strategic program through the Furniture Industry Association of Australia (FIAA) identifying major targets and commitments.

Some of these commitments were:

- Increase quantity and quality of R&D activities to encourage the uptake of new technologies
- Promote innovation, product design and novel uses of old and new materials
- Raise awareness of the need for R&D activities within the industry (CRC Wood Innovations 2005).

The goals of Program 2 and the FIAA are similar and the desired outcomes have many similarities. To explain further, Program 2 is research and development focussed and its aim is to create new materials and new technologies. The FIAA desires to create a competitive edge for the Australian furniture manufacturers, utilising new developments such as the results emerging out of Program 2.

While some CRCs have used designers in the past as external consultants, ‘design’ has never been involved from the beginning of a CRC, as contributors to the strategic direction of the research programs. Design and design research are being employed as a catalyst for innovation, primarily assisting the CRCWI in developing a commercially viable method for wood processing and wood modification through the use of microwave technology.

The concept of a ‘Pre-Commercial Technology Push’ strategy was proposed and accepted by the CRCWI board as the best way to achieve the CRC goals. To successfully employ this strategy required a change in the mainstream design process. As described by Anderson (2004), typically ‘the generic design process is market led whereas a technology-push process must incorporate a particular technology or material at the front end of product development’ (Anderson 2004 p5) The design process was further complicated because the core technology was at a pre-commercial stage of development, challenging the designers to produce realistic product outcomes using only the experimental materials and developing technologies.

2.4 Use of Design in Australian Furniture Industry

In 2001 Ong received a grant to complete a research study on the furniture industry, focussing on some of the world’s most successful furniture producing countries – Italy, Spain, France and Germany. Ong (2001) commented on how design and designers are highly regarded and extremely involved in the design and development of furniture products, with their participation in the furniture production process being more of a ‘holistic approach’ which differs greatly to how the services of designers are viewed and employed in the Australian furniture industry. In Europe, design is ‘beyond just aesthetic and functionality. It must involve social-cultural
expressions, use of new and unique materials and innovative manufacturing processes and packaging’ (Ong 2001 p1). The report highlights the different practices of the manufacturers in these countries to those of the Australian furniture industry.

It is also evident in the local furniture retail sector that ‘European Design’ is highly desired in Australia, often being used as a marketing, sales and promotional tool. The popularity of IKEA in this country is evidence enough to support the argument that Australian customers, as much as most consumers around the world, desire inventive design in their furniture at reasonable prices. IKEA’s success is attributed to the use of clever design, the economical use of inexpensive materials, and sourcing inexpensive manufacturers resulting in the low retail costs.

The IKEA Concept is based on offering a wide range of well designed, functional home furnishing products at prices so low that as many people as possible will be able to afford them. While most retailers use design to justify a higher price, IKEA designers work in exactly the opposite way. Instead they use design to secure the lowest possible price. IKEA designers design every IKEA product starting with a functional need and a price. Then they use their vast knowledge of innovative, low-cost manufacturing processes to create functional products, often co-ordinated in style…. Most IKEA products are also designed to be transported in flat packs and assembled at the customer’s home. This lowers the price by minimising assembly, transportation and storage costs (Inter IKEA Systems B.V. 2005 website).

Although there are no other furniture companies in the world that rival IKEA’s success, many companies, from small to large, seek to emulate some part of the methodology to try to reproduce IKEA’s achievements. Large Australian furniture companies such as Freedom and Fantastic Furniture are two such examples.

Ong (2001) commented on other outstanding differences seen in the European approach towards design and designers. Firstly, there is the trend to make payment for design services in the form of royalties, based upon sales and performance of a product. There is also the current fashion of product manufacturers using the designers’ name as a sales and marketing tool to promote the product, such as ‘Optical Mouse’ by Philippe Starck for Microsoft (Figure 2) or the ‘Morrison Sofa’ by Jasper Morrison for Vitra (Figure 1). Fashion houses started this trend of creating a subconscious association between product and designer. For example, the iconic Louis Vuitton logo is recognised by women all over the world as synonymous with luxury handbags (Figure 3).
Figure 1 - “Morrison Sofa” by Jasper Morrison for Vitra

Figure 2 - “Optical Mouse” by Philippe Starck for Microsoft

Figure 3 – Detail of Louis Vuitton Handbag

In summary, Ong (2001 p2) believed that ‘Australian manufacturers should focus on creating customer value such as quality, design, use of unique local materials and capacity to effectively service a dynamic local retail sector and competitive global markets.’ Local manufacturers do consider these issues, but they also have the day-to-day issues facing their companies, as they constantly referred to during the interviews, such as chasing suppliers, completing retail orders, creating future sales and keeping costs to a minimum. One is left with the clear impression that Australian manufacturers do not have the same regard and affection for design that their international associates do.
Company F (located in Melbourne, Victoria) is an example of how successful merging of design and industry can be. This company currently employ a number of young designers to create modern product designs for production; however, there is a range of furniture that the company still produce that highlights the success and longevity of good design. Company F make a range of furniture pieces designed in the 1970s by a successful Australian designer, such as the innovative and stunning T4 hammock design (Figure 4), that are still sold in sufficient numbers in large Australia-wide retail stores like Harvey Norman and Myers. This domestic furniture company is one of the rare few in Australia who engage designers on a regular basis to assist in the design and production of new products.

![Figure 4 – T4 Chair and Footstool for Company F](image)

Other manufacturers who were interviewed by the author prefer to do their own design based on current trends or ‘gut-feel’. Some manufacturers steer clear of using designers and cite bad previous experiences. The managing Director of Company A related a story of an experience collaborating with a designer. An aesthetic concept was presented that he believed was first-rate, fitting in with their house style. However, the relationship between client and designer soured when the designer was unwilling to compromise the design to suit the companies manufacturing parameters. The Director stated that the original design would have cost too much to produce in material, time and labour. Consequently, Company A generates its own designs to this day; constructing rough prototypes to view the design in three-dimensions and then creating the relevant drawing package for the production of the product.

Company D uses a similar approach to the design and development of its furniture ranges to Company A. The difference is that besides selling its products to the usual retail outlets, Company D also works with other manufacturers by supplying components as well as having its own retail outlet in Melbourne. Another example of the diversity of business practices of furniture manufacturers in Australia, Company B only produces furniture specifically to order. It specialises in aged-care hospice furniture, making furniture to interior designer specifications and ordered quantities. This company imports some bentwood chair frames from Italy, however,
the imports are based on external orders, as Company B does not have any retail outlet for its products.

A point of difference to the manufacturers mentioned above is Company E, one of the largest outdoor furniture manufacturers in Australia, based in Western Australia. Company E has a large segment of the outdoor furniture market in Australia and is also successfully exporting its products to the US. According to the director and owner, 50 per cent of its product is exported, which in turn generates 75 per cent of the overall profit for the company.

Company E regularly uses the services of furniture designer based in another State. The designers experience and skills are secured through a regular fee structure known as a retainer (a fee paid to retain a professional advisor). It is due to the long-term nature of this relationship that the designer understands not only what is achievable using the material and manufacturing processes available, but also the future goals and direction of the company. As part of its R&D process, Company E prototypes all concepts to provide evidence that the design works. This allows time to review and modify the design to fit into production and assembly line processes.

There are a number of ways to secure the services of a designer, however, every designer/manufacturer relationship is different and arrangements should be agreed upon that suit each individual relationship best. The major issue here is that most of the manufacturers interviewed expressed their disillusionment with designers, and believed that they could get the desired outcomes by designing their own furniture and/or copying and modifying existing pieces from overseas companies to suit the Australian market.

The companies mentioned above are producers of domestic furniture. There are many leading Australian commercial furniture manufacturers who employ one or more designer. Sebel, one of the largest commercial, stadium and healthcare furniture manufacturers in Australia, claims that ‘it is the role of the design department to transform comprehensive design briefs into unique Sebel products. Comprised of industrial designers, engineers and draftspeople the design group employs the latest in 2D & 3D design tools’ (Sebel Furniture 2006). Schiavello, a family owned company with over 1100 employees, also ‘work closely with project designers and clients to discern market directions and trends, focusing on creating innovative solutions and satisfying the meanings of function and design’ (Schiavello 2006) through its own team of designers and engineers. Ong (2001 p26) summarises the situation in Australia concisely in declaring that ‘presently Australia has some great designers and some of the most capable furniture manufacturers but rarely are successful partnerships established.’

Before any design work could commence in the current project, an extensive investigation into the history of bentwood furniture manufacture was completed, focussing on manufacturing
techniques past and present. The following chapter examines how design can assist the new
technology to best benefit the Australian furniture industry in the future.
3.0 Chronological history of bentwood furniture and technology

The topics researched and documented in this chapter have varying degrees of influence on the work produced for this research project, as can be seen in later chapters. It is important as a designer and a researcher, to not only understand the technical aspects relating and influencing the outcomes of this project, such as manufacturing methods and the selected material being worked with, but also to have a good understanding of the design history in the relevant area.

3.1 History of bentwood furniture

‘...the practice of bending timber dates back to antiquity’ (Stevens & Turner 1970 p.1)

Humankind discovered that the bending of timber not only enhances the structural stability of a product, but also allows for a more economical use of materials and manpower. When this knowledge was applied to mass-manufacture during the Industrial Revolution of the early 1800s, the reductive nature of the bending process was truly appreciated. It lowered the cost of manufacture and gave bent wood a competitive edge over products made by more laborious and conventional means (Ostergard 1987).

Although Michael Thonet is most often credited for developing the bentwood technology for application into mass-manufacture, many examples of bentwood components being used throughout human history are available. Information has been found in ancient Egyptian documents that a technique of bending wood was developed BC 1971-1928 (Ostergard 1987). This technique is described as being similar to today’s cooperage method (Stevens & Turner 1970) where the timber was exposed to a naked flame to heat the material for processing.

Different methods of bending wood have been applied over the centuries, ranging from heating the timber over an exposed flame, immersing in hot water and submerging in hot sand, to Thonet’s method of steaming the timber to create enough malleability for mild to severe bending. Enhancing the natural elastic characteristic of timber by exposing it to one of the many different artificial bending techniques, as described above, has produced many of the following products: casks for wine preservation, snowshoes, wagon wheels, boat building and household implements such as spoons, bowls and baskets.

The evolution of bending wood for the use of humankind, since the Egyptians and Greeks built their boats and chairs, and its adaptation into mass-manufacturing are summarised in this chapter.
3.1.1 Windsor chair

Originally produced using a very old wood bending technique where the wood was immersed in hot sand to create the plasticity in the material, the Windsor chair is traditionally recognised by the saddle-seat into which the legs, armrests and spindles have been mortised (Goldstein 2003). There are nine variations of the Windsor chair catalogued (Windsor chair resources 2005), however, it is the arm-back rail that is a bentwood strap, holding the spindles in place. *Figure 5* shows an example of a Windsor chair.

*Figure 5 - Sackback Windsor chair*

The Windsor chair is produced in large quantities in factories all over the world, but the craft is being kept alive by many who produce these chairs by hand. The original methods are followed closely with the spindles assembled individually. However, the back and arm rails are nowadays steam bent rather than immersed in hot sand. The spindles are located into the arm/back rail by hand drilling the holes by eye (*Figure 6*), and are fixed into place using a wedge joint (*Figure 7*) (Windsor chair resources 2005).

*Figure 6 – Drilling for spindles*  
*Figure 7 – Wedge Joint*
3.1.2 Samuel Gragg
Samuel Gragg (1772 – 1855) was most likely trained in methods to produce bentwood parts by his father, a wheelwright according to written documents by the latter, Samuel Gregg (Kane 1971). Awarded a US patent for his ‘Elastic Chair’ on August 31, 1808, Gragg’s work predates Michael Thonet by almost fifty years. It has been claimed that Samuel Gragg ‘…introduced a revolutionary new process for building chairs with bentwood’ (Podmaniczky 2003), however, it was Michael Thonet who designed and developed a bending process that propelled shop production into mass production.

Figure 8 – Elastic chair

3.1.3 Thonet
Michael Thonet (1796-1871) was a cabinetmaker from Boppard-am-Rhein in Prussia when he started experimenting with the process of bending wood to form various parts. In 1842, when Thonet moved to Vienna, the city was undergoing industrial expansion and there was a great need for inexpensive, mass-produced items.

Thonet’s achievements are a successful example of the ambition of the Industrial Revolution, where all things should be available to all classes of man. The simplification of form allowed by the bending process, created an increased use of standardised elements that revolutionised the principles of furniture construction. Consequently this standardisation of parts opened the course for the mass production of furniture products. More importantly, the designs for Thonet’s furniture evolved from the production process, revealing an ideal integration of design and production.

When exhibited at the Paris Exposition Universelle in 1855, it was apparent that Thonet furniture had international appeal, with visual beauty and economic and environmental practicalities. Thonet produced products that were ideal for export as they consisted of few components, which could be easily packed and assembled at the destination, a feature of all designs by Thonet (Ostergard 1987).
At this time many production issues began to arise when Gebrüder Thonet started exporting pre-assembled products around the world, to places as far away as the Americas. The change of environmental conditions on the transport ships and final destination saw the glue melting and the products falling apart prior to them even reaching a retail shop. A decision was made at this time that the best solution for mass-manufacture was to bend solid wood rather than continue with the exploration and development of the veneer/glue-boiling method.

Thonet needed to find a wood that had a sufficiently straight grain and was available in abundance. European beech was identified as the perfect material to use in conjunction with the patented bending process. To save costs in the transport of materials, Thonet closed down the Vienna manufacturing plant. By the nineteenth century he had built seven factories near the copper beech forests throughout the Austro-Hungarian Empire. With six thousand workers churning out one million pieces per year, the Thonet range of furniture expanded to include ‘tip-up’ seats for theatres, sofas, beds, bookshelves, washtands and so on.

**Thonet develops new bending technique for mass production**

In 1856, Thonet was awarded his patent ‘For manufacturing chairs and table legs of bent wood, the curvature of which is affected through the agency of steam or boiling liquids,’ which allowed him a monopoly on the bentwood furniture market for 13 years. When bending wood, three different zones are created within the grain; Inner curvature – compression where grain gathers, Outer curvature – tension where grain stretches and the Neutral axis – which moves towards the outer curvature when undergoing the bending process (*Figure 10*).
To minimise the severe tension failures that occur during the bending process on the outer curvature, Thonet attached a metal strip along the length of wood. The neutral axis was pushed towards the outer surface and the grain gathered on the inner surface creating a curve. As a result of using the metal strip, the strain on the wood was equalised during the bending process, however, the main issue affecting the bending process was the selection of wood based on the potential of structural strength and straightness of grain. This metal strip and its variations are still used today in all the large bentwood manufacturing factories.

Peter Danko, principal of Peter Danko + Associates (Danko 2005), states that there are four clear drawbacks to the Thonet method: the steam process requires wood grain to be perfectly straight and any defects or irregularities will fail, but every piece of wood is different and it is difficult to get each piece to fit into standard jigs (Figure 11), and timber will not compress more than 20 per cent. It is therefore necessary to hold the timber in a metal strap to assist with
minimising tension failures on the outer surface of the components during bending, and also the steam bending process and only one piece can be done at a time.

Danko’s comments about solid wood furniture are valid, if not somewhat biased, as the core focus of his company is to produce plywood furniture. ‘The furniture we make is largely Ply-bent, a relatively new medium whose aesthetics have been explored by a mere handful of designers…. Ply-bent furniture is the perfect sustainable material because veneer yields 8-10 times more usable wood from a log than solid lumber’ (Danko 2005). What he does not comment on are the negative aspects to the production and use of plywood; the high cost in time and energy to produce rotary peeled ply sheets (mostly softwoods), the cost of producing male/female high frequency formers to produce the shapes, post-production machining and handling to produce individual components out of one former, and the need to coat each individual sheet in urea-formaldehyde based resins (although there are some non-toxic but expensive resins available). There is also the notion that some find the multiple layers of ply unappealing and cheap, compared to the visual elegance of solid timber which is purely subjective depending on the individuals’ opinion (B.Ozarska 2006, pers comm., 15 January) and it is an accepted fact that plywood does not last as long as solid wood furniture.

Whatever his argument, it is clear to see that Thonet’s process of bending solid timber is still a popular solution for the mass-production of bentwood components to this day. The only embellishments to the process since the mid-nineteenth century are the development of various bending machines, steaming chambers and automated factories – all of which have helped to achieve the modern world’s desire to speed up and economise product manufacturing.

**Design of Café Chair #14**

The most recognisable chair designed by Thonet was the ‘…famous café chair, known in the Thonet catalogue as Chair No. 14,’ (Rieder 1996, p106) which is still in production in many incarnations throughout the world today. First appearing in 1859, the design was a revelation to the population of the time due to its minimal style and the very economical use of material. Thonet had reduced the number of pieces in the chair to only six pieces of bentwood, with the back legs and backrest made of a single piece of bentwood, ten screws and two washers. This design was found to have structural weaknesses so two arc side brackets were introduced.
The evolution of the No.14 chair (Figure 12) showed a movement away from laminated glue-boiled veneers to the more reliable solid bentwood components. Forty million No.14 chairs were sold between 1859 and 1914 (Steelform 2005), with no true accounting of the number of sales of the original Thonet No.14 chair or manufactured copies since that time.

3.1.4 Jacob & Josef Kohn
Thonet’s patents expired in 1869, opening the doors for many companies to attempt to imitate the technology, designs and successes of Gebrudër Thonet. By the 1890s there were 50 or more companies in Europe carrying on this work, however, Jacob & Josef Kohn, a father and son team, were considered the most serious competitors of Thonet (Rieder 1996). J&J Kohn are credited as being the first furniture manufacturer to engage and produce architect-designed furniture.
Another noteworthy technological development in the production of steam bentwood components is that while Thonet required one to two hours to make their wooden rods flexible using steam, their rival Kohn ‘…had installed a machine which could produce these parts within 3 - 5 minutes. This allowed the four factories belonging to the Kohn brothers to produce 5,500 pieces of furniture daily’ (Wokalamps 2005). Following the merger of these companies in 1922, it is believed that the papers of J&J Kohn were destroyed in the late 1930s and therefore it is difficult to substantiate this claim (Getty 2006).

3.1.5 Thonet-Kohn-Mundus

In 1922, after the conclusion of World War One, there was a merger of the three largest bending furniture manufacturers (Nasatir 1989). From this period on, the company was responsible for the development of what is considered today as classic modern furniture, using well-known designer/architects such as Marcel Breuer, Otto Wagner, Adolf Loos, Josef Hoffmann, Ludwig Mies Van Der Rohe and Le Corbusier.

