A Design Investigation into the Use of Recycled Thermoplastics for Furniture Applications in the Australian Market

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A Design Investigation into the Use of Recycled Thermoplastics for Furniture Applications in the Australian Market

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Declaration

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

David Burke

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Malte Wagenfeld, for help starting this process. Kjell Grant and Harry Krane as intermediaries. My Supervisors Enda Crossin, and Frank Feltham for advice, structure and polish. And to Christine.
Abstract

The use of recycled thermoplastic materials in furniture products is the result of the application of a methodology that is grounded in design and making within an ecodesign framework. This framework includes techniques and methods for ease of assembly and disassembly, material efficiency and reuse, economy of production and lifecycle extension within the practice of furniture design.

Through the development of innovative furniture products that incorporate recycled thermoplastics derived from mixed material and product sources, this project challenges the proposition that thermoplastics may only be successfully recycled into products of significant value when separated into single polymer types.

Grounded in research through design this practice combines the use of waste from plastic recycling in Victoria as a source material to explore and create a range of furniture that challenges the value proposition above. This research proposes that the process of furniture design incorporating recycled thermoplastics produces new forms, techniques and implications for design practice.

Figure 1, Detail Baby Bubo, David Burke, 2000

1 Detail of Repocol recycled thermoplastic shell included on document cover page
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1.  Introduction

**Mr. McGuire:** I just want to say one word to you. Just one word.

**Benjamin:** Yes, sir.

**Mr. McGuire:** Are you listening?

**Benjamin:** Yes, I am.

**Mr. McGuire:** Plastics.

Dialogue from Film ‘The Graduate’ 1967.

This thesis will examine, through the process of design, the potential for recycled thermoplastics to be used as source materials for new and exciting developments in furniture design. The research undertaken into the evolution and potential of plastic recycling processes, materials and products also contributes to related issues of sustainable design practice.

An examination of the issues surrounding the use of recycled plastics is discussed and this discourse provides a practical context for the recycling of plastics in furniture applications. This practice is based on the development of eodesign strategies and techniques. It challenges the acceptance of downcycling, the creation of lesser products with lower material qualities, as the inevitable means of remaking thermoplastic waste. ‘Although many plastics can be recycled in one form or another, there must be an upper limit to the number of dark grey, rough-textured countertops that can be usefully employed. Plastics that contain similar molecular structures can be co-recycled, but it is better procedure to keep plastic materials separate’ (Papanek, 1995 p. 39).

This statement by Papanek was made when plastic recycling was in its infancy and when new recycled thermoplastic materials and products were still being explored by a broad cross section of industrial interests. Early recycling initiatives in Australia separated plastic materials by type and were focused on the plastics contained in soft drink and milk bottles found in commercial quantities in domestic waste streams. The remaining commingle plastics were typically remoulded using rudimentary extrusion technology which resulted in the ‘dark grey rough textured’ forms that Papanek references (1995). In this development phase the application of professional industrial design skills and new technologies to create the form and appearance of separate and mixed recycled thermoplastics was barely explored beyond the replication of simple and rustic products.

1.1 The Nature of Plastics

The primary mouldable qualities and the potential for thermoplastic materials to be remade are central to this research. Plastics since their inception into the marketplace have replicated a wide range of materials. Parkesine, invented in 1856, was promoted as a material copy for ivory, and consequent iterations of early plastic materials replicated shell, stone and wood in ephemera and decorative goods (Brydson, 1999).
Advances in material science and moulding technologies accelerated and expanded the manufacture of plastic products into the realm of universal mass production from the 1950s. No longer did plastic products rely solely on replication of other materials for their market acceptance. A new aesthetic emerged, linked to low prices, bright colours, and a myriad of replaceable products with shiny antiseptic surfaces. If any one thing then identified the plastics of mass consumption, it was the breadth of moulded product applications visible in the marketplace.

Plastic is both a highly fashionable material of colour, form and finish, whilst also an invisible material in that it can mirror and mimic the substance and form of materials such as glass, timber and metal (Tonkinwise, 1998). Plastics are suited to components and machine parts and are also favoured for the qualities of moisture resistance and electrical non-conductivity in a myriad of machine and industrial applications. It is a material eminently suited to mass production, without peer in seamless moulded form and capable of significant economies due to low raw material costs and advanced manufacturing technologies.