3.1.6 Decline of bentwood furniture

It was during this period that Thonet-Kohn-Mundus started using tubular steel as a replacement material in their furniture designs, as it visually expressed its machine origins. Le Corbusier stated ‘wood, being a traditional material limited the scope of the designers' initiatives’ (Ostergard 1987). Ostergard (1987) claims that stagnation had occurred in the bentwood industry due to outmoded technologies and materials. When the newer production processes were applied to the newer materials such as tubular steel, it created a world of opportunities and thus a revolution in furniture design had begun.

Marcel Breuer was one of the first to apply chrome-plated tubular steel in furniture with the ‘Wassily Chair’ (Figure 14), claiming ‘metal furniture is intended to be nothing but a necessary apparatus for contemporary life’ (Rieder 1996). There were some designers who were able to combine the two different materials into their designs, as done by Marcel Breuer in his ‘Cesca’ (Rieder 1996) side chair (Figure 15). This was achieved by placing a wood-framed caned seat and back panels on a steel support.
The most notable development during this period was the creation of the cantilevered chair. Unlike traditional chairs that are supported at both front and back, a cantilevered chair is supported at one end, eliminating the traditional structure of chairs by exploiting the material properties. A true cantilevered chair eliminates the need to distinguish between frame support and seat/back, with the seat noticeably flexing under the weight of the sitter. It is the flexible and resilient frame that gives ergonomic comfort as a substitute for the traditional cushion/seat support.

As with most trends, there was a reaction against the cold machine aesthetic by the late 1930s. Le Corbusier is credited with reintroducing the bentwood furniture (Vienna Chair (Figure 16)) of Thonet into the twentieth century, by using them in his early architectural interiors.
3.1.7 Place of plywood in the story of bentwood furniture
The purpose of including the history of the development and vast acceptance of plywood into the furniture industry at this point of the thesis is to highlight a competitive material, one that the new bending technology had to measure itself against as a reliable source of bentwood components.

Prior to World War 1, plywood was used in tea chests and in the furniture industry in unseen areas such as backing and drawer bottoms. Wood was reinstated as a commercially suitable material by the 1930s due to the technological development and production of plywood. Plywood was used in military service during World War 1, which rapidly advanced quality and production techniques, bringing plywood forward as a structural material. Most importantly, the introduction of plywood into the furniture industry removed the need for upholstered seats and backs, due to the ability of the material to be flexible and malleable.

3.1.7a Alvar Aalto
Finnish-born Hugo Alvar Henrik Aalto was born in 1898 and died in 1976. While he initially worked as an exhibition designer in his early career, he later turned to architecture and furniture design in 1923 and 1925 respectively, studying architecture at the Technical University of Helsinki from 1916 to 1921 (Scandinavian Design 2005).

Alvar Aalto began designing furnishings as a natural and important extension of his architectural thinking. The Paimio lounge chair (1933) (Figure 17) is considered Aalto’s first notable piece of furniture design. The continuous frame is an unconventional form, suspending the intricately shaped back and seat firmly in mid-air. The ingeniously designed seat/back is made up of a single sheet of plywood formed in one plane.

Figure 17 - Paimio Chair (1933)
The stacking stool is cited as Aalto’s most important contribution to furniture design with a new technique developed to create the ability to bend wood at 90°. However, it is his application of using a single sheet of plywood to form a chair back and seat that is most emulated today, starting with Arne Jacobsen’s Ant Chair (1951).

3.1.7b Charles and Ray Eames
The most significant innovation of the Eames’ work is that they were the first to bend plywood into two planes (Figure 18). Combination of plywood properties and rubber shock mounts made possible the resistance and flexibility in the chair designs. Introduction of shock mounts (using cycle-welding) represented a new level of innovation and invention which took Eames furniture past Aalto’s earlier use of plywood. Like the cantilevered tubular steel chairs of the 1920s, Eames chairs rely on structural properties of the design to provide comfort and stability. Upholstery was not needed. Eames brought a remarkable degree of technical experimentation and innovation to the furniture manufacturing process.

Figure 18 – LCW Chair (1945) by Charles and Ray Eames for Herman Miller

The main difference between Eames and Aalto is that furniture design became separated from its architectural influences early in the century and developed into a practice of its own.
3.1.8 Examples of recent bentwood furniture

The following are more recent examples of bent solid wood and plywood furniture. These examples have been selected to show aesthetic variety as well as the versatility of bent wood.

3.1.8a Frank Gehry

Frank Gehry's 1992 furniture collection for Knoll Inc. consists of ribbon-like designs inspired by the woven construction of apple crates and sculpted from interwoven maple strips (Figure 19 and Figure 20).

3.1.8b David Trubridge Design

David Trubridge graduated from Newcastle University in Northern England in 1972 with a degree in Naval Architecture (boat design). Since then, he has sailed around the world 'using nature as his muse' to produce distinctive furniture. Many of the products in his recent collections utilise steam-bent solid timber components and the visual design of these pieces give the viewer the impression of a boat skeleton.

Figure 19 – ‘Hat trick’ chair  Figure 20 – ‘Face Off’ table

Figure 21 - Body Raft 2000
The manufacturing rights of the ‘Body Raft’ (*Figure 21*) were purchased by Cappellini, a renowned Italian furniture manufacturer, and now features as a core product in its range.

### 3.1.8c David Colwell Design (AKA Trannon)

The primary objective (Colwell 2005) in David Colwell’s mind, when establishing his company ‘Trannon’ over thirty years ago, was to design furniture that was sustainable. The end result is a range of furniture that satisfies this criterion due to the combination of the material used, good design and smart manufacturing. Following the path of his ‘sustainability’ goal, Colwell’s aim was to produce furniture that the owners would not want to throw away, because of the attractive design and seating comfort.

When looking for appropriate materials, wood stands head and shoulders above other structural materials. Merely growing it has environmental benefits. Of the temperate hardwoods Ash stands out above all others because it is the toughest, and is strongest when grown fast, it is self seeding, it has no sap wood so less wastage in conversion, it grows particularly well in the UK where it makes best use of the climate and soil conditions, it is good for steam bending and it is plentiful and not expensive (Colwell 2005).

*Figure 22 – C3 Stacking chair (1989)*
Colwell’s philosophy is simple and is a good summary for the need to develop a new bending technology specifically to exploit the benefits of Australian hardwoods.

3.1.8d Allermuir, UK
This design was the winning entry in the Danish Design Week Awards 2001 competition, which sought furniture designs that would express the use of formed laminated ply construction in beautiful and innovative ways suitable for mass production. The judges, including Philip Thonet, Nanna Ditzel and other eminent Danish designers, concluded that it was an elegant, poetic, quiet and well-balanced design that could be used in any building context. They applauded the minimalist thinking and the excellent balance between the well detailed stainless steel frame and the moulded ‘wave’ seat (Figure 24).
3.1.8e Herman Miller

The ‘Capelli’ stool is a lyrical, imaginative place to sit that resembles a Japanese puzzle box. The ‘fingers’ of the stool’s two identical halves interlock without fasteners to form a comfortable, stable, cantilevered structure. The thin, curved form is constructed from two halves of undulating moulded plywood. The structure is strong, because where the surfaces meet between the fingers, they become the stops that hold each half of the stool firmly in place. Similar to the flat-pack ethos of IKEA, the stool unfolds, and the two halves can be stacked together, allowing for easy shipping and storage.

![Figure 25 – ‘Capelli’ stool (2002) by Carol Catalano](image)

At this stage, it is time to move from a review of the design history of bentwood furniture to examine and analyse existing wood bending technologies. This research is applicable because it is necessary to understand the limitations of current manufacturing technologies to then find the opportunities for the developing microwave wood bending technology.

3.2 Bending technologies

The research being undertaken by the CRCWI into wood bending is necessary because there is little empirical information to evaluate the new technology against. The areas being researched, as listed in Chapter 2, are intended to contribute to the design and development of a better bending system and faster, more efficient softening and drying methods.

To understand the requirements that the new bending technology must satisfy to be a competitive and commercially viable method for manufacture, the existing bending technologies such as steam or compression should be reviewed. The aim here is to develop an understanding of what is currently available and how Australian timber responds to the existing technologies. This will therefore give a greater understanding of what is required of the new technology to produce bentwood components that are consistent in form, have a reliable supply source, are cost-effective and of high quality.
3.2.1 Steam bending

Steam bending has not altered much since it was developed to its current production system between the years 1830-1850 by Michael Thonet (Alvera 1987), as can be seen when comparing photographs (Figure 26 and Figure 27), which show that a large amount of the complex bending is still done by hand. To get the best results using steam treatment for timber plasticisation, it is best used in conjunction with European timbers such as beech, oak, and elm, however, it does apply quite successfully to North American native timbers (Colwell 1997).

In 1939, R.S. Kingston (1948) completed a comprehensive study of the bending properties of Australian hardwoods. While this study determined that steam bending has some success with Australian hardwoods, it focused more specifically on discovering the bending properties of old-growth timbers. The characteristics of regrowth or young plantation-grown timbers for bending have never been determined.

In February 2003, a Workshop on Wood Bending was held at the Australian School of Fine Furniture in Launceston, Tasmania. A prominent Australian furniture designer-maker specialising in the design and manufacture of furniture using bentwood components, coordinated the workshop, passing on his experience in the method of producing components of steam-bent Australian hardwoods.

While discussing the process of producing steam bentwood components, the coordinator commented that the technique is mainly based on the ‘trial and error’ method, relying on the practical skill and experience of the operator (Ozarska et al 2003). Although steaming time does not appear to be critical providing that a minimum temperature is maintained (approximately 100°C), it is commonly accepted that three-quarters of an hour per inch of timber thickness is required (Stevens & Turner 1970). It is the lack of empirical data that is much of the motivation behind the CRCWI investigations into the application of microwaves to bend timber. The research program aims to prove how it can potentially improve current bending techniques into a highly developed new production process.
Steam bending follows this process; soak timber pieces in water (if the moisture content is too low), heat them in a steaming chamber at normal atmospheric pressure, place hot pieces in metal straps and quickly form into the desired shape. The pieces are then restrained and dried in a kiln or air-dried to the final required moisture content, which for Australian furniture is approximately 12 per cent (Australian Standard 2796.3). The steps taken through this process are important to note, as some are used in the case studies designed and completed for this project.

Below are some photographs documenting the steam bending process from a visit to Bentwood Furniture Company in Jasienica Stock Corporation, Poland (Figure 28 – Figure 31).

![Figure 28 – Soaking timber, 2004](image)

![Figure 29 – Steam chambers, 2004](image)
Although steam bending is predominantly used to create any solid bentwood furniture, there are a number of disadvantages to this process; some are clearly stated by Peter Danko as discussed earlier in this chapter and others are listed below:

- Time required to heat timber to required temperature
- Environmental issues including use of large quantities of water to create steam
- Reject rate of components during bending process (20 per cent on average (Ozarska 2003))
- Failure of components during drying period

### 3.2.2 Compression of hardwood

Another method of altering timber to make it more malleable for bending is to use a technology commonly referred to as Compwood (the compression of hardwood).

Timber pieces are steamed for about two hours, heating and plasticising the timber and thereby making the timber soft enough to compress (Candidus Prugger 2004). The hot timber is then placed in a rectangular chamber within the compression machine and is compressed along its length using a hydraulic piston. The process compresses the timber piece as much as 30 per
cent of the original length with the residual compression being between 5 and 15 per cent, depending on the species.

The technology to produce compressed wood has been commercialised by Compwood Machines Ltd., who owns the right to use the patented technology (United States Patent Number US190088 1989) from the Dansk Teknologisk Institut. Curvatura Fruilana, located in Udine, Italy, has purchased the technology from Compwood Machines Ltd to offer an alternative technology to bend wood, other than steam bending. The owner, Angelo Maros, estimates that it makes up less than 10 per cent of the overall orders for bentwood components (Allnutt 2005).

Candidus Prugger is an Italian wooden ornament manufacturer who produces and sells Bendywood™ and Flexywood™ in commercial quantities for use in furniture or architectural products. Bendywood™ is a material supplied in wet form that dries rigidly into a formed shape, and Flexywood™ is a similar material produced through extreme compression that retains a flexible form indefinitely.

Design companies such as Mallinson Ltd. in England, in collaboration with Candidus Prugger, are constantly exploring the possibilities of compressed wood within the furniture industry (Figure 32), and other companies are using the material successfully in handrails, furniture, office fitouts and lighting. Hardwoods like Oak, Hard Maple, Beech, Cherry and Walnut are suitable for compression and can be produced in lengths corresponding to the dimensions of the finished product.

\[Figure 32 - Stool (n.d.) by Jane Dillon for Mallinson Ltd\]

Dr Lyndon Anderson, Associate Professor from the Faculty of Design, Swinburne University, attempted to harness the strengths of this material modification process by producing a
prototype of a unique table design where the base and leg structure are formed out of a single timber board (*Figure 33*).

*Figure 33 – Compwood table (2004) by Dr Lyndon Anderson*

Dr Anderson’s intention was to see how far the process could be pushed, thereby creating a situation in which an assessment of the microwave bending process could be made. The future direction of his experimental project is to replace the Beech timber with a variety of Australian hardwoods, attempting to replicate the results of the original prototype. This project is ongoing.

An outcome of discussions between Dr Barbara Ozarska, Project 2.3 Manager, and Compwood Machines Ltd. was that the company agreed to do some initial experiments using a variety of Australian hardwoods in conjunction with the compression process. The function of these tests was to create an environment where the results from the new bending technology could be compared against competitor technology. The results from these tests were e-mailed to Dr Ozarska informally, and are seen in Table 1, which shows the comparative reaction of the timbers to steam bending (*Figure 34 and Figure 35*).
<table>
<thead>
<tr>
<th>Timber Species</th>
<th>Testing timber by Compression¹</th>
<th>Timber testing with Steam²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountain ash</td>
<td>The result is very good on the light coloured mountain ash (E. regnans). This wood can be compressed 20% and bends easy. We can do almost everything with this wood without any problems. Very easy to work with. Good for compressing and bending. (Figure 34)</td>
<td>Good</td>
</tr>
<tr>
<td>(Eucalyptus regnans)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spotted gum</td>
<td>The spotted gum (C. maculata) was good until 12% compressing, which is similar to European Ash where we normally only compress a maximum 15%. This wood is not easy to compress, but we think it looks like the acacia wood from Malaysia and can be compressed after several trials. We only received one bundle of this wood and conclude it is possible to compress the wood (Figure 35)</td>
<td>Fair to Good ranking - depending on the timber's origin in either Queensland or New South Wales</td>
</tr>
<tr>
<td>(Corymbia maculata)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jarrah</td>
<td>The jarrah (E. marginata) brown coloured wood was almost as good as the Spotted gum to compress. The result is good and it can be compressed 20% with success.</td>
<td>Difficult due to sloping grain</td>
</tr>
<tr>
<td>(Eucalyptus marginata)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ Email from Compwood Machines to Dr B. Ozarska ² Division of Forest Products (1948) Timber Bending.

Table 1 – Comparison of bending ability of Australian hardwoods

Figure 34 - Mountain ash bending after compression applied
Figure 35 - Size reduction visible after compression applied

The results from these tests were inconclusive and no further investigations have been commissioned. However, the initial results highlight the need to develop a successful new bending technology to be used specifically with Australian hardwoods to increase the adaptability of these timbers in the local and international furniture markets.

It should be noted at this point that the major ‘hold-up’ for this process is the fact that the technology involves steam-heating the timber prior to compression for bending. There is a need to further investigate the new technology to perhaps introduce microwave-heating as a substitute to steam-heating timber in the near future.

3.2.3 Microwave modification bending technology
The new manufacturing method being investigated by Project 2.3 is currently at a pre-commercial stage. There is a great opportunity to develop this technology into a commercial production technique of forming bentwood components.

The purposes for developing this technology from a pre-commercial research project into a commercially viable manufacturing process are varied, depending on who is discussing it within the forestry and manufacturing industries. Some claim that it is necessary to develop this technology to give the Australian furniture industry an advantage against the cheaper furniture import market, a view held by many of the furniture manufacturers interviewed. Others believe that the microwave bending process adds value to Australian hardwoods as it will reduce waste of material, which in turn makes it a more economically attractive production method compared with the current method of carving and sanding the necessary curved components. This is supported by research completed by Misato Norimoto, who states that microwave heating of wet timber is highly efficient and that the yield rate of wood bending may be greatly improved.
He also comments that this technology allows wood species not currently considered suitable for bending, to become a feasible manufacturing material (Norimoto & Gril 1989).

Norimoto & Gril (1989) claims to heat and soften wet wood using microwaves with mechanical forming and setting operations to occur within the microwave oven. Many advantages and benefits are claimed in using this process, such as:

- Heating within the specimen allows complete softening of timber within 1-2 minutes
- Temperatures can be controlled to get best processing conditions
- Applicability of wood bending is enlarged.

As stated by Norimoto, the supply of good bending-quality hardwoods is decreasing and therefore a new technology specifically designed to be to be used with alternative softwood timbers should be developed (Norimoto & Gril 1989). The difference between Norimoto’s work and Project 2.3 is that he has mainly addressed ‘technical issues’ and he has not looked deeply into the commercial parameters of his process.

The effect of microwave irradiation on timber depends on several factors, all of which can alter the success of bending after microwave heating. These variables are the dimensions of the sample, the moisture content, the growth rings, orientation, the output of the microwave and the permeability of the timber. The power output, as well as irradiation time, should be chosen according to species and dimensions of the sample, to create optimal conditions for softening and consequent bending of the timber. Currently optical fibre probes are being used to measure the internal temperature of the sample during the heating process. A controlled environment is created, allowing the operator to decide upon the microwave output and thus to control the speed of irradiation of the sample to achieve the required temperature.

The proposed benefits of this technology are:

- Greater component strength compared to carved components
- Greater recovery of timber as up to 100 per cent higher yields can be gained compared to the traditional techniques used in shaping wood
- Remarkably higher quality finish of component
- Greater durability of the finished product
- Lower production costs
- Improved cost benefit to the industry
- Great reduction in material waste
- Quicker bending process
- Environmentally friendly process.

The main objective of Project 2.3 is to develop a new bending technology, utilising microwave power, to use with Australian hardwoods to produce bentwood components that are stable and
easily produced. The project will also compare old growth, regrowth and young plantation timber of specific species and analyse the results when exposed to the new microwave bending process. A secondary stream of research is being performed to test the performance of Western Australian hardwoods with the steam process, combined with a spiral bending machine (Juniper & Beel Australian Patent Application Number A2004910949) to investigate which are most suitable to use for bending and to compare the mechanism of softening and bending using the two methods.

As stated earlier in the chapter, it is necessary for a designer to not only understand where bentwood has been used from a design perspective, but also understand what are the other influencing issues when designing furniture containing bentwood components. One such issue that has been covered in this chapter has been to gain a deeper understanding of the existing bentwood manufacturing methods as well as understanding the abilities of the new developing technology. Further influencing factors are discussed in the following chapter.
4.0  Not historical or technological but important
To allow the information in this document to flow smoothly, making reading and comprehension straightforward, the literature review has been divided into two separate chapters. This second chapter includes topics researched that do not necessary relate to the historical development of bentwood technologies but do affect the outcomes of this project. It was necessary to look into the topics documented below to have a rounded understanding of all influences on the design and development of new products using the new bending technology.

4.1  Patents for bending wood
The bending of timber has been part of the furniture manufacturing industry for over 150 years since Michael Thonet first applied for a patent in 1856. After the patent expired 13 years later, many companies and individual inventors have been developing a range of different bending techniques, processes and machinery.

To assist with the patenting of the new microwave bending process and equipment designed specifically for the purpose, the author initiated and completed an in-depth patent search through the US, Australian, UK, European Union, German, Danish and Asian patent office records. The search was originally undertaken to find out if there were any products similar to those developed by Project 2.3. Having found this was not the case, the information found through this search allowed the author to identify the patentable claims of the new bending process and related equipment. By completing such a thorough search of local and international patent databases, it eliminated the need for the patent attorneys to do this work, ultimately reducing costs and speeding up the patent process.

The patent search did identify one claim regarding microwave technology. In the patent titled ‘Method and apparatus for shaping wood material into a predetermined configuration’, Norimoto (1984) claims to use the application of microwaves to timber to soften the material for bending. However, this patented process employs a completely different method to mechanically alter the shape of the timber (Figure 36). As seen in Figure 36, the area of the diagram highlighted shows that Norimoto’s method of altering the shape of the timber is through the use of weights beneath the sample. The timber is bent in a semi-controlled manner, resulting in mathematically defined curvature.
The patent search was used to develop an understanding of the history of the technological and methods development since Thonet’s original patent. This historical review shows that there have been no great technological advances in the field of wood bending since that year. Metal straps are still utilised to prevent tension failures and timber is still pre-soaked to allow greater softening of the fibres and the forming and drying of components. While the production of bentwood components is more automated, the equipment still closely resembles the original manufacturing equipment used on Thonet’s workshop floor.

4.2 Previous studies into bending Australian hardwoods
There have been some previous studies completed looking at the bending suitability of Australian hardwoods, starting with Trade Circular No.22 for the Division of Forest Products, Council for Scientific and Industrial Research in 1934. This was expanded upon in the second revision (1948) and since then there have been smaller forays into updating the data in specific states, such as a 1988 technical publication by the Forestry Commission of New South Wales.

Another resource for wood bending facts is the ‘Wood Bending Handbook’ by W.C. Stevens and N. Turner, published in 1970. The investigations compiled for this book included a large selection of Australian hardwoods, however, the authors do not stipulate whether the sample pieces were supplied from; mature, regrowth or plantation. It is most likely that the timber used is mature wood with South African-grown karri an exception. Therefore there was a need to undertake a study to test the bending ability of Australian hardwoods with steam heating and microwave irradiation.
4.3 Mode of operations for furniture manufacture

It was important to gain knowledge and understanding about how furniture is made in a production environment, however, this is a brief account, documenting only information relevant to the desired outcomes of this project.

For an industrial designer to design furniture products that are appropriate, many topics must be researched, and parameters and requirements recognised and comprehended. For this project, it was important to not only understand the bending technologies available and the invested interests of different government or academic bodies, but it was also vitally important to understand the daily operations of the target audience for the new bending process.

Therefore, as part of the personal interviews conducted by the author for this project, a tour of the manufacturing facilities and verbal explanations of business practices were included. In this way the author, a designer, could see first hand what machines were commonplace on a workshop floor and how timber was handled from beginning to end of the manufacturing process. These tours were used by the designer to develop a thorough understanding of what problems and limitations were faced during the production of furniture.

Machines that were typical of the many manufacturers visited were bandsaws, CNC machines (Figure 37), spindle moulders, routers, sanders (Figure 38), planers, mortisers and many other pieces of equipment.

![SCM Record 110 CNC Machining Centre](image1)

![DMC Technosand 1350 Widebelt sander](image2)

The research was interested in identifying technologies that could be incorporated into existing manufacturing environments. By understanding what machines were available and their purpose, the products created for the two case studies were designed within current commercial parameters. This demonstrates that the new technology can be easily integrated into current furniture manufacturing practice.
4.3.1 Joinery research
As with the review of production machinery, it is also essential for a designer to understand the different assembly methods used during the production of a piece of furniture. Therefore, a review of the most commonly used jointing methods used by manufacturers was completed. Below are some examples of the more frequently used joints as well as the joints that are most applicable to the furniture designed for this project.

Figure 39 – Dovetail joints

Figure 40 – Halving cross joint

Figure 41 – Variety of mortice and tenon joints

Figure 42 – Bridle joint

Figure 43 – Feathered (or Slip-tongue) joint
4.4 Importance of timber quality

It is important to have a good understanding of the structure of timber; e.g. how new cells can form into four types of wood tissue, the physical distinction between sapwood and heartwood or the difference between earlywood and latewood. However, an industrial designer must understand the parameters of the material that they will be working with, in this case the aspects of timber that affect bending.

The characteristics required in timber for bending are;

- Straight clean grain free of knots and gum veins
- Boards cut quartersawn\(^1\)
- Minimal internal checking\(^2\)
- Minimal collapse\(^3\)
- High moisture content (20 per cent or more)
- Timber surface free of any imperfections (Project 2.3 team meeting 2004).

These features are very important when selecting timber pieces for bending and also when designing furniture that use bentwood components.

\(^1\) Quartersawn timber is when the growth rings are more or less at right angles to the face
\(^2\) Internal checking is characterized by separation of the fibres appearing as internal collapse
\(^3\) Collapse is the flattening or buckling of wood cells during drying, often seen on the surface as greater than normal, uneven, or irregular shrinkage
4.4.1 Timber species being tested in Project 2.3

The research focus of Project 2.3 was primarily based on Mountain ash (*Eucalyptus regnans*) to understand the science behind microwave bending. It is also the most commonly used timber in the Australian furniture industry and a known difficult timber to bend. With the high demand for this material resource, much timber is still sourced from mature and regrowth forests, but many plantations have been established for future harvesting of a sustainable resource.

Other timbers are being investigated for a variety of reasons being used in the research because they are replacement timbers for mature forest timbers, they will be available in large quantities from plantations in the future, and some mature timbers are still in great demand by the furniture industry. The bending characteristics and a minimum radius of curvature will be determined in a wide range of species used by the furniture industry. That is other timbers were evaluated for their reaction to the new technology and minimum radius achievable. Examples of these other woods included Jarrah (*Eucalyptus marginata*), Karri (*Eucalyptus diversicolor*) and Blackbutt (*Eucalyptus pilularis*). These are available in old growth and regrowth resources but are still in high demand from the furniture industry. Research into the application of the new technology to these timbers will contribute to the reduction of waste, which can be achieved by bending. Red gum (*Eucalyptus camaldulensis*) is currently sourced from old-growth forests but there are plantations of this species so it should be investigated whereas Radiata Pine (*Pinus radiata*), a softwood used regularly in the low-end furniture market, does not have a high profile but companies have repeatedly asked for the testing of this material. Finally, Sydney blue gum (*Eucalyptus saligna*), Tasmanian blue gum (*Eucalyptus globulus*), Gympie messmate (*Eucalyptus cloeziana*), Rose gum (*Eucalyptus grandis*) and Spotted gum (*Corymbia maculata*) are future commercial species growing in plantations. Experiments to determine the minimum radius of curvature in old and young timbers allows for comparison.

Part of the larger research project was the testing of a selected sample of Australian hardwoods using the developing new microwave technology. A range of timbers has been selected, as listed above, for a variety of reasons. These timbers were selected based on current and future availability, use by furniture manufacturers, and results from previous research into the bending of Australian hardwoods using steam technology.
4.4.2 Cost analysis of bentwood components

A number of bentwood suppliers were interviewed in the early stages of Project 2.3 to support the decision to undertake research into developing a new bending process using microwave technology. A wood bender in New South Wales, described the situation accurately and simply; ‘Bent components are cheaper than machine curved components but the cost difference depends on the timber species and the shape of the components’ (Ozarska 2004).

This comment is further supported by a comparative costing of a single curved component based on a chair back slat completed by an experienced Wood bender from Tasmania. The savings made by using bentwood components rather than other forms of producing the ‘S’ curve, whether using laminates and solid wood, are approximately 35 per cent to 90 per cent. The Tasmanian wood bender estimated that steam-bent back slat from solid wood would cost AU$2.25 per slat to produce, compared with a laminated slat at AU$3.18 and machined solid wood costing AU$4.10 per slat. These prices take into account machining, transport, basic material costs, adhesives, processing and the labour required to produce these components. In conclusion, the wood bender believed that not only does steam bending produce the most economical component but it is also the best in terms of its structural strength and aesthetics. The advantage of using steam bent components is not only the price. It provides an opportunity for design and presentation of innovative form.

4.5 Marketing research

There are various marketing techniques that can be used to collect information about people’s preferences, e.g. individual interviews, survey research, participant observation, secondary research, choice models and experiments. In marketing research, the research objective states in a single sentence what is desired and needs to be achieved through the use of a particular research technique. The benefits of articulating the aims in a concise and concrete statement are that it forces researchers to stop and think what do they want to achieve, and often it is discovered that the objective is insufficient, reflecting only part of the desirable outcome.

Many of these methods can be used in conjunction with another method to give both a quantitative (surveys) and qualitative analysis of the topic of interest. In Project 2.3 Wood bending, there was a need to do research to gain a clear understanding of what furniture manufacturers needed in the way of components that could be replaced with bentwood parts, and how these manufacturers predict the use of bentwood components in the future.
4.5.1 Market research survey into bentwood

The marketing data gathered for this project relates specifically to the user of the new technology, the furniture manufacturer, rather than focusing on the purchaser of the final furniture product. The information following was collected through a series of interviews conducted directly by the author and a comprehensive market research survey, commissioned by the CRCWI and completed by BFG Consulting Group. The results of the survey are outlined below, as are the interview outcomes in Table 2.

The collection of marketing data was imperative for this project because it was necessary to know the predicted quantities and required shapes that the future customers of this technology were going to be using. This allowed the author to create suitable case studies to use design as a means to assist constructively in the development of the pre-commercial bending technology. These case studies are discussed in-depth in the following chapters.

The CRCWI management decreed that a questionnaire was the most suitable method for data collection due to the vast size and the vast geographical distances of the sample group. The format and questions included in the questionnaire were developed through a collaborative effort between the scientists in Project 2.3 and BFG Consulting Group. BFG compiled the questions into generic terms that would stimulate the most amount of feedback from the sample group.

This sample group was selected from members of the Furniture Industry Association of Australia (FIAA) who use solid timber in their day-to-day operations. The survey excluded responses from manufacturers of upholstered products, metal products and commercial furniture manufacturers.

BFG Consulting Group faxed the questionnaire and compiled the results into a thorough report on the use of curved components, use of bentwood components and future requirements for the mass-production of microwave bentwood parts.

Below is a summary of the responses:

- A high level of interest in the technology was indicated by 76.7 per cent of respondents identifying existing & future shapes
- The amenable market is estimated to be approximately ten million machine shaped components per year, which could be replaced by the bentwood technology
- Eighteen species of Australian timber are used, with the top four being ash, blackwood, jarrah and radiata pine
- The major componentry parts currently used are chair legs, backs and arms
- Bentwood componentry is principally used in Dining and Bedroom sectors.
• *Figure 45* identifies the percentage of responses favouring the following lengths:
  
  o 52 per cent less than 1 metre
  o 37 per cent 1-2 metres
  o 11 per cent 2-3 metres

![Figure 45 - Length of wood used for bent and/or machine shaped components](image)

While all shapes (*Figure 46*) and thicknesses (*Figure 47*) were used by some of the respondents, the largest responses (52 per cent) were for rectangular shapes in the 19 mm to 39 mm thickness range.

![Figure 46 – Preferred cross sectional areas](image)  
**Figure 46 – Preferred cross sectional areas**

![Figure 47 – Cross-sectional thicknesses and shapes using bentwood](image)  
**Figure 47 – Cross-sectional thicknesses and shapes using bentwood**

The results from this marketing survey supported data gathered during the author’s interviews with a number of local and interstate manufacturing companies.

4.5.2 Interviews regarding the use of bentwood components

Apart from the general market survey completed by BFG Consulting, a number of interviews were conducted by the author with a group of Australian furniture manufacturers, the majority based in Melbourne, Victoria. Much of the relevant information collected from these interviews...
has been included in this document, and below is a summary of the current situation and future views for the use of bentwood components.

During a visit to the Australian School for Fine Furniture, projects utilising steam bentwood components were exhibited. The noticeable detail with the design of the furniture with bentwood components was how the timber pieces were shaped prior to steaming and bending, reducing the thickness of material in the bending zone, as seen in Figure 48. The design of this component allowed easier bending through a thinner section, eliminating many compression and tension failures.

![Component Blank - Shaped prior to bending](image)

**Figure 48– Timber blank prior and after manipulation by steam bending**

Table 2, on the next page, documents and summarises the comments obtained through personal interviews held by the author with a range of furniture manufacturers during the course of this project.
<table>
<thead>
<tr>
<th>Furniture manufacturer</th>
<th>Comments on bentwood</th>
</tr>
</thead>
</table>
| **Company A**          | - Currently use bentwood components in buffet and wall units  
                                       - Sourced components from manufacturer in country Victoria who has since closed his business  
                                       - Ordered a large quantity of components from manufacturer for future production |
| **Company B**          | - Import bentwood chair frames from Italy |
| **Company C**          | - Do not use bentwood components  
                                       - Mostly shape and carve required forms |
| **Company D**          | - Use bentwood red gum components  
                                       - Have to dry components prior to use  
                                       - Expect to do lots of machining to eliminate tension and compression failures  
                                       - Use manufacturer in suburban Melbourne |
| **Company E**          | - No bentwood components used as unsure about weathering effect on modified shapes  
                                       - Prefer to use shaped and carved forms due to five year guarantee on all furniture items |
| **Company F**          | - Use steam-bent components but must be air-dried for six months prior to use in production line  
                                       - Lose one of every three components, tight bends R430 get stress marks |

Table 2 – Comments from manufacturers interviewed about bentwood components

As stated earlier in this chapter, a good understanding of the issues that influence the design and development of bentwood furniture is very important for a designer to have, to produce the best possible outcome. The following chapter on the design strategy of this project describes topics within the field of design research that have also strongly influenced the outcomes of this project.
5.0 **Story of the design strategy**

The project title reflects upon the issue of whether design (and therefore the design and development of new products) can assist in the research development of a new technology.

**Can design generate information to aid in technological innovation? An investigation using industry-based case studies.**

The general aim of this project is to use design and design research to assist in the development and commercialisation of a new timber bending technique, by applying design from the experimental stages to a commercially viable manufacturing method. The strategy to achieve this goal is discussed in detail in this chapter.

The Design Council (2005) states that ‘...the overall aim of design research is to develop an accessible, robust body of knowledge that enhances our understanding of design processes, applications, methods and contexts. Often, this knowledge helps to define best practice and workable methods in dealing with design and design related problems.’ Used in conjunction with professional design practices, design research gives the designer an opportunity to reflect, analyse and learn from the process and products produced in a project.

In addition, a secondary objective of this project was identified and integrated into the project. During the research phase of this project, it was evident that there was a need to create an environment where straightforward communication between the end user and research scientists would be possible. The method to create the communication link was found through an analysis of the design process and therefore the most appropriate part of the process was focused upon; i.e. the production of prototypes.

Although the rationale is described in detail later in this chapter, the author made a decision that it was most suitable to use prototypes to create a ‘common language’ between all the different participants of this project. By placing a picture or object before an audience, with the intention to stimulate discussions, meant that the likelihood of misinterpretation could be lessened because the same image would be in front of each individual.

A commonality seen in the Australian furniture industry is its minimal use of design and designers. Although prototyping is a common industry practice, it does not make the rest of the design process any less valuable. Manufacturers, in countries such as Italy, understand the value of design as a means to gain a competitive edge (see Chapter Two). Through ideation and concept generation, a designer can create and discard many ideas (both good and bad) in the early stages of a project, before settling on one or two to develop further. The purpose of this stage is to select the best ideas without wasting the time and money required to prototype each idea into a three-dimensional form.
The design method derived for this project included a series of small design and development projects and culminated in two industry-based case studies. Through the design strategy, an opportunity was created by the author to design and develop furniture products that would allow essential information to be generated and passed into the research loop. The proposed strategy, explained later in the chapter, also enabled a demonstration of the benefits of the new bending technology to the Australian furniture industry, through methods that are easily understood and currently employed by manufacturers (as stated earlier, through the production of prototypes).

Through their involvement and correct execution of the strategy, the manufacturers themselves will be contributing to and directing the design and development of the new bending technology to suit their current and future manufacturing and production requirements. They will have helped themselves and the Australian furniture industry at large, by creating an environment where the improved design, competitive technologies and supply of Australian-made furniture may reduce the growing trend of furniture being imported into an already saturated domestic market. A positive reaction to this change could possibly be the increase in the export of Australian furniture, by having a novel and innovative product to offer the international market.

5.1 Design
Raymond Loewy (2000) believed that designers ought to get involved at the inception of a program, not in the middle or the end as design is not just an applied veneer to make products aesthetically pleasing. Industrial design is a creative discipline where many factors are considered during the process. Any industrial design project is a melding of many different technical, aesthetic, functional and business parameters.

Although designers have been used previously by CRCs as external consultants for ‘aesthetic enhancement’, on this occasion ‘design’ has been integrated into the CRCWI program at the research level for the first time. The early integration of design was to assist in the development of technologies from an experimental and theoretical to a commercially viable manufacturing technique.