The ubiquitous presence of plastics had been equated with cheap, brittle, disposable products of mass production, but that seemingly simple description has continued to expand, transform and reinvent itself (Fiell and Fiell, 2009). Plastics now challenge steel as the dominant material for mass production being found in all aspects of consumer and industrial products. Plastics are particularly visible in the automotive, computer, electronic, telecommunications, accessories and furniture fields. It is this diverse range of applications and properties that has stimulated this research into recycled plastics.

Through the practice of designing furniture this research aims to identify, test and evaluate mixed and streamed recyclable polymer materials now found increasingly in waste streams. It is concerned with products composed of synthetic polymers that have been identified as recyclable, being those polymers represented by plastic identification codes one (1) through to seven (7)\(^2\). These specific plastics are largely derived from fossil fuel production and reshaped by the process of thermoforming; the application of heat and pressure to fuse and form plastic particles into materials that harden when cooled.

### 1.2 Technical Meaning and Properties of Recycled Thermoplastics

As manufactured technical materials, thermoplastics bear little physical relationship to the organic timber and plywood materials that they have replicated and superseded for furniture applications. Synthetic plastic materials are not created within the visible organic cycle of germination, growth, harvest and regeneration. Their formation is largely invisible as a product of long underground gestation and chemical processing. The creation of plastic materials at a molecular level can be seen to add layers of meaning that, though communicated through materiality, are not expressed transparently, in that they may be understood at a tacit rather than explicit level.

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\(^2\) See Table 1 on page No 10
Timber materials can be recycled, but the process of recycling them does not reduce them to their constituent chemistry of cellulose and water from which they may be reformed in the manner that plastics are recycled.

A general understanding of plastics can be equally complex and unclear as soft, elastic or malleable descriptions exist in conjunction with hard, rigid and brittle labels. Application of a single set of characteristics does not necessarily identify specific plastic types as evidenced by elastic qualities of PVCs that may typically be altered and modified with the addition of plasticisers. The range of products available in PVC formulations is as diverse as soft pliable upholstery fabrics and hard, brittle industrial piping. The function of plastic materials as a source for new industrial production and the ongoing creation of plastic formulations for new product applications continue to expand the parameters of meaning in terms of material, aesthetics, function and future reuse.

1.3 Why Recycle Thermoplastics into New Furniture Products?

In the 1991 Recycling-Industry Commission Report it is stated that, ‘Infinite recycling of the same plastic material is technically impossible as reprocessing and contamination generally degrade plastic polymers and adversely affect characteristics such as durability and dimensional stability’. The longevity of plastic materials, and their unconsumed state at the end of product life (Fry, 2009), would seem to suggest that the point of recycling impossibility may be far into the future. What is relevant to this research is the statement in the Commission’s report that ‘degradation of some properties can be reduced with the use of additives, by incorporating some virgin material, by making the reprocessed product thicker, or by co-extrusion.’ (Industry Commission, 1991, p. 83).

This research does not claim infinite recycling is feasible, nor precludes loss of quality, but rather that the factors that diminish successful recycling may be differentiated by keeping similar plastics in a technical cycle (McDonough and Braungart, 2002), or by treating recycled plastics as materials with new and different qualities that challenge their description as waste in considering them as a garden of materials that can be cultivated and fostered through the practice of design (Manzini, 1992a).

In terms of cultural values, the links between the desire for new products and new materials, the short time spans of fashion cycles and the limited lifespans of consumer products, are predicated on disposal rather than reuse or recycling. In this project, the use of additives, the incorporation of virgin material into recyclate, the making of reprocessed products thicker and co-extrusion, are all explored using recycled thermoplastics in an attempt to extend the lifecycle of these products and further define and demonstrate new and different aesthetic and material qualities in reusing them.

The first attempts to recycle mixed or blended (commingle) domestic plastic waste into new plastic products was predicated on collecting and re-making a complex stream of mixed plastic feedstock. By avoiding labour and capital intensive washing, sorting and separation processes, the economic viability of such production could be enhanced, but the resultant mixed source products bear no relationship to the form of the products from which they are derived.
Prevailing attitudes within environmental design during this formative period as expressed by Papanek and later McDonough and Braungart, were dismissive of the value of commingled recycling, in particular its aesthetic qualities, and limitations in product application. ‘What about recycling? As we have noted, most recycling is actually downcycling; it reduces the quality of a material over time.’ (McDonough and Braungart, 2002, p. 56).