Historically industrial design has focused on making technology usable in forms that are accessible and comprehensible to the greatest number of people (Heskett 1980) It is this fundamental skill of industrial design that justifies and substantiates its involvement in the development of the new microwave bending technology of the CRCWI.
5.1.1 Definition of ‘design’
The definition of design used in this thesis is ‘the art or action of planning the look and function
of something’ (Oxford Dictionary 2006). When applied to the person, the word designer is ‘…a
person who plans the form, look, or workings of something before its being made or built,
typically by drawing it in detail’ (Oxford Dictionary 2006). The title of designer is given to those
who work in the many different fields of creative thought.

The Industrial Design Society of America (IDSA) defines the profession as follows:
Industrial design is the professional service of creating and developing
concepts and specifications that optimise the function, value and
appearance of products and systems for the mutual benefit of both user and
manufacturer (IDSA 2004).

The IDSA further clarifies this definition when it states that

…Industrial designers develop these concepts and specifications through
the collection, analysis and synthesis of data, guided by the special
requirements of the end user, client and manufacturer…. to also maintain a
practical concern for technical processes and requirements for
manufacture…. to ensure that design recommendations use
specific materials and technologies effectively, and the design complies with
all legal and regulatory requirements (IDSA 2004).

The author believes this statement to be the most accurate description of the roles and practice
of industrial design. The author’s approach to the research project, set by the CRCWI, has been
formed by many years of professional experience in a variety of diverse design consulting and
manufacturing environments, as well as some research into the field of design research.

5.1.2 Snapshot of the practice of industrial design
Industrial design had its early emergence during the industrial revolution of the 19th century,
creating a link between increasingly modern mass-production methods and the manufacturers
need to inspire consumers to purchase their product in an ever more competitive marketplace.

Industrial design only emerged as a recognised profession in the early 20th century although
there were earlier indicators of the rise of design as a profession. For example, English
manufacturers such as Wedgwood introduced mass-production methods to replace artisan work
during the 19th century. Another example is the designer Christopher Dresser (1834-1904)
whose work is still being reproduced to this day (by Alessi, Italy) two hundred years after the
first production runs.
Industrial design facilitates the creation of objects. While combining elements of science, technology and art, it uses a systematic approach to problem solving, engaging creative thought processes to produce new solutions to identified problems. In essence, industrial design is an activity, an area of work that combines the mass-production methodologies of the machine age (and now information technology), with the traditions of arts and crafts for the benefit of the consumer and the manufacturer (Heskett 1980).

Industrial designers are creative people who can make a synthesis of technical possibilities, cost limitations, market acceptability, material and process characteristics and other factors – many of which are often in conflict (Central to Design.Central to Industry 1982 p. 161).

Aside from creating solutions to problems in the process of new product development, it is the ability to think laterally and view the many different influencing factors in perspective that permits Industrial designers to offer good-looking functional solutions to manufacturing and production issues. It is the role of an industrial designer to take the challenging parameters and preset limitations of a project and develop suitable solutions within existing boundaries, sometimes finding solutions outside the ‘square’.

An alternative view is to consider design as a different approach to identifying present and future issues in projects. At present design thinking is being used more frequently outside the product development process and is more often being called upon to assist with business planning and strategic management issues.

The designer’s traditional approach to solving problems, especially if they are ill-defined is to move fairly quickly to a potential solution. Even if the solution does not fit immediately, it reveals further aspects of the problem and hence can clarify issues for another attempt at a solution’ (Dormer 1993, p.54).

It is by keeping within this approach that design can greatly assist the direction for development of this new microwave wood bending technology.

Figure 49 is a simple diagram which demonstrates how information flows during a generic product design project in Australia. The diagram highlights the fact that on most occasions ‘design’ does not have direct contact with the ‘end user’, most often due to insufficient budgets, which do not allow designers the time to either do or be involved in initial market research. This distance between ‘design’ and the ‘end user’ has been found to be typical of the design process in Australia, through the author’s personal experiences as an external consultant or in-house designer.
The communication cycle (Figure 50) proposed is based on the ten years of professional practice of the author, research into the field of user-centred design, and the work of Dr Anne Bruseberg, who states that ‘… direct contact with users can provide a valuable resource for designers, who often design products for use outside their own experience’ (Bruseberg & McDonagh-Philp 2000, p.1).

It is common practice for the client to instigate and complete the initial consumer research relating to the development of a product. The marketing research methods usually take the form of interviews, focus groups or simply a search for information to review the market segment. From the information gathered, the client has the basics for a brief to guide the direction the designer should work towards. However, this does not always necessarily give the designer all the information he desires or requires.

Design is an iterative process, it is not linear. Sometimes you have to step back in the process in order to go forward (Bevan 2006).

At this point, the author suggests that design be placed in the central position of the cycle (Figure 50). Consequently the flow of information between the client and the end user would pass through ‘design’. The design method, therefore, becomes the language with which the client (CRCWI) and the end user (furniture manufacturer) communicate. In this environment, an ever-evolving set of parameters would be created, challenging the designer to create a variety of suitable physical outcomes. Due to the results of the scientific research of the CRCWI constantly evolving, it has been necessary for ‘… the design strategy (to be) dynamic and able to respond to changing circumstances within a commercial timeframe’ (Anderson 2004, p.7).

Returning to the IDSA statement above, which refers to the ‘user and manufacturer’ both gaining advantages from using industrial design in the product development process, it should be made clear that the designer is focussing more on the development of a new technology and
its merger into current manufacturing procedures. Given that the case studies required close contact with the selected manufacturers, it was inevitable that the requirements of the end user (consumer) (Figure 50) will have influenced the outcomes of this project.

While the author is not directly dealing with the consumer, the manufacturers are. It is through these conversations, between consumer and manufacturer, that the consumer needs are fed into the process of design and consequentially have an effect on the information received from the manufacturers.

The design method proposed for this project has attempted to create a free-flowing communication link between the CRCWI and furniture manufacturers by using industry-based case studies and the production of furniture prototypes. The strategy detailed was designed as a means for testing and generating information to assist the research team in developing the new microwave bending technology to a commercially viable stage, while keeping faithful to the principles of industrial design, as recognised by the author.

5.2 Statement of the proposed design method
The method for the project was developed to allow easy integration into the overall aims of the CRCWI, complementing the existing research programs as well as identifying potential new areas for research.

5.2.1 Why was this project created?
To summarise from Chapter Two, the goals of the CRCWI are to add value to the Australian timber industry and its offshoots, through the research and development of new technologies and materials. An obligation of being part of this government-sponsored program is to realise the commercialisation of research outcomes. Project 2.3 originated due to the need to find out further information about the bendability of Australian hardwoods and also to assist in developing a new technique for wood bending, specifically utilising microwave energy.

A multidisciplinary team was formed, comprising of timber technologists, a mechanical engineer, an electrical engineer and an industrial designer under the leadership of Associate Professor Dr Barbara Ozarska. Dr Ozarska has been involved for many years in the timber and furniture industry in Australia and her work is widely published in local and international forums.

The method proposed in this document, aims to identify and address major opportunities within the bending project where design can better generate appropriate commercial outcomes. The design method was formulated to satisfy the following requirements and desires of the following: the CRCWI’s aim to commercialise the new bending technology and to assist the Australian furniture manufacturers who are the end users of microwave bentwood components. The
method also uses design to generate information with the aim to assist in further development of the technology.

*Figure 51* is a graphic representation of the method designed for this project, showing the areas of interaction and desired outcomes of the project.

5.2.2 Significance of the project

The primary objective of Project 2.3 in the CRCWI is to develop innovative techniques for the production of bentwood components, including the use of microwave technology. It was by merging the goals of the CRCWI and Project 2.3 with issues and concerns, mentioned repeatedly by various furniture manufacturing companies that the design strategy for the project evolved and took shape.
The idea to work directly with furniture manufacturers in developing collaborative projects ensued from studying all the CRCWI requirements (to work with industry in commercialising the developing technologies), and in-depth discussions with other Project 2.3 team members. The team agreed that this approach created invaluable opportunities to gather and analyse information that would otherwise take a much longer time to collect.

The decision to pursue this avenue of research was also supported by further investigation into the field of user-centred design. This research confirmed that the involvement with industry at this point of the program was important, as this approach would give the most valuable feedback to Project 2.3. The design method proposed seemed the most appropriate when the approaches of the industrial design profession (in considering the manufacturing and production issues which furniture manufacturers face daily) is combined with Project 2.3 goals.

A fundamental aim of the design method was to use the existing parameters of the new bending technology; marketing and manufacturing techniques, to produce furniture prototypes which utilise microwave bent wood components. The importance of producing these prototypes was that they allowed the testing of the bentwood manufacturing techniques and component reliability. In addition, the technology was placed and tested in a simulated commercial production environment, and finally the performance of the final products could be examined.

Furthermore, the production of prototypes allows the designer to go through a retrospective product and process analysis. This creates a situation to not only suggest improvements to the pre-commercialised technique but also to contribute educated opinions to the future mass-manufacturing method of bending hardwoods.

### 5.2.3 Realisation of project goals

The design method emphasises that the best way to test and improve the pre-commercial technology is to produce components using the new microwave bending technology and utilising the said components in three-dimensional (3-D) prototypes. By doing this, the project developed a method for testing the reliability and consistency of the technology while promoting the technology to industry through tangible products. The proposed strategy creates a continual loop of research, technological development and product design, and consecutively, a flow of information through this process from manufacturers back into the research program.

A critical requirement of the research strategy was to involve industry partners early in the research program for a number of reasons. The first and most important reason for involving furniture manufacturers in the design strategy was to gain perspectives and opinion on how the industry foresees the use of the technology and subsequently what the most significant concerns would be.
The second reason was to work into an existing market and use a modern manufacturing resource (operating furniture manufacturing company) to develop prototypes through collaborative projects. The third and final reason was to continuously promote the developing technology of the CRC into the furniture industry, in order that manufacturers remain aware of the processes when developing new products.

Through a series of discussions with industry representatives and the creation of collaborative projects with industry partners, the items produced were designed within practical parameters and took into account current market demands. The case studies simulate industry realities and identify the issues of producing furniture utilising bentwood components by constructing the prototypes in an actual commercial manufacturing environment.

5.2.4 Proposed outcomes from the design method
A series of tests were conducted prior to the initiation of the case studies. The combination of test results assisted in tapering the research work of Project 2.3 to develop the most reliable commercially viable technology. A significant benefit of completing the case studies was that the products using bentwood components were manufactured in an authentic industry environment, working around real-world material, mechanical and environmental parameters.

5.2.5 Industry-based case studies
The first case study working with Company G produced three café tables edged in bent Mountain Ash, all of which were made on the production floor (not the in-house prototype department) by a shopfloor cabinetmaker.

Case study Two, in conjunction with the prototype team at Company E has pushed the technology a little farther by combining microwave heating, form pressing and jarrah (another hardwood) to produce S-bend chair backs slats.

The design method can be summarised into the following points:

- To identify collective needs and desires of Australian furniture manufacturers, with a direct focus on bentwood components;
- Creation of collaborative projects (case studies) developing furniture prototypes, concentrating on existing market segments of the project partners;
- To use the prototypes to stimulate discussion, opinion and generate further product development ideas using bentwood components.

An analysis of the production process and the feedback the prototypes have generated, has been completed to assist in the transition of a pre-commercial technology to a commercially viable manufacturing technique (see Chapter Six) from a design perspective.
5.3 Integration of design research and professional practice

A key issue arising out of the Project 2.3 is the diverse backgrounds of the various stakeholders of the project. Working alongside each other there are timber technologists, a mechanical engineer, an electrical engineer and an industrial designer. Including in this mix timber suppliers, furniture manufacturers and microwave scientists, the result is a very large and diverse project team with each member of the team having valid contributions to make to the project. However these ideas are respective to the relevant professional backgrounds, and as such carry differing weight to influence the final directions decided upon.

Often a common problem inherent in multi-disciplinary teams is how dialogue can be quite limited due to the lack of 'common language' between the members.

The design method aims to encourage discourse between the various interested parties by creating a 'common language'. There are many different ways a designer can communicate their ideas through the whole design process, however, as stated earlier in this chapter, the use of two-dimensional (2-D) and three-dimensional (3-D) prototypes were selected as the best tool given the project parameters.

5.3.1 Why prototypes?

Prototypes are underrated tools (Schrage 2000, p.4) that can easily be used to encourage communication between people of different disciplines. The communication void between stakeholders can be bridged through the use of visual images and tangible prototypes.

The ARKI projects found that ‘... earlier visual elements acted as stimulus for getting people to talk, they were a tool for facilitating collaboration and for helping to discuss future possibilities’ (Haddon & Kommonen 2004,p.10). In addition to visual stimuli like sketches and computer models, tangible three-dimensional objects can be used successfully in stimulating discourse.

Michael Schrage (2000, p.10) states that prototypes can be used ‘... to produce a common language which makes the communication between all stakeholders easier.’ A 3-D prototype allows the involvement of parties who were not involved earlier, due to their inability to visualise 2-D concepts such as sketches or working drawings, thus broadening the forum for wider discussion, interaction and analysis.

Modelling enables designers to turn the process of their inner discourse into visible form. It also helps them to persuade the client of the value of their ideas. But designers seldom think of modelling as an end in itself (Gornick 2003).

Schrage (2000, p.15) maintains that ‘... the value of prototyping arises from how people behave around prototypes’, a statement that the author upholds since the design method used in this project intends on using the prototype as a catalyst for discussion, not as an end in itself.
A prototype can be characterized as ‘... a first or preliminary form from which other forms are developed or copied’ (Oxford Dictionary 2006).

During interviews with furniture manufacturers, it became apparent that design drawings were not used to explore designed future furniture ranges as frequently as the building of a rough full-size prototype out of wood and other relevant materials. The managing director of Company A, uses the shopfloor expertise within his company during the R&D phase, e.g. to mock up quick concepts to assist making decisions regarding what new product to introduce to their furniture range. He claims that it takes them less time to 'rough up' a working prototype than to explore designs on paper. It communicates quickly the sense of design, scale, proportion and complexity of assembly of the piece, which gives enough information to make decisions about the future of the piece.

Other companies such as Company D and Company E also use prototypes early on in their development of new furniture. While this may not be the best way to design products because better designs may not even be considered due to the lack of conceptual exploration, it seems to be a standard industry practice. To create the easiest flow of communication it seemed a suitable course of action to pursue in controlled conditions.

‘The value of prototypes resides less in the models themselves than in the interactions – the conversations, arguments, consultations, collaborations – they invite’ (Schrage 2000, p.20). This statement was echoed in similar sentiments expressed by all manufacturers interviewed during the course of this project. The people interviewed stated that they believe it gives each person involved; from design, administration, production and so on, a sense of ownership of the product as well as a feeling that they contributed towards the final product.

Following this lead, the use of prototypes in a design research sense was pursued and this field of research was found to be in the early stages of scholarly definition. However it was chosen as part of this project’s research strategy for a number of reasons:

- Extensive use of prototypes by furniture manufacturers
- Need to produce 3-D forms to demonstrate and prove design and engineering decisions
- Testing of research parameters and methods developed to date
- Testing of bentwood components going through manufacturing processing
- Testing of bentwood components utilised in a finished furniture piece
- Allowing future environmental testing to occur
- Exhibition of bentwood furniture for information generation from a large industry group
- Future research and information generation through marketing and ethnographic methods
- As a stimulus for discussion
Creating a ‘common language’ in a multi-disciplinary team
As a means to transfer new technology from research into industry

Through his research, Associate Professor Chris Conley from the Illinois Institute of Technology (Futureground 2004) commented that people react very quickly to the potential of a prototype. They react to what a prototype stands for as a basis for future stages, not to the prototype itself. Most designers will agree that “…quickly and continuously converting new product ideas into crude mock-ups and working models, turns traditional perceptions of the innovation cycle inside out: instead of using the innovation process to come up with finished prototypes, the prototypes themselves drive the innovation process’ (Schrage 2000, p.64). More often than not, prototypes (of differing media at various stages of the design process) will provoke thought and raise unexpected questions that are not considered at the outset of the project.

The ingrained strength in producing prototypes is that ‘… the best and most powerful models are provocative and the unexpected questions that a model raises are sometimes far more important than the explicit questions it was designed to answer’ (Schrage 2000, p.76). This is the sentiment and the goal that the author hoped to achieve at the outset of this project; that questions would be raised and answers discovered to assist in the further development of the new microwave bending technology through a common visual language.

The introduction of industrial design into Project 2.3 of the CRCWI, and specifically the prototyping of designs actually draws the many disciplines into a focused discussion, and by doing so, encourages creative intercourse and input, broadening the cross fertilisation of ideas, resulting in a richer and more comprehensive outcome for all.
6.0 Research, Design and Development work

As suggested in earlier chapters, an industrial designer needs to have a broad understanding of the many different influences on the design and development of their current project. The information gathered into areas such as the design history of bentwood furniture, mechanical and physical parameters of the existing and developing bending technologies used to produce bentwood products, material characteristics and many others, all help to form a solid foundation of knowledge for the creation of suitably designed bentwood furniture. The knowledge enables the author of this document, an industrial designer, to produce work that satisfies the parameters established by the many different organisations involved in the CRCWI.

With the above in mind, the work completed for this project takes the form of a series of smaller exercises. The project culminates with two case studies that involve working closely with industry partners to produce furniture containing microwave bentwood components.

The current technological parameters of Program 2.3 placed some tight restrictions on the type of products that could be designed and produced at this present time. The requirements that, 1) the minimum radius to be used is R300 mm, 2) Mountain ash is the primary timber and 3) the component section size 25x25 mm set the parameters for the project brief for the first case study, producing a café table with bentwood edges with Company G. The second case study was designed with outdoor furniture in mind, focussing on Jarrah which is a timber that is known to be difficult to bend. The results of these case studies are discussed later in this chapter.

There are also a number of unknowns attached to the new wood bending process. The material having a ‘memory’ where the timber piece may try to return to its natural form is one such issue. The design work has to make allowance for this possible movement because there are always environmental influences affecting the timber structure. Another unknown is the effect of microwave drying on microwave bent components, which is currently in the early stages of research. Thus, it is not possible to predict the effects of the microwave technology on the final bentwood component supplied to furniture manufacturers.

6.1 Workshop in Tasmania

As detailed in Chapter Three, a Wood Bending Workshop was held at the Australian School of Fine Furniture in Launceston, Tasmania by an experienced furniture maker and wood bender, which was designed to give participants practical skills and training in steam bending of wood.

The workshop was divided into two parts. Part One consisted of specific research tasks such as the evaluation of bending quality using a range of selected timber species, a comparison of bending properties of backsawn versus quartersawn timber and a comparison of moisture content during bending with or without metal straps. Part Two consisted of more experimental work with participants designing their own project aiming to bend various shapes, gain
experience in making forms, using clamps, restraining components after bending and in general testing the knowledge of steam bending gained in the first days of the workshop. It was during this workshop that two prototypes were designed and constructed by the author. The primary reason for producing these prototypes was to see what difficulties could face commercial manufacturers when constructing furniture using bentwood components. The products produced for this workshop were a Rocking Roger Horse and the 'Cairo' stool, a design reminiscent of the klismos chair of ancient times.

6.1.1 ‘Rocking Roger’ Horse

Some samples of spotted gum (Corymbia maculata) were brought to Launceston from Melbourne for the testing of its bending properties. There were also some tools available, this included a range of jigs. In group discussions, it was decided to produce a piece of furniture that utilized the bent wood samples and the available jigs as making new jigs and formers would use up valuable time. The ensuing conceptual sketching resulted in a rocking horse product. The rocking horse allowed for the use of existing jigs to produce the rocking struts and the ribs. This approach also imitates what occurs during manufacturing where tools are often used for multiple purposes.

To produce the struts for the rocking feet, two lengths of spotted gum (38x38 mm) were soaked overnight for the attempt to bend them in the hydraulic press, to the radius of R500 mm using an existing bending press-former. This failed. The section size of these components was based on parameters set by the Program 2.3 research program, however, the soaking in water and the long steaming time (one and a half hours) did not achieve what was desired so the team moved onto Plan B.

Plan B was to cut thinner strips of myrtle and to steam them in order to hand bend around an existing jig with a radius of approximately R500 mm. This was successful and the two rocking parts were placed restrained into a conventional kiln for five hours of drying.
In the meantime, the spotted gum was sliced into 10x38 mm sections and placed in the steam box for half an hour. Then the ‘ribs’ were hand bent around the Cairo leg jig and a purpose built drying jig was constructed to hold the ribs in form during drying and until final assembly. The rocking horse was designed in a hurry, with only a little time allowed to calculate ergonomics or to refine the construction methods. Therefore, the design is not as refined as it would be if the purpose was for manufacture. This artefact is not for comparisons with professionally finished furniture as it is made specifically to demonstrating the bent wood technology. The results of the bending of the spotted gum were that tension failures occurred during the initial bending of the ribs and worsened overnight when drying. For this prototype the tension failures were glued to prevent further peeling and the rocking horse was considered a success at this early stage of the research program as it was an examplar of what could be achieved of the technology and the author gained knowledge during the making of this prototype which was applied at later stages of the research.

The knowledge gained through the production of the rocking horse helped to better appreciate the bending parameters of spotted gum at differing thicknesses. It also gave the author first hand understanding of the problems caused by the bending process, such as the tension and compression failures that can occur due to the speed and time needed to bend a rib component. Issues regarding the drying of bentwood components, which had not surfaced until this time, such as exaggerating tension and compression failures, were also observed.

6.1.2 ‘Cairo’ Stool
As with the rocking horse, the parameters set for the production of the stool prototype were set by the research team to push and explore the limitations of steam bending. The prototype parameters set; Blue gum sections of 20x25 mm to make the seat rails and legs, all edges were routed prior to bending with radii of 3 mm and the final requirement was for the final product to be disassembled for transport and to easily view the bent components.
Initially, a jig was built with the correct leg profile and an existing strap was modified to accept the correct dimensions and length for the leg. Then the legs and seat components were bent and left overnight in the kiln for drying. The remaining parts were machined and shaped by a very helpful student of the school. The following day the stool was assembled and reviewed.

A review of the stool prototype revealed the following issues:

- Blue gum legs discoloured overnight due to reaction between tannin in timber and mild-steel strap.
- All surface failures (compression and tension) occurred during bending process were exaggerated by overnight drying
- There was also some collapse of outer surface due to drying

In conclusion, the research and prototypes built during the duration of the workshop gave the author a very good understanding of the issues and problems faced in order to produce bentwood components on a commercial scale. It exposed the author not only to the physical realities of wood bending (construction of jigs for bending, drying and time limitations between the heating and bending of components) but also gave a deeper appreciation of the scientific data being generated and collated as part of the Project 2.3 research program.

6.2 Concept sketches of furniture using bentwood components
Following the workshop in Tasmania, a literature review into the background of bentwood furniture was undertaken to gain better knowledge of the field. The result of this investigation is documented in Chapter three. Based upon this knowledge, a lot of sketches were generated by the author, in order to design a variety of furniture products that best utilised the benefits of bentwood. Some of the key knowledge gained was that the benefits of bentwood over cut wood are that it is mechanically stronger, may be considered more aesthetically pleasing to some and is cheaper to produce.

The following designs attempt to use the best elements of bentwood components, and the microwave softening process, by utilising them in designs in both functional (structural) and aesthetic (non-structural) ways.
Figure 56 – Design sketches of ‘Arch’ table
Figure 57 – Design sketch of metal strap to form arch

The above design sketch (Figure 56 and Figure 57) is for a side table where the structural benefits as well as the aesthetic style of bentwood are used to the best effect. The two legs are identical, thus reducing the number of components needed for this table to two shapes – legs and butt-jointed table top.

The legs are firstly shaped with a narrower section in the middle for easier bending. This is to allow the timber to be bent to a smaller radius than R300 mm, as currently achievable for 25x25 mm sections. The metal strap required some modification to fit around the non-uniform timber length. The design harnesses the negative aspect of bentwood, this is where the component will have a tendency to straighten and turns it into a positive. The leg locates into the two slots in the table top and the outward movement of the leg straightening creates a tighter join between the leg and table top. This restraint of the timber makes the table more stable and holds the bend more securely.
This design (Figure 58) came about after discussions with Company D about the need to produce wide asymmetrical timber sections. The potential problem with this design is that the ends of the timber bends are unrestrained and currently it is not known what amount of movement occurs in a bentwood component after the final drying process. Ideally it is preferred not to have to restrain the ends of the arms, as the bend is not only aesthetic but a mechanical feature of the component whereby the arms can be used as springs, as with the Paimio chair by Aalto (see chapter three), to allow the chair to adjust to each individual.
Figure 59 – Extendable table with bent legs

Figure 60 – Extendable table with bent legs and edges
Figure 61 – Small couch flips into dining table
Figure 62 – Bent legs turns side table into dining table
Figure 63 – Extendable table
Figure 64 – Extendable table
Figure 65 – Extendable table
The intention of these table designs (Figure 59 to Figure 67) is to cater for the increase of high-density living in cities all around Australia. There is a market for the design and manufacture of furniture that fits into these small spaces and has a multipurpose use such as this table that can transform from a coffee table to dining table easily. The design sketch shows an asymmetrical leg that pivots, having a short section that holds the table top at coffee table height (350 mm) and a longer section that creates a dining level table (850 mm).
Figure 68 – Mobile buffet extends to table
Another piece of furniture that can be multi-purpose is a mobile buffet or credenza (*Figure 68 and Figure 69*) that stores dining utensils but that can also pull apart to create a bench top to seat four people during meals.
Figure 70 – Long table with half-circle ends

Figure 71 – Bentwood legs and table edges
The use of bentwood components as table edging is not reserved for only commercial use. The bent wood does not have to band the full circumference of the table either as seem in the sketches Figure 70 and Figure 71. Bentwood edging can be used as a highlight detail on only some edges, or to create the supporting table legs.

Figure 72 – Café Table

Case Study One originated with the ideas presented in this sketch (Figure 72).

Figure 73 – Folding chair

To be used as a folding chair (Figure 73) these bentwood components are not only ergonomically comfortable (as seen in similar chair designs manufactured out of cut wood components) but the integral mechanical strength of bentwood is also exploited.
Figure 74 – ‘Wishbone’ legs made out of one piece of timber

Figure 75 – ‘A’ chair
Similar to the ‘Arch’ table, the goal with these sketches was to design a table that had the legs made out of one piece of timber. The idea is to cut down the centre of the timber piece and part the pieces from the inside to create the legs. This splitting of the component can also be used to create some unique chair shapes (Figure 74 and Figure 75).

Figure 76 – ‘Sling back’ bentwood chair

Figure 77 – More chair sketches using bentwood components in a variety of ways
6.3 Bending tests with slots
A folding table was designed with intention to use bentwood components in a manner that made them structurally necessary and also visually pleasing. This was achieved by making the bentwood handle an integral part of the folding and storage mechanism.

![Figure 78 – Original design sketch of folding table with bent wood legs](image)

![Figure 79 – Sketch of folding table](image)
Figure 80 – Exploded sketch of one half of table

Figure 81 – Detail sketch of leg
Figure 82 – Folding action

The design required the table top to slide into grooves down the inside surface of the bent edges. It was designed this way to reduce the need for fixings (glues, screws etc) and to minimise assembly complexity. At the time, it was thought that it would be easier to machine the slots into the edges prior to bending (which was found later not to be true.) A secondary reason for doing these tests was that it is currently achievable to compress hardwood, machine the required shapes and then bend and twist the piece of timber, as seen in Figure 83.

Figure 83 – CD stand designed and manufactured by Curvatura Frulana
Based on this design, a series of bending tests were completed.

The timber section of 25x25 mm had a slot machined down the centre length measuring 9x9 mm. This timber was then microwave softened and bent around the R300 mm former using the hydraulic bending table.

![Figure 84 – Section profile of table edge](image)

The results from the tests, which were performed in May 2004 at the Melbourne University Bending Laboratory, Parkville were not positive and do not compare favourably against the abilities of some compressed hardwoods. There were three reasons for the failure of these components.

The first failure, and most severe, is due to the stress concentration brought about by the square corners ‘within’ the slotted specimen. These stress concentrations can increase stress levels by three or four times within the immediate area of the corner. Already in a highly stressed state, these concentrations increase the stress levels above the ultimate limits of the wood. To further aggravate stress levels, the machining of the slot possibly cuts across grain direction. Consequently, shear stresses were developed and also greatly increased due to the stress concentration factor. As a result of wood shear properties (tension and compression) being much weaker compared to longitudinal properties, they fail rapidly and more easily.

The second reason for failure is perhaps separate from the above corner stress concentration, and is more difficult to define from the preliminary analysis. Within the slots there is a longitudinal compression type of failure occurring. Looking at a non-slotted specimen there are similar compression creases, however, the slotted specimen seems to have these more frequently and severely. So the resulting compression stresses exceed the ultimate compression strength of timber.

The third explanation for the failures is due to the great variation in the timber structure which results in the distortion of the pre-grooved components. Timber is an orthotropic material meaning it tends to grow or form along a vertical axis.
In summary, the final failure is a splitting of the wood at the slot corner due to stress concentrations which promote higher longitudinal compression and shear stresses. Thinking about it practically, if there is a slot cut out from the middle of the specimen, then there is less material supporting this cross-section so it’s not as strong and failure is more likely. The problem could be overcome if the bending former is designed to support the cut-out, however, tests to support this theory have not been carried out to date.

Figure 85 – Sketch of bending table with new former

Figure 86 – Sketch of timber with slot and former

Another suggested solution is to change the slot profile from square into rounded, eliminating the square corners and reducing the stress concentration at these points.

After the tests were concluded, the results reviewed, and taking into account that a common industry practice is to machine bent components after bending, a decision was made that for the design of any future products it would be best to machine bentwood components post-bending. There were so many factors influencing the success or failure of a bend (grain direction, moisture content and others) that it was more sensible not to introduce any other additional features that could cause possible failures into the bending ‘equation’.
6.4 Justification for creating industry-based case studies

From the very beginning of this project, the author felt it was very important to collaborate with industry partners for a variety of reasons. To begin with, collaboration would provide firsthand insight into the manufacturers’ concerns regarding the developing new technology and how they foresaw the use of the technology. Also by working with industry partners, it gave an opportunity to design products using bentwood components for an existing market, rather than designing a product that does not have commercial purpose.

Another reason for working with industry-based partners was to continually promote the technology into the furniture industry thus satisfying part of the CRC mandate for technology transfer. The integration of industry-based case studies into this design project also allowed the author to test abilities of the research technology to date (parameters and other limitations.)

A number of furniture manufacturers were contacted and interviewed, however, only two case studies were selected for this project due to the scope in each individual project including a variety of materials, dissimilar methods to produce the bentwood components, distinctly different market sectors and end use of the products. It was agreed by the Program Manager that the two case studies would be satisfactory to test the technology at this time, with every intention to do further case studies at a later date, with the continuing developments of the technology.

The case studies can be summarised as seen in Table 3:

<table>
<thead>
<tr>
<th>Case Study One</th>
<th>Case Study Two</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer: Company G</td>
<td>Manufacturer: Company E</td>
</tr>
<tr>
<td>Material: Mountain ash (<em>Eucalyptus regnans</em>)</td>
<td>Material: Jarrah (<em>Eucalyptus marginata</em>)</td>
</tr>
<tr>
<td>Market: Commercial/Hospitality</td>
<td>Market: Domestic</td>
</tr>
<tr>
<td>Furniture location: Indoor</td>
<td>Furniture location: Outdoor</td>
</tr>
</tbody>
</table>

*Table 3 – Case study parameters*
6.5 Case Study One: Café tables with bent edges with Company G

The product for this case study, a café table, was selected for a number of reasons. The product selected for this case study fitted well into the range of existing products developed by Company G; round tables are made in the thousands per annum throughout Australia by a range of commercial furniture manufacturers. For example Company G alone manufactures approximately 6000 café tables per annum with 40 per cent being round. The minimal diameter size Ø600 (R300 mm) also matched with the current technological parameters of the bending technology. Company G currently offer round café tables at Ø600 mm, Ø700 mm and Ø800 mm and larger if required.

Currently solid wood edged tables are offered by a number of commercial furniture manufacturers including Company G, but have limited sales with customers due to the premium price attached. This is due to the amount of material required and the time taken to manufacture each round table with solid wood edges. Each table is constructed with rectangular pieces which are glued together and then carved and sanded down to the required shape (Figure 87). This process takes more time than a manufacturer wants and produces a lot of material waste.

![Figure 87 – Carving and sanding to produce solid wood edged table](image)

Another reason for a table with bentwood edges to be selected as a case study was that there was an identified gap in the market: no manufacturers currently make these types of tables. Thonet (Germany), Ton a.s.(Czech Republic), Bentwood Furniture Company (Poland) and many Asian manufacturers, who all produce hundreds of thousands of bentwood components
per annum, do not feature bentwood edges as part of their catalogue (Figure 88). This could open a new opportunity to Australian furniture manufacturers.

6.5.1 Bending of pieces in experimental machine at University of Melbourne, Parkville

The new bending process being developed by the Project 2.3 team, using microwave technology to heat and soften the timber blanks was used to produce components for this case study. The components used for this case study correspond with the current parameters of the pre-commercial technology. These parameters are that the component size is 25x25 mm, Mountain ash timber and has a minimum radius of R300.

The timber pieces were soaked overnight to increase the moisture content of the wood from an average 25 per cent to 35-40 per cent. The need for increased moisture in the wood was based on previous tests completed by researchers when using mountain ash. It was necessary to increase the moisture of the timber to fibre saturation level to achieve constant successful bends if the minimum radius was to be achieved.

Figure 88 – Table from Ton a.s. catalogue (2004)

Figure 89 – Large tension failure

Figure 90 – Small tension failure
The bending rig used to produce the components for this case study was an experimental unit, designed for the express purpose of collecting the research data required to further this project. As shown in Figure 91, it has a horizontal flat surface with an MDF former R300 mm moving horizontally by a hydraulic piston. A metal strap, based on the design created by Thonet, is placed on the outside face of the timber piece to prevent tension failures during the bending process. The strap has force release screws on the ends and it moves against the two rotating pins when the former is in motion.

![Figure 91 – Bending table with R300 former, metal strap and timber component](image)

The microwave softening unit used to produce components for this case study is also an experimental machine, designed and assembled to allow research tests to take place to generate data. The unit consists of primarily three areas, the generator, applicator head and guidance tunnel. (Figure 92) The unit has a variable power output between 300 Watt and 5000 Watt, with a frequency of 2.45 GHz.
The conveyor belt moves the timber piece past the applicator head with a speed range between 13 mm/sec to 245 mm/sec. The guidance tunnel itself has an internal measurement of 45x45 mm, allowing a timber piece with a maximum section size of 38x38 mm to pass through.

6.5.2 Drying components in humidity chamber at University of Melbourne, Parkville

Once bent and restrained (Figure 93), the components were first placed in the 20 per cent humidity chamber to reduce the moisture content (MC) from 30-40 per cent to 20 per cent. They were then moved into the second chamber to bring the MC down to the required 12 per cent. It is the standard practice of furniture manufacturers to use 12 per cent MC for indoor and 15 per cent MC for outdoor timber.
It was found that during the drying process in the conditioning chambers, a number of components split on the outer surface, with tension failures due to internal checks and other unknown material imperfections as seen in Figure 94. There was no way to predict that these failures would occur. During the bending process the blanks seemed to respond well to the processing (microwave heating and restrained bending) and there was no visual indication of the tension failures that would occur.

Figure 93 – Bent component restrained with metal strap

Figure 94 – Tension failure occurred during drying in conditioning chamber
Program 2.3 researchers had to develop an improved method of restraining the bentwood components during the drying process to reduce the twisting and warping of components during drying. As described in detail in the previous chapter (Chapter Five), the design strategy for this project aimed at giving direction to the researchers to improve the bending and drying of bentwood components, using the new heating technology. The original method of restraining the components during drying was not acceptable. Due to feedback and comments from the author, alterations were made and the process of drying bentwood components was modified, reducing the rate of failure during drying.

6.5.3 Prototype Table #1
The first prototype produced was a low cost café table with solid bentwood edges. At the present time, Company G and other commercial furniture manufacturers do offer solid wood edged tables in a range of sizes to their customers. The production technique described above (edges are assembled from straight edged blocks) means that a large amount of material is wasted by milling or sanding the blocks to the final form. (Figure 87)

The aim of this project was to produce a similar table but to replace the current edges with bentwood edges; in theory reducing material costs, material waste and time required to cut and sand the round edges.

The product description, as given to Company G, for the production of the prototype was as follows:

- Table to be Ø620, internal diameter of edges to be Ø600
- Mountain ash bentwood edges supplied by the CRCWI
  - Two pieces are to be used to make the full 360 degree circumference
  - Edges to be left unstained and coated with clear varnish
- Table top centre to be 18 mm Medium density fibreboard (MDF)
  - 1 mm Beech veneer on top surface
  - Table top to be stained dark brown, 'wenge' colour
- Standard stainless steel central leg attached to 'Luna Disc' base

Below are the sketches used as a basis for the production of a low-cost café table using bentwood edges.
Figure 95 – Sketch of Café table #1

TABLE HEIGHT — 700mm or similar to typical café table
Figure 96 – Exploded view of the components of the Café table #1

Table Surface
Veneer with Wenge Finish
Refer to DWG3

Table Top
MDF substrate 19.0mm or same as existing table tops
Refer to DWG4

Table Edges
Mountain Ash Bent Edges
Join edges with finger joint or biscuit joint
Clear natural finish
Refer to DWG3

Base
‘Luna Disk Base and Column’ or similar Dia 450
Stainless Steel polished

Figure 97 – Section view of bentwood edge (not to scale)
Figure 98 – Section view of MDF table top

Figure 99 – Assembly section view of bentwood edge, table top and veneer
The final design differed slightly from the original brief and drawings submitted to Company G to prototype the table. An explanation of the changes, description of the final outcome for this table and an evaluation of the process is discussed in the following chapter (Chapter Seven).

6.5.4 Prototype Table #2
Whilst Table #1 was designed to be streamlined with the current manufacturing practices of Company G, this second table was more complex and was designed to satisfy alternative desires with which a café table must comply. The table still uses bentwood as the edging detail, however, they are used more as decorative cladding than an integral part of the table structure. The brief stated that the table was to be stackable, structurally sound, easily cleanable, and lightweight using bentwood edges.

6.5.4a Concept Designs for Table #2
The sketches below describe the iterative process behind the design of Table #2. The difficulty with this design was that due to the legs having to be located to the outside of the table, to allow for the stacking of multiple frames, they had to be attached to the bentwood edges.

With this constraint, the obvious solution was to attach the timber legs to the timber bentwood edges but this presented a major problem because this joint would be too weak (Figure 101 to Figure 107). While there were two main reasons why a frame had to be designed, the most important reason was to make the table strong enough to cater for the weight of a grown man leaning or sitting on the table. Another purpose for the frame was to restrain the ends of the bentwood edges to stop any movement where the edges may try to return to their original straight form.
Figure 101 – Table #2 stacking

STACKING TABLE
MIN $\phi 600 - \phi 800$
Figure 102 – Attaching leg to table edge
Figure 103 – Restraining ends of table bentwood edges

Figure 104 – Joint designs to hold edge ends and legs
Figure 105 – Joint designs to hold edge ends and legs

Figure 106 – Frame designs
6.5.4b Table #2 design and development

The original specifications to produce original design for Table #2 are listed below and there were some modifications needed to suit production. These changes are discussed in Chapter 7 in greater detail.

- 18 mm MDF with wenge stained beech veneer table top
- Table edges, internal diameter Ø600, 22x22 mm section with a clear finish
- 3 mm aluminium frame
- Solid Mountain ash legs with a clear finish
- Three aluminium pins to attach each leg to frame

The images contained in this section were used as production drawings to build the two prototypes of this table design. As commented by Andrew Thompson, head designer at Company G, they often work from less detailed sketches to produce a prototype. Once the design is approved by the relevant person, it is at this time when a package of detailed drawings is produced for the mass-production of a product.
Figure 108 – 3D sketch line drawing defining materials and surface finishes

This drawing (Figure 108) depicts in line form the final appearance of Table #2 as created by the designer.
Through past experiences of the author, working with many different manufacturers and variety of products and materials, it has been observed that there is always a chance that the interpretation by the person making the product may be different to that intended by the designer. The author has always found it best to provide more detailed drawings than considered necessary to give the manufacturer of a product a clear understanding of the intended design in order to avoid any future problems or misunderstandings. Experience has taught the author that the best drawing to start with is always a fully assembled image of the product, providing all details of the materials to be used, finishes and quantity required for each component (Figure 109).

The types of drawings seen here and used during the project are typical of what would go to the prototype shop prior to producing production drawing to Australian Standards.

![Figure 109 – 3D sketch exploded view drawing](image-url)
The purpose of the above drawing (Figure 109) is to explain the construction and assembly method in detail to allow minimal chance for any personal interpretation.

*Figure 110 – 3D sketch drawing of leg component*

*Figure 111 – 3D sketch detail drawing of leg/frame assembly*
The joint attaching the leg to the frame was a crucial part of the design and therefore drawn in great detail, again to avoid any miscommunication or misinterpretation by the person making and assembling the prototypes.
As mentioned earlier, the final design was slightly altered from the original brief and drawings submitted, however, an explanation of the final outcome and an evaluation of the whole process is included in Chapter Seven.
6.6 Case Study Two: Rocking Chair with Company E

Company E is a large outdoor furniture manufacturer based in an urban area of Western Australia. As the furniture produced is made of jarrah, a species native Western Australia. After meeting with the director and his team, it was agreed to attempt to bend jarrah slats to fit into an existing product thus making this project about component replacement. The product in question is the Rocking Chair.

![Rocking Chair](image)

*Figure 114 – Rocking Chair (2005)*

The Western Australian State Government’s new forestry policies which limit the amount of plantation jarrah to be harvested per annum and also directs the amount distributed into select areas of manufacture affects the availability of jarrah.
Jarrah is a fine-grained, dense timber that has traditionally been suited to a wide range of indoor and outdoor, appearance and structural end uses. These end uses reflect its strength, durability and warm, rich colour. The natural characteristics of jarrah trees and the quantity of regrowth from heavy timber cutting in the early part of the last century provide a large quantity of jarrah that is not suitable for sawmilling, either due to its small size or presence of internal defects. Jarrah residue is not suitable for papermaking, which has limited its use compared with other timbers. However, it is low in ash and impurities, which makes un-millable jarrah suitable for activated carbon, industrial charcoal or domestic firewood (Forest Industry Statement, January 2004, p.2)

The prediction of a reduction in available material is accurate (Forest Industry Statement, p 2) and makes it essential for the future of a company such as Company E to consider other methods to extend the use of and minimize waste.

The area of component replacement has always been considered a large segment of future business for microwave bentwood. If successful, microwaved bentwood would be able to replace components that are currently carved or sanded into bent shapes. Microwaved bentwood also offers the advantaged of being environmentally friendly due to less material waste. There is an added attraction to businesses as these components would also be cheaper to produce.
The possibilities for the future of manufacturing for a business like company E are, thus, apparent. So utilizing the technology on their products is useful. In this case the rocking chair provides a platform for experimenting with component replacement.

The dimensions for the back slat, 46x15x800 mm, were selected; allowances were made for longitude and radial shrinkage, the need for excess material for surface finishing and to allow some length to dock the pieces to final required dimension. The timber also had to be quite ‘green’ with a high moisture content of 20-25 per cent which would be dried after bending to an accepted industry level of 15 per cent MC for outdoor furniture. The project was designed in such a way that once the components were bent, they would be returned to Company E for testing by assembling them into the chair back. One of the issues concerning the bending of jarrah was that being a high density timber with a tight spiral grain; it would not remain bent unless restrained at either end in the final product.

The press-former and drying jig were designed after extensive research of existing bending equipment with much consideration being given to the restraint of the components for drying. The jigs were designed to imitate the commercial method of wood bending and therefore to speed up the quantity of components produced. This parameter created the need to design a process to bend and dry more than one piece at a time, working easily with the experimental microwave machinery.

In order to imitate the mass-production of overseas manufacturers without investing too much time or money should the principle of restraint during drying not succeed, this case study attempted to bend only five pieces at a time. If it would work on five components then it would prove the process works well with the microwave technology and can be expanded upon when the commercialisation of the technology takes place. Also the case study aimed to dry ten pieces simultaneously, dictating the need to complete two rounds of bending the jarrah to fill one drying rack. Section 6.6.5 contains more detail about this part of the project.

The components, once bent and dried, were transported back to Company E for assembly in to a Rocking Chair, and then to have further environmental testing done as discussed later in Chapter Seven. They were transported in racks similar to the drying rack to stop any spring back that may have occurred during the transition from the differing environmental conditions of Victoria to Western Australia.

The Prototype Manager at Company E was to assemble the components into a back frame of the Rocking chair and expose them to environmental testing according to the companies standard testing methods.
The instruction was to environmentally test the bentwood components by exposing the back frame to the outside elements, which is how Company E test all their products to see if they are suitable (in design or construction) to outdoor use. This testing procedure places the timber outside to be weathered by wind, rain and the temperature variations over day and night, mimicking the final location of Company E furniture as recorded in section 6.6.8.

Working within the current technological parameters and unknown elements of the bending technology, the sequence of events for this project was:

- Timber to be machined to dimensions 47x15x800 mm with a 20-25 per cent MC
- Five pieces bundled together and microwaved simultaneously using the larger microwave tunnel located at the Creswick campus of the University of Melbourne
- Place five pieces on former and press to required bend
- Allow component to cool, then transfer to drying rack
- Dry the restrained components in kiln till MC reduced to 15 per cent
- Transport restrained components to Company E
- Company E to do final machining (surface sanding and tenoning of ends) and then assemble components in back frame of Rocking Chair
- Assembled back frame with bent slats to undergo environmental testing

6.6.1 Bending of Jarrah by Bending Workshop coordinator, 18th May 2005
A starting point for this case study was created by attempting to bend a sample group of Jarrah pieces by traditional steam heating and press-forming to compare against the results of microwave bending. This furniture maker, an experienced wood bender of twenty years from agreed to complete this test. He used an existing press-former which had a similar S-bend shape required for the chair.

The sample group of timber sent to his workshop for steam bending had the same characteristics as required by the microwave bending technology, which was specified by the author to the timber supplier;

- Dimensions 15 x 47 x 800 mm long
- Moisture content variable between 20-25 per cent
- Straight even grain free of knots, gum veins and surface imperfection

Below are some sketches (Figure 116 and Figure 117) of the bending press and drying rack used for the tests completed. The real purpose of these jigs is to produce S-bend chair back slats for a major retailer
Figure 116 – 10 tonne pneumatic press with double layer press-former

Figure 117 – Drying rack
The furniture maker stated (personal communication 2005) that the tests ‘went better this time than in his past experiments.’ He stated that the main factor in this success was most likely due to the timber having a moisture content of on average of 22 per cent which in experience is ideal for bending.

The method followed to carry out the tests was to steam the samples for 35 minutes, place them in the press-former for 10 minutes with ten tonnes of pneumatic pressure and then transfer them into a restraining drying rack. This rack was placed into a conventional kiln which dried the samples for 25 hours at 65 degrees Celsius (C).

The test results were that the jarrah retained the required shape to a satisfactory level, Grade 2 as judged against the bending grading system developed by Dr Barbara Ozarska and Martin Beel (Table 4), however, there were a number of issues that affected the final components.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Basis for rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No damage – piece can be used without further work</td>
</tr>
<tr>
<td>2</td>
<td>Slight damage – additional sanding required prior to use</td>
</tr>
<tr>
<td>3</td>
<td>Moderate damage – additional machining and sanding required</td>
</tr>
<tr>
<td>4</td>
<td>Irreparable damage – some value can be recovered</td>
</tr>
<tr>
<td>5</td>
<td>Irreparable damage – no value can be recovered</td>
</tr>
</tbody>
</table>

Table 4 – Grading System for assessing bend quality

First, there were a number of tension failures (on the outer surface of the bend) due to grain runout. Another problem that was identified on the samples was the surface collapse of the timber that occurred during post-bend drying. This second problem may be due to the initial high moisture content, inappropriately selected drying parameters (temperature and humidity) or the speed at which the samples were then dried to drop to the required level of 15 per cent for outdoor furniture, as stated in Australian Standard AS2796.3.
6.6.2 Microwave softening, bending and drying tests

Dr Grigory Torgovnikov and Dr Alex Shaginov, from Program One of the CRCWI, completed some tests using microwave facilities at Creswick, Victoria plant to test the viability of microwave heating five timber samples at once. The outcomes that were required were to see if the timber samples, when sandwiched together, would heat evenly through the thickness and along the full 800 mm length.

![Microwave installation with box applicator for wood treatment](image)

To prevent the outer lengths-ends from overheating additional boards were used. Different schedules and wood positioning was studied and such rational parameters (more even temperature distribution) were calculated.

- Microwave power – 10.8kW at frequency 0.922 GHz
- Electric field strength vector E orientation – parallel to the wood grain
- Position of timber – larger size of timber set (five in a row) was horizontal
- Feeding speed of timber – 10 mm/sec
- Temperature of air – 120-135°C

The result was that the temperature of the samples ranged from 96 degrees Celsius to 106 degrees Celsius after microwaving, which are well within the accepted range of temperatures for bending timber, based on research currently being performed by Program 2.3 researchers.
6.6.3 **Bending jig**

The jig designed to produce the bent wood components for Company E is based on the requirement to produce more than one component at a time, thus mimicking commercial requirements to mass-produce components quickly. Working in conjunction with the CRC staff engineer, the design of the jig was based on an existing bending former (*Figure 121 and Figure 122*). The design of this jig is also supported by the use of similar machines in large European bending companies such as Curvatura Fruilana, Italy and Bentwood Furniture Company in Jasienca Stock Company, Poland.

*Figure 121 – Bending former at the Bentwood company in Jasienca Stock Company, Poland*

*Figure 122 – Bending former at Curvatura Fruilana, Italy*

The components for Company E do not require strapping, as the required radii of the bends are very subtle and the former itself acts as the strap. The very subtleness of the curves poses a problem in itself. It is possible that the wood may not bend past its elastic limits therefore not plasticising the fibres enough to hold the required bend. The results of this will be discussed in the following evaluation chapter.

---

*Figure 123 – Backslat drawing from Company E*
Below are some conceptual sketches of the mechanical design for the press-former for this case study (*Figure 124 and Figure 125*). Also shown is the final technical drawing (*Figure 126*, as drawn by the CRCWI staff engineer) to be used for quotation and production purposes.

*Figure 124 – Exploded view of Press-former*
Figure 125 – Sketches for design of bending rack
Figure 126 – Technical drawing for the manufacture of a press-former (B.Bellingham)
6.6.4 Bending tests

On the first visit to the University of Melbourne, Creswick Campus, it was necessary to do two rounds of bending tests. The first was to trial the press using test timber samples. The timber samples were used by Prof Torgovnikov, (Section 6.6.2) to calculate the optimal microwave parameters for heating multiple pieces. This test allowed the team to work out timing issues and assembly issues of the make-do press.

Initially it was intended to use a press machine that was located in the research laboratories at the Creswick site, the bending former was not able to fit into the space allowed. The MDF former was deeper than originally planned and it was necessary to modify the former design in order to have enough strength to bend the timber slats without causing any deformation. As can be seen in Figure 127, the tests were done on an improvised press, using an A-frame steel brace with a hand pump pneumatic piston and two metal spacers.

Figure 127 – Assembled bending jig
The bending process for this case study followed the following steps:

Timber slats were bundled into groups of five pieces with a timber piece on either side (Figure 128). The timber on the edges concentrated the microwave energy into the centre thereby heating the five boards equally. These bundles were then soaked in water for twenty-four hours prior to the tests. The reason for soaking them in water was an understanding that this would help increase the MC in the timber to make it easier to soften and bend. As Jarrah has a tight spiral grain, the water did not permeate deeply which is why it was necessary from the outset to have green timber (above 20 per cent MC).

Figure 128 – Soaking timber
The timber bundles were treated with the microwave power (determined by the earlier tests) to soften the slats for bending (*Figure 129*).

A layer of Teflon™ 0.35 mm sheet was placed beneath the slats and the MDF former to prevent staining of the timber and any swelling of the former through the absorption of water. The slats were then placed on the bottom former with a minimum of 10 mm between each piece (*Figure 130*). With the timber sandwiched between Teflon™ sheets, the top former was located (*Figure 131*) and the pneumatic piston and spacers placed into position (*Figure 132*).
Figure 130 – Heated samples placed on base former

Figure 131 – Side view of bending jig with timber pieces
The slats were left in the press-former under pressure from the pneumatic piston and hand clamps for one hour, to be allowed to cool in to shape. Once the pressure and top former were removed, the samples were quickly assembled into the drying rack.
These trials allowed the team to work out how to heat the timber in the large microwave unit and to place the timber samples in the bending press, for how long the samples had to be held in the press and how to assemble the drying racks.

6.6.5 Design of the drying rack

The task of this piece of equipment was to dry multiple units simultaneously, by restraining the component into the S-bend and allowing air to circulate around to assist in drying the components.

Figure 133 – Sketches of the original design for the drying rack
A problem was identified: the drying racks were not strong enough to hold the samples in the S-curve. The timber forces were stronger than anticipated, trying to return to their original straight form. This effect is caused by the subtle curve, required in the case study, was not enough to bend the timber grain past its limits of elasticity.
Figure 135 – Samples being assembled into drying rack

Figure 136 – Assembled drying rack with spacers between assembled into drying rack samples to allow air flow
To strengthen the drying rack, larger blocks of wood (Figure 138) were placed at the top and bottom and screwed together by the vertical brackets. Extra spacers were also inserted to guarantee that all of the components would dry in the same shape. (Figure 137)
6.6.6 Equipment to transport bentwood components
Specific equipment was designed to hold the bent slats in the required shape during transport to Company E in Western Australia. The purpose of the apparatus was to reduce the chance of component movement that may have occurred due to any environmental influences in transport, such as temperature and humidity.

![Diagram of transport equipment]

*Figure 139 – Sketch of transport equipment*

Once the slats were dried to the correct moisture content, they were sandwiched tightly together using the top and bottom forms of a drying rack and the 10 mm spacers were removed. The components with the top and bottom forms of the drying rack were then located in place by timber lengths in a vertical direction which were screwed to the forms (*Figure 139*). Transport from Victoria to Western Australia was via aeroplane.

6.6.7 What happened?
The samples from the bending tests at the Creswick laboratories were sent to Company E at the end of July 2005. Follow up contact with Company E was problematic but feedback regarding the bent jarrah slats was obtained in November 2005 from the Prototype manager.

The original discussions regarding the set up of this project were held between the Director of Company E and the author of this document. The direction and outcomes were agreed upon by these two people. Following the agreement for the final outcomes of this project, the Production manager was involved to source and supply the timber required to carry out the bending tests. It was documented in emails between the Production manager and the author of how Company E was to test the bent slats. This testing process required for the slats to be assembled into a back frame of the Rocking Chair and then exposed as an assembled unit to outdoor conditions.
The bent timber slats were transported to Company E in Western Australia and delivered to a third person, the Prototype manager. He had not been informed of the agreed method of testing. The result of this was that the slats were tested in the traditional method for that company and did not conform to the author’s methods intended methods. They were placed unrestrained and exposed to environmental conditions both indoors and outdoors.

Following is the email by the Prototype manager to Company E director, reporting on the results of these tests.

‘3rd November 2005

The slats from Michelle Hyams have been tested for the past two months. Half of them were kept inside on the shelf and the others were exposed to the weather. The weather has been variable with rain every couple of days. This has been fairly typical of a winter in the south west. I brought the slats in from the testing area last week. [name] has put the slats from the shelves that have had no exposure beside the ones that have been exposed.

‘I have photographed this. Please see attached photo’ (Figure 140).

Figure 140 – Tested samples
The slats that have not been exposed have not changed at all. The slats that have been exposed have all straightened out and vary from the original line on the board. Some vary as much as 3mm from the shape they were before they were exposed to the rain.

I suspect the blue-black stain on the slats is from contact with water and steel. This is time consuming to remove by sanding. If we were able to get these slats bent without the blue staining they would be suitable for an internal dining chair. We do not currently make an internal dining chair. I would still like to see a bent slat that we can put on a chair outside for five years and know it will be OK. Saving timber by bending rather than shaping is not a reality yet (Prototype manager, per comm., November 2005).

The Prototype manager had commented on a number of issues, highlighting the problems with the stains in the timber and how the timber that had been placed outdoors had moved as much as three millimetres after two months exposure. In response to the report, the author wrote an extensive email in December 2005 arguing against his claim that ‘saving timber by bending rather than shaping is not a reality yet.’

The replying email from the author gave explanation and justification to issues regarded at Company E as big problems with the new technology. For example, the reason that the slats were stained was due to pre-soaking prior to bending. This soaking stage has never been intended to be part of the normal process for microwave bending, however, for these tests metal plates had to be used in Creswick laboratory to submerge the slats in water as the timber supplied was too dry (low MC).

The issue with the oversizing of the components was also rationalised. The author explained that the slats were oversized deliberately to allow for some material to be removed by sanding in order to finish the parts. This issue had been discussed with the Production manager at the time of trying to source the material for the tests. An email from the latter stated that ‘the current slats are machined to 45x14 mm, I propose that we pre machine the wetter material to 46x15 mm not 44x13 mm to allow for shrinkage during the final drying process. Once bent, you can return the slats to us for final machining and assembly into chair backs which we in turn will return to you for environmental testing’ (Production manager, per comm., December 2004).

Project 2.3 manager, Dr Ozarska also supported this oversizing of components stating that the ‘oversizing the timber is a good idea. However, I would propose to use the following dimensions: 47x15 mm. Unit shrinkage of jarrah is 0.3 per cent in tangential and 0.24 per cent in radial direction. This means that the moisture loss of 8 -13 per cent will result in shrinkage between 1.1 mm and 1.7 mm. Therefore to be safe you should ask for 47 mm width. The
thickness of 15 mm will be okay, because the thickness will be reduced for max 0.6 mm’ (Ozarska, per comm., December 2004). It was necessary to oversize the components for a variety of reasons - unknown shrinkage during the bending process, the need to finish off parts with partial sanding and to allow for material removal due to surface imperfections (which may occur before, during or after the bending process). All of this was communicated with the Prototype manager and he agreed with these comments.

The next issue was to clarify the method intended to be used to environmentally test the bent Jarrah slats. ‘It was always intended that any bent jarrah components were to be assembled into the back frame of the chair prior to being exposed to external weather. The fact that the combination of soaking, microwave heating and bending the jarrah slats was successful (as the slats you left indoors have retained the required shape) shows us that this process will work after (doing) some more testing and handling of the parts. It supports our belief that we will be able to use this process, successfully and repetitively, to produce outdoor furniture’ (Hyams, per comm., December 2005).

The issue of the pieces losing their bend when left outside unrestrained for a period of time is not a great concern as even with indoor furniture that contains bentwood pieces, these parts are typically held restrained through the design and construction of a product. This point is significant when looking at the construction methods of the bentwood furniture by Thonet. Its application is generally for indoor use and the bent components are held rigidly to form by either using screws, fixtures or other wooden structures.

The Prototype manager wrote an email to Company E Director that he ‘would still like to see a bent slat that we can put on a chair outside for five years and know it will be OK’ (Prototype manager, per comm., November 2005). This goal is also a high priority of Program 2.3 which will be achieved by assembling the slats into a back frame and testing as originally intended.

6.6.8 Placement of bent pieces into prototype rocking chair

The prototype of the Rocking Chair was completed and transported from Western Australia for final assembly by the author. As seen in Figure 141, the rocking chair looks very similar like the previous model (Figure 114) however the back frame uses the microwave bent back slats, rather than sanded and shaped components as previously used.

The goal of this project was to see if microwave bentwood components could be easily substituted into current production for existing products, as stated in section 6.6. By receiving the chair in the standard packaging with the existing assembly instructions (Figure 142), it can be seen that this project was successful in comparison to the expectation of the research team in its aim to replace components with microwave bentwood without having to modify any stage
in production. The successful completion of the chair shows that the new technology can be easily integrated into current manufacturing systems.

Figure 141 - Prototype of Rocking Chair with bentwood back slats

The Prototype manager states in his report that the components handled well, requiring minimum sanding and shaping to achieve the desired form. He also continues on to state that they would be very interested in doing further work with microwave bent components if the problems that arose from this case study could be ironed out, such as finding a reliable source of suitable material and being able to ‘colour match the parts prior to assembly’ (Prototype manager, per comm., June 2006).
The standard assembly instructions (Figure 142) were supplied with the prototype, to assist with the putting together of the chair. This shows that the use of bentwood components can insert simply and smoothly into current production systems.

This image (Figure 143) shows that however subtle the curve is in the back slats, it increases ergonomic comfort in the chair and also the design appeal to compete more strongly against imported outdoor furniture, according to Company E knowledge of their product market.

The next chapter comments of the changes made and issues identified, during the production of the case study prototypes, to aid in developing a research technology into a commercially viable manufacturing method.
In summary, both case studies have had successful (but problematic) conclusions. The physical outcomes of each project have utilised the strengths of the new microwave bending technology, exposing the finished bentwood components to industry environments. The use of these components to produce furniture prototypes has shown all involved that the technology can contribute to help the furniture industry. However, the building of these prototypes has also highlighted areas in the pre-commercial research technology that need further work to move this technology into a commercial reality.
7.0 Project outcomes: A synopsis of learning

In this chapter the author presents the outcomes of the exercises and industry-based case studies which were completed during this project. Included is a detailed account of what knowledge was gained through the completion of a range of experiments and how this knowledge was communicated and applied into the Project 2.3 research program.

The strictly defined parameters of the first case study were:

- Mountain Ash (*Eucalyptus regnans*) was the main timber being used in all research experiments
- Material parameters were stringent (no imperfections, correct MC, etc.)
- Timber section size available - 25x25 mm
- Experimental apparatus available for production of microwave bent timber
- Minimum radius of R300 mm achievable for Mountain Ash

These constraints relate primarily to Case Study One with Company G. The second case study, with Company E, makes use of an alternative Australian timber with different bending properties, and specifically designed and built equipment to produce timber pieces in an S-bend shape.

7.1 Case Study One: Café tables with bent edges with Company G

The design for the Table Edges project was based around the bending parameters that were current at the time of creating the collaborative project with Company G, using the parameters listed above. There were other factors that had to be considered during the design and development of the tables, such as the unknown creep characteristics of bent components and internal stresses within wood that may affect the components during drying and stabilisation.

Generating suitable pieces for the table edge project was challenging as many variables influenced the production of successful bentwood components. The parameters that the material had to meet in regard to wood bending specifications were set by the research team; straight grain with no imperfections (knots, grain deviations, gum veins, saw marks), high moisture content (MC) of 20 per cent and above, and sections machined exactly to the size of 25x25 mm. Other issues that affected the production of components was the difficulty of producing a full half-circle radius off the experimental former and bending table, complications and delays with the microwave unit and the availability of personnel to do the actual bending.

7.1.1 Bending Trial #1

The first attempt made for bending the components required for the production of the table prototypes resulted with not one piece being serviceable. The quality of material supplied by a sawmill, low MC of the timber, surface finish of material samples and general mechanical
problems (material not correct width or length and coming away from former) were identified as the causes for the failed attempt.

7.1.2 Bending Trial #2
The second attempt to produce the required components was more successful, with only minimal failures. The issues that caused the failure of Trial #1 were addressed in a variety of ways. For example, the author visited the Timber Mill where the timber was to be cut to oversee the selection of timber planks for the second round of bending for this case study. At the wood shed, the timber selected had on average a high MC of 23 per cent and above with few surface grain irregularities. This timber was then machined to size at an undisclosed location resulting in the timber being dressed a little oversized, at 26x26 mm. This left a 1 mm differential between what was requested and what was delivered.

In the manufacturing industry at large (metalwork, plastic mouldings etc), it is a common manufacturing practise to have minimum and maximum tolerances, allowing for some irregularity in component sizes. During the bending process, the 1mm oversize created tension failures on the outside surface of the bend because the metal restraining strap was only 25 mm wide. (Figure 144) This failure at the very time of processing illustrates the limited nature of the current bending procedures and highlights an area of the process to be examined. Allowances for variances (tolerances) need to be made for size and length differences.

![Failures in bentwood component Trial #2](image)

**Figure 144 - Failures in bentwood component Trial #2**

The result of having a 1 mm differential in component size and the problems it caused emphasises the need for the pre-bending preparation of material to be taken extremely seriously and clear communication between the parties involved in microwave wood bending. It has also been suggested that an oversized strap should be used for all future bending.

Due to a lack of understanding of the importance of having tight specifications requiring the timber to have a high MC for successful bending, an extra step had to be added into the
process. The timber samples were soaked in water for twenty-four hours to increase the MC to preferred levels.

This parameter has very impractical consequences, a claim supported by the author’s research into timber technology, independent discussions with sawmill technicians and interviews with furniture manufacturers. If the MC was increased in the timber delivered directly from the suppliers (to match the same levels achieved by soaking), it increases the chance of failure through every step of the bending process; from finding a reliable source of suitable materials from sawmills, the difficulty of machining the timber to the required sizes, through to the drying the timber, from 30-40 per cent down to 12-15 per cent, without having any effect on the actual bent components. However, as shown by further studies within the CRCWI bending project, having moisture content of above 40% is the optimal level for achieving the minimum radius of curvature.

The simple evidence for this concern of drying the timber from high to low moisture content can be seen in the outcomes of Bending Trial #2. When the timber was bent to produce components to make table edges, a number of bends failed severely during the drying process. The bends appeared successful at time of manipulation but extreme splits occurred during drying in the humidity chambers at University of Melbourne, on the outer tension surface resulting in unusable components (Figure 145) This was caused by improper machining of the timber (saw cuts on the surface) and improper drying process, which resulted in a high MC gradient within the timber.

Again this issue highlights the need for clear communication between the material supplier, bentwood component manufacturer and all those in-between. While the sawmill did not take seriously the request to have clean cut and dressed timber (no marks) to be delivered for bending, the new technology must make allowance for some surface variations or defects in the material being bent.

![Figure 145 - Tension failure occurred during drying](image)

Another issue that was raised during discussions with furniture manufacturers was the restrictiveness of the radii currently achievable. The ability to achieve a radius of R300 mm
allows for a broad range of applications, however, the ability of achieving this small radius was still not reliable this was due to the experimental machinery that was available at the time of writing this document (see Chapter Eight). Many manufacturers expressed their desire for the components being produced by Project 2.3 to compete equally with the bends achievable by the combination of steam and European beech or substituted components made of plywood. It has to be acknowledged at this point that Australian timbers are different than from European ‘bendable’ timbers as they are of very different properties. In particular, Australian timbers have almost double the material density of their European rivals. It is important to educate Australian manufacturers on the limitations that come with using Australian hardwoods, because they cannot compare to the European softwoods when it comes to malleability.

![Figure 146 – Lamination to create larger bent components](image)

The final comment on the parameters of the microwave bending process relates to the section size currently being used for experimental purposes. The component research size of 25x25 mm is very restrictive; however, the proposed section of 38x38 mm is more flexible for furniture manufacturers to use. At the time of writing, preparations for tests of a variety of sizes have been made but as yet not undertaken. It is an ongoing aim of the author to design pieces of furniture to circumvent this limitation. (Figure 146) Please refer to Chapter Eight for greater explanation about this intention.

7.1.3 Table #1 Description of final design
As seen in Figure 147, the final design was modified from the initial brief in order to create the most ‘production friendly’ table design possible using the microwave bentwood edges. The changes that occurred to the design and assembly of the café table came about during the
production of the prototype. The changes were made to make the product the most commercially viable piece of furniture possible.

The bent edge (Figure 148) is visible with a 12 mm edge on top and the full 22 mm side edge visible. Initially it was specified for the edge to be a pale gold timber with a clear finish to contrast against a dark wenge stained veneer in the centre of the table. This contrast was aimed to accent and easily identify that the edges were bentwood, not carved and shaped.

The final outcome was that the edges were stained as well. The edges were assembled to the centre piece prior to staining and, therefore, it was not possible to mask the edges neatly to get the desired finish. For the table to have ‘golden’ timber edging, it would have required more labour as well as complicated masking, thus, consuming more time and money which would defeat the primary aim — to produce a low-cost café table.

The other change to the project brief in relation to the production of a prototype was that where the design had originally aimed to only use two pieces of bentwood to create the ø600 mm table it now required three pieces (Figure 149). Even though the pieces were restrained after bending and during drying it was not possible to achieve the bend required using the laboratory bending table, that is, the internal radius of the components was not R300 mm (Figure 151). To produce the prototype, a lot of material had to be machined off to get the required diameter. Thus, three components were used to create the full 360° edge, rather than the two as originally designed (Figure 150).
The centre piece is loaded from above and screwed to the edges from underneath. The tabletop has an outer size of ø620, overlapping the inner surface of the table edge by 10 mm (Figure 152). There are dual reasons for this design; firstly it hides any compression failures (Figure 153 and Figure 154) that were not removed during the preparation of the component and secondly it gives a rebate to rest and attach the edges to the centre piece. A standard stainless steel column and the ‘Luna Disc’ base (Figure 142) were then attached to the underside of the centre piece to complete the table design.

The centre piece comprises of 18 mm MDF substrate with a 1.0 mm veneer lamination stained in a dark ‘wenge’ finish. The combined use of MDF and solid wood is an accepted industry practice of commercial furniture manufacturers. The consequences in this situation are that the table is lighter and cheaper to produce, and the table retains a quality look and feel by using the solid timber edges.
An MDF table top also gives a greater stability to the furniture as the differential movement of MDF is lower than solid wood. The unit shrinkage in both directions is equal in comparison to solid wood table tops where the movement is greater across the width of the timber rather than along the length.
7.1.4 Modifications to Table #2 Final design
The original specifications to produce original design for Table #2 were listed earlier, and as expected some modifications occurred to suit production constraints. There were only a few small changes to produce the two prototypes.

The aluminium frame was increased to 5 mm thickness as the thinner material did not weld well or have the strength required. There was also a spacer inserted to create enough space for the tables to stack easily. (*Figure 155 and Figure 156*)

![Figure 155 – Modified frame](image1)
![Figure 156 – Modified frame and leg assembly](image2)

7.1.5 Summary of knowledge gained from Case Study One
The main goal during the course of this project was to generate information to assist with the development of the microwave bending technology. When inquiring about the condition of the component or meeting delivery deadlines, the author was constantly reminded that in its current state the technology is still very much a ‘research project’ with the work only done in a small laboratory with experimental machinery. From the start of the project it had to be accepted that production quality components would not be achievable using the laboratory research equipment.

The first issue that emerged through the prototyping process for this case study was the need for unambiguous and constant communication between all groups involved; in this case the researchers, designer, timber merchant and furniture manufacturer. This claim is supported by the problems evidenced during the production of the table prototypes; oversized timber...
sections, the need to soak the timber to increase the MC and the design changes that occurred to the tables during the manufacturing stage.

The quality of preparation of the timber pieces prior to bending corresponds to the success or failure of bentwood component production. A tight quality control procedure must be installed to guarantee the correct preparation of the timber, from exact component sizing to surface dressing, but all within flexible tolerances to allow for the expected variables found in a natural material such as wood.

As mentioned above, the timber criteria are stringent but some allowance for the variable nature of the material must be made. Although the requirement for high MC may help with the initial bending of the timber, it may contribute to the increased number of post-production failures that occurred during the drying phase of the process. At the time of these studies, only the traditional and slow drying method was available. At present, there have been great advances in the research of using microwaves to also dry the bentwood components. This new drying process is more reliable, faster and flexible in terms of reducing the MC of timber.

In relation to microwave bending, the commercial manufacturing process has to make allowances for the inconsistencies in the timber such as slight size, MC or grain differences.

Although the radii currently achievable thought the microwave bending technology can be used successfully in a large range of applications, the minimum radius currently available is R300 mm. This is a great achievement because the researcher’s believed that, based on existing literature, the minimum radius possible is R600 mm when using the steam bending method. It was also found that the components were not bent to the full 180° meaning that for Table #1 (Figure 151), the edges were constructed out of three pieces, not two as was originally specified.

For Table #2, the bentwood edges were thinner than the original 22 mm, reduced to 12mm, due to the fact that the internal diameter was not R300 mm as required (Figure 157). Approximately 40 per cent of the material was sanded to get the bentwood components to the required diameter to match the aluminium frame. This issue needs to be addressed. Despite the fact that it is accepted in the furniture industry to oversize components to allow for shaping and finishing, a main goal of producing bentwood components is to eliminate the time and cost involved to complete these process and reduce unnecessary waste of material.
Finally, the successful production of the café tables show that microwave softening does not alter the characteristics of the timber. The material can be handled the same as any wood product. To expand, the microwave bent timber components could be sanded, machined, stained and assembled the same as untreated materials.

Aside from the issues raised by the production of Table #1 and Table #2 prototypes, the author has suggested to Program 2.3, based on a review of the current market style and future design trends, that bentwood components should also be available as asymmetrical shapes, as well as the more general symmetrical shapes. The employment of this suggestion can be seen in the making of bentwood components for the ‘Scoop Chair’, as seen in Chapter Eight.
7.2 Case Study Two: Rocking Chair with Company E

The parameters for this project were very different to the first case study. Mountain Ash (Eucalyptus regnans) was the primary material being used to test the abilities of the technology and the results from these tests were to become the base data to compare all other tests results against. Jarrah (Eucalyptus marginata) is known to be a difficult timber to bend, however, if the case study was successful it would open up new possibilities to a range of other Australian hardwoods like Karri (Eucalyptus diversicolor) and Spotted Gum (Corymbia maculata). At the time of creating this case study, the microwave technology had never been applied to Jarrah or a similar high density timber.
The technological parameters that defined this case study are as listed below:

- Timber material to be used was Jarrah
- Moisture content of 20 per cent or higher
- Timber section size 45 x 15 x 800 mm
- Large experimental microwave apparatus available at main CRCWI research laboratory (Creswick, Victoria)
- Custom designed bending former and drying rack
- Desired profile was an S-bend with radii of R4579 and R1421 (Figure 123)

7.2.1 Comparison of Steam bent and Microwave bent S-bends

Figure 159 shows a ‘Grade 2 - Slight damage, additional sanding required prior to use’ (Table 4) tension failure in a component bent by the Tasmanian wood bender through the use of steam heating. The wood bender stated that he believed the failures were due to the rapid drying he put the component through. The drying aggravated the grain runout on the outer (tension) surface, causing a number of the components to fail in a similar manner.

There were no such failures in any of the components microwave bent for this case study. This can be attributed to the combination of a slow drying timetable (approximately 3 weeks) and the method of restraint during the drying process. The MC of the batch of microwave bent components was measured twice a week and at set levels, the components were moved from a high MC chamber to a low MC chamber, allowing the MC to drop slowly to the 15 per cent required for outdoor furniture.
7.2.2 Bending Trials: Jarrah material and custom designed equipment

Through this case study with Company E, for the first time in the Wood Bending project Jarrah material was exposed to the microwave softening technology and an attempt to bend the components to a specified shape was made. The process of these tests is documented in great detail in Chapter Six. Below is a summary of the knowledge gained from completing these tests, outlining the positive results and identifying the areas of the process that should be researched further.

The physical outcomes of the project were that two Rocking chair prototypes with bent back slats were built. One unit was returned to the CRCWI main office at Swinburne University, for a range of purposes such as testing of the process and exhibiting the prototype. The second unit remained with Company E and has been placed in their testing program. This chair has been placed outside, with other products from the Company E range, and exposed to the Western Australia weather for a six month period.

7.2.3 Summary of knowledge gained from Case Study Two

From the very beginning of the project the author was concerned that the radii specified by Company E (Figure 123) were too mild to push the timber past its elastic limits. Although evidence must be found through further tests to support this claim, the author believes that for timber such as Jarrah and similar, the components should be over-bent by more than the 5 per cent recommended by literature to successfully create subtle curves that are reliable and long-lasting.

The timber needed to be supplied from the saw-mill in a ‘green’ state of over 25 per cent to avoid the need for soaking. The actual MC of the timber supplied was below 20 per cent and therefore the timber intended for bending was placed into a metal container filled with tap water. Placing the jarrah into water to increase the MC was not all that helpful as the grain is too tight and the water does not penetrate deep enough into the timber even after being submerged for many days. For these trials the timber pieces were put into water for over 5 days yet when tested with a calibrated measuring device, the MC had increased insignificantly, from 18-19 per cent to 20–21 per cent.

This case study required multiple components to be heated simultaneously, simulating the current steam bending autoclaving systems. The success of heating many pieces of timber at one time, as evidenced in Chapter Six, proves that the technology can be used to produce commercial quantities of heated timber components. The tests show that the microwave heating of timber can be easily combined with existing equipment found in bending factories around the world because the former design was based on existing press-formers used in large bending factories. Although it is much faster to heat the timber by applying microwaves, the heat rapidly disperses the same as with steam heating. Any future press-former designs have to allow for
multiple pieces to be quickly located into the equipment, so not to lose too much of the heat required for successful bending.

Unlike the jarrah slats bent using the steam process (Section 7.2.1), none of the microwave bent components failed during the drying process. Figure 161 illustrates that even an imperfection such as a knot does not affect the bending, drying and finishing of a jarrah component.

As of February 2006, the Prototype Manager confirmed that “The slats that have not been exposed have not moved.” This comment is very positive because these are the components that were placed unrestrained on a shelf in the prototype workshop at Company E. The components were then assembled into the chair seen in Figure 158 and Figure 160 and on 23rd May 2006 the unit was delivered to the author for final assembly.

The Rocking chair containing microwave bent back slats was delivered in the same state as a regular unit would be and put together using the existing instructions (Figure 146). When the chair was assembled on 23rd May 2006, it was found that all but one back slat retained the original S-bend curve (Figure 160). Since that date the chair has been located inside an office building, with regulated temperature and humidity, and still appears to retain the S-bend.

Figure 160 - Detail image of microwave bentwood back slats (23 May 2006)
As observed during the bending tests (Section 6.6) the mechanical forces within the jarrah are very strong in trying to return the components back to its original natural state. Further testing is required to ascertain if these components will retain their shape for an extended period. Until such tests are completed, the author recommends that any products specified to use microwave bentwood components should be designed to restrain the pieces securely. Also, there needs to be a specifically designed environmental testing program initiated to satisfy the five year guarantee given by Company E on all their products.

7.3 Concise summary of all project work
The following conclusions have been made after a close analysis of all the work contained within this document. Some of the issues have already been taken into consideration by the team at Wood Shapes Ltd, the company responsible for the commercialisation of the microwave wood bending technology. However all issues, concerns and suggestions have been included at this point to encapsulate the knowledge generated and information contributed by the author during the course of the project.

As expected with a pre-commercial technology, there are some shortcomings with the process which need to be overcome. One of these issues is that the quality of timber required needs to be very high. The requirement for minimal irregularities in the timber may make it difficult to source enough material to use in conjunction with the microwave bending process. Also, through the completed experiments and case studies, a concern arose that the high moisture content may affect the ability to source good material and any post-bending processes.
Improvements also need to be made on experimental bending machinery and the actual process of microwave heating and bending the timber pieces. The designs of the machines, including mechanical and ergonomic elements, have to be refined and to be made more adaptable to accept a variety of timber species and sizes. It should be noted that since this study was completed, a more flexible bending jig was built, in Creswick (Victoria), for the express purpose of bending a variety of component sizes. The author believes, in keeping with current mass-production methods overseas, that bending individual pieces of timber does not produce enough components fast enough for the proposed target market.

The strategy used in this project was underpinned by the understanding that, by building furniture prototypes, information could be generated that could assist scientists to develop a more specific and useful technology. The theory behind this was to stimulate ideas about the future development of other products utilising microwave bentwood components. For example, when the bent components intended for the café tables were shown to Company G, the immediate response of the company representatives was to propose alternate uses for the components. As desired, the prototypes created an environment where a free-flowing conversation was encouraged and feedback of relevant information from designers and other industry members was conveyed.
8.0 Reflections and suggestions

An opportunity has been taken in this chapter, with the luxury of hindsight, to reflect on the project documented in this thesis, while objectively assessing the benefits gained using design research in a scientific research program and consequently reviewing the final outcomes of the project. Contained below are some comments on the project journey and the design strategy created and used as a basis for all the research undertaken. Some suggestions regarding future design research directions have been made, and how this new research can contribute to the wood bending project.

This chapter has been included to illustrate to the reader how the design strategy from this thesis can be applied beyond research, and in fact can be easily integrated with the business plans of Wood Shapes Pty Ltd, the start-up company established to develop the microwave bending technology into a commercial mass-manufacturing process.

There were many influences that affected the strategy created for this project, but the most important criteria to meet were to create outcomes that would foster the technological innovation, and to realise the potential of developing the microwave bentwood technology into a commercially viable technology. This project was just one of several working towards the same end goal within Program 2.3 (see Chapter Two). However, it was placing the microwave bentwood into pieces of functional furniture that was the unique contribution that design could offer the program. To recap, the strategy created in this thesis was based on using three dimensional prototypes to allow communication between the parties with a vested interest in seeing this research technology succeed.

The strategy applied in this project is supported by other design research work, such as Daria Loy and her ‘playful triggers’ (Loy 2004), which can be considered extremely applicable to the CRCWI program and very useful in meeting the specific goals of Program 2.3. Through the production of prototypes, furniture manufacturers were able to respond to the physical use of bentwood, allowing them to identify their industry requirements within reasonable parameters. The production of bentwood components for the use in real products (i.e. furniture) gave the Program 2.3 researchers an opportunity to ‘fine tune’ their experimental process and refine the method to suit commercial requirements. The manufacture of furniture prototypes gave outside investors the ability to see physical outcomes of the research, which had previously only been discussed in conceptual and verbal terms. The theory and justification behind this strategy is comprehensively detailed in Chapter Five.
8.1 Overall summary of outcomes

Through the implementation of the design strategy created for this project, information was generated to help direct the research into some new technology into areas that specifically apply to the intended end user, i.e. Australian furniture manufacturers. From the production of furniture prototypes for the case studies (documented in Chapter Six) and the design/manufacture of the Scoop chair for an exhibition (Furnitex 2006), a number of issues emerged that have been fed back into the research program to assist in the development of the pre-commercial technology into a reliable manufacturing process for the Australian furniture industry. These issues are listed below:

- The parameters defined by Project 2.3 guidelines (see Chapter Seven), such as minimal irregularities in the timber (grain direction, gum veins, knots and high moisture content, etc), must be closely adhered to. This means that the timber supplied should be tightly graded to suit the microwave bending process.

- While high MC of 25 per cent and above is required to make bending easier, it has also been identified as a possible cause contributing to component failure during the conventional drying process (Figure 145). At the time of writing, research into microwave drying is still in the early research phase.

- The equipment must be designed to accept a range of dimensions (within reason) and able to achieve a full 180° arc (refer to Chapter Seven, Figure 150 and Figure 151).

- Literature recommends to initially over-bend timber to 5 per cent more than the product requires (refer to Chapter Six, Figure 123 and Figure 126) to allow for material spring-back. Based on the outcomes from Case Study Two, the author would recommend that a larger over-bend ratio (say 10 per cent) should be applied for large radii and subtle curves.

- When designing a product incorporating microwave bentwood components, the designer has to consider the process parameters and make allowances to cater for these limitations in the design and assembly of the product. Some of the issues to consider are the minimal radii possible with different species, maximum component thickness (currently 25 mm and proposed 38 mm), unknown movement in the variable material (expansion, contraction and bend spring-back) and suitable restraining of the bend (refer to Case Study One, Two and Scoop Chair).

- Since microwave drying is in its infancy, reliable component restraining methods must be created to be used in conjunction with traditional drying processes, because a component remains in the drying rack and kiln for a longer time period than when restrained during the bending process.
The microwave bending process is suitable to use on Australian timbers considered ‘difficult’ to bend (i.e. high density timbers), as seen in Case Study Two.
Based on research into competitor bending technologies and to compete successfully with overseas production capabilities (see Section 3.2), multiple components should be bent and dried simultaneously to make the quantities of bentwood components predicted by the Market Research Report by BFG Consulting.

Following the completion of the work outlined as part of this project (Case Studies One and Two), further design and development has been carried out using the knowledge gained during this process, on a new piece of bentwood furniture. A second generation prototype was designed and manufactured, using the microwave bentwood components for different material characteristics. Thereafter these components were placed in a completely new and different piece of furniture, and compared to the other products produced for this project.

8.2 Applying project learning to new products
Following the completion of the case studies a new piece of furniture was designed to exhibit (Furnitex 2006), the largest furniture trade show in Australia. The aim of producing this furniture was to demonstrate and promote the improved abilities and benefits that microwave bending can contribute to the furniture industry. The occasional chair was designed to use the existing experimental microwave and bending equipment, as well as other process parameters such as different timber species.

The ‘Scoop Chair’ was designed based on the knowledge gained during the course of this thesis (see Chapter Six), reflecting both the application of design research knowledge and also the advances in the technological development of the process since the beginning of this project.

The bentwood components for the chair (as seen in the sketch below) were made out of Mountain ash (Eucalyptus regnans), with the material selected for these products to have minimal imperfections and high moisture content. The section size was 25x25 mm, and a minimum radius of R500 was the smallest arc available to use during the design of the furniture for Furnitex 2006.
Figure 162 – Original design profile of the ‘Scoop’ Chair

The legs of the chair were to be two bent pieces at R500 in an 180° arc, and laminated together to give greater thickness and strength. Ideally, the arc of the legs was to be held in place by two joints, in the back of the chair and the seat. The final prototype (Figure 164) did not have bentwood legs due to time restraints occurring during the drying process. The only uncertainty and concern about this design relates to how the legs may behave when left unrestrained at either end of the bend. Until the chair is properly tested by leaving it to sit long term in the final environment, there is no way of knowing whether leaving the ends unrestrained will result in a positive and successful design.

The rationale behind this design was to exploit the structural and mechanical properties of microwave bentwood, rather than just focusing on the aesthetic appeal of curved timber. The benefits of bentwood are given in greater detail in Chapter Three, but in this case the benefits that bentwood offered this design were strength due to continuous grain direction, economic reductions because less material was used, and a minimal amount of material was wasted in forming the asymmetrical arc of the chair profile. In fact, the curve of the chair was created using only three pieces of bentwood and a number of horizontal bracing beams to construct a rigid frame (Figure 163).
Another element unique to this chair, and different to previous prototypes, was the fact that the bentwood components were asymmetrical, with the centre of the arc orientated closer to one end of the timber piece. Up until this time, no one had attempted to create a bentwood piece that had a straight part at one end, while using the existing equipment. This exercise was challenging for researchers as it added a new knowledge to the bending process and therefore opened new opportunities for future investigation. Achieving this design required some mental and physical adjustments to manipulate the current equipment to produce new and exciting shapes. By successfully making the asymmetrical curves, it allowed the frame to be constructed out of three singular curves without having to attach extra wood to one end to create the straight upper back and headrest area.

Figure 163 – Detail drawing of chair frame

The prototype chair that is pictured in Figure 165 was altered a few times from the original design that was initially presented to the Program 2.3 team (Figure 162) and the manufacturer of the product. The first version had bent legs and a bentwood frame, whereas the second version had the arch legs eliminated due to the unavailability of some of the bentwood components. As detailed in Figure 164, the frame was supposed to be upholstered over so that the bentwood components were only to be visible from underneath. Due to the tight deadline, the manufacturer had to modify the design to be able to produce a piece of furniture in time for the exhibition.
Figure 164 – Drawing of Scoop chair (modified for prototyping)

Figure 165 – Scoop Chair at Furnitex 2006
8.3 Directions for design research

A number of design research opportunities became apparent to the author as future possibilities for design research to contribute to the CRC WI research program. One such field of design research, ‘design ethnography’, briefly touched upon in Chapter Five through the work of Bruseberg and McDonagh-Phillip, stands out as the most applicable field of research to pursue to further assist in the development of the microwave bending technology.

To be more specific, the author believes that the most applicable areas to pursue, if further design research was to be undertaken in the microwave wood bending program, would be to combine select participatory design (PD) data collection methods with existing marketing techniques, such as focus groups. The strategy would produce outcomes that would be extremely useful and applicable to the future development of microwave wood bending. The designers would be able to engage the end user in greater depth, extracting their thoughts and ideals about microwave bentwood, which have been produced through many years of furniture manufacturing experience. This strategy then gives the research program and start-up company information and direction as to what are the industry requirements, and also gives these requirements greater influence when developing the technology into a suitable manufacturing process.

8.4 … and finally…

While the products produced during the course of this project were functional they also aimed to be aesthetically creative. This was achieved in a situation where there were restrictive parameters regarding technology and timeframes set by the research program. The physical outcomes of this project; two café tables, a rocking chair and ultimately the ‘Scoop Chair’; utilise the bentwood components in a manner that reflect mass-production parameters such as reduced material and labour costs. To answer the question raised in the very first chapter of this document, design can and has, in this instance, contributed to technological innovation through the production of furniture prototypes that use, test and embrace microwave bentwood.
Bibliography
Allnutt, L 2005, *Report on visit to Udine Italy: Curvatura Fruiiana*, Swinburne University of Technology, Melbourne


Anon., Forest Products Commission Western Australia 2004, *Forest Industry Statement*, Government of Western Australia


Burke, T & Hayward, D 2000, *Housing Past. Housing Futures*. Department of Infrastructure, Melbourne


Colwell, D 199?, *Steam Bending Video*, viewed 24 February 2003, Launceston School of Fine Furniture, Launceston

Conley, C 2004, ‘The Use of Prototypes in Pre-Development Activities’, *Futureground*, Design Research Society, Monash University, Melbourne, pp. 61 - 72


Cox, G & Gilleard, J 2004, *Market Research Study on the Market Opportunities for Pre-curved wood in Australian Furniture manufacturing companies*, BFG Consulting Group


IBISworld Australia 2003, ‘Furniture manufacturing n.e.c. in Australia,’ (C2929) Published 8 December 2003, viewed 3 March 2005.


Kingston, R.S.T 1939, *A reconnaissance of the bending qualities of some Australian timbers*, Journal of the Council for Scientific and Industrial, Vol 12, CSIRO Division of Forest Products

Livermore, A 2004, 241 Charles St, Launceston Tasmania 7250


Ozarska, Dr B 200?, New South Wales, *Interview with Peter Darby from Corowa*


Personal communication with Andrew Thompson, CDe Group Design Director

Personal communication from Compwood Machines to Dr B. Ozarska,

Personal communication from Dr Barbara Ozarska to Michelle Hyams 6 December 2004

Personal communication from Gavin Hammond to Max Jensen 3 November 2005

Personal communication from Gavin Hammond to Michelle Hyams 2 June 2006

Personal communication from Michelle Hyams to Gavin Hammond 16 December 2005

Personal communication from Wilf Mees to Michelle Hyams 1 December 2004

Personal conversation with Dr Barbara Ozarska, January 2005

Personal conversation with Dr Barbara Ozarska, January 2006


Standards Association of Australia 1999, *Timber Hardwood sawn and milled products: Timber for furniture components*, (AS2796.3-1999), Standards Australia, Homebush, NSW


Timber Bending, 1948, Trade Circular No.22, Division of Forest Products, Melbourne