The re-formed materials that Papanek (1995) describes ‘as dark grey and rough-textured’ were the earliest product of the intermixing of various thermoplastic materials. These plastic composites, typified by Syntal which was developed in Australia in the 1980s, included third party materials, such as polypropylene ring caps attached to PET bottles, labels on containers, food residues and metal and grit particles. These additional inputs are representative of the broad scale of sampling material existent in domestic kerbside collection, and of waste sorting and processing in its crudest and most direct fashion (Figure 2).

Figure 2, Syntal, outdoor setting, circa 1990

In their book ‘Cradle to Cradle - Remaking the Way We Make Things’, McDonough and Braungart (2002) put forward the proposition in regard to recycling that, ‘Being less bad is no good’ and then go into the specific issue of plastics recycling. In terms of downcycling they focus on those same grey and rough textured forms that Papanek discussed a decade previously. ‘When plastics other than those found in soda and water bottles are recycled, they are mixed with different plastics to produce a hybrid of lower quality, which is then moulded into something amorphous and cheap, such as a park bench or a speed hump’ (McDonough and Braungart, 2002, p. 56).
In the context of recycled commingle plastic materials, such statements ignore the fact that the problem of what to do with intermixed and contaminated plastics remains, and is yet to be solved by the mantra of keeping materials separate. Furthermore, downcycling is likely to continue as an economic and social solution as long as we have mixed waste streams that are not viable to separate, imperfect systems to manage them, and a growing market for plastic mouldings derived from these sources, which typically are amorphous and cheap.

However the statements by McDonough and Braungart would seem oblivious of the higher properties and economic advantages that recycling of engineering plastics may have in comparison with commodity plastics such as those used in soda and water bottle production (Figure 3).

Figure 3, MRI, electronic waste recycling, Melbourne, 2007

Schiers in his book ‘Polymer recycling’ says; ‘In contrast to commodity plastics, the recycling of engineering plastics is economically attractive because the retained properties of recycled engineering plastics are generally higher than those of virgin commodity plastics.’ In regard to loss of material values inherent in the label of downcycling, Schiers argues that; ‘unfortunately the widespread use of recycled engineering resins is somewhat hindered by the stigma associated with the term recycled and the perception of an accompanying property loss’ (Schiers, 1998, pp. 304-5).

The relationship between plastic materials, recycling and new products is complex and evolutionary, and is highlighted by the association between the retention of properties in plastic recyclate, the availability of uncontaminated feedstock and economies of reuse. The retention of higher properties in recycled engineering plastics for example, can provide an economic stimulus for reuse, whereas negative perceptions in regard to material property losses, and limited economic benefits associated with less valuable plastic types, can inhibit such recycling efforts (Schiers, 1998).
The explosion in the adoption of plastics for new products has led to exponential increases in plastic garbage. The question that then arises is what to do with it. It had long been understood that plastic in the form of mouldable resinous polymers was admirably suited to reprocessing. When the patent for the Acrylonitrile Butadiene Styrene (ABS) group of engineering plastic resins was established in 1948 in the USA, reprocessing was clearly identified as a future reality, and recycling or reprocessing were viewed as viable options. It was this suitability of thermoformed plastics for reuse and recycling that raised the question of how to fully utilise and value this resource.

1.4 Research Proposition

The proposition of this research is that the process of furniture design incorporating recycled thermoplastics produces new forms, techniques and implications for design practice. These new forms and techniques challenge the assertions made by Papanek, McDonough and Braungart that the products of thermoplastic recycling from mixed sources results in amorphous and cheap applications with lower material qualities. It will be demonstrated both through the processes adopted and the outcomes delivered in chapters 4 and 5 that recycled thermoplastic products need not be derived from single products or single polymer formulations to be products of significant value.

The further contribution of this research is the systematic reflection on this practice to incorporate ecodesign strategies considered relevant to furniture design. These strategies are:

- Design incorporating recycled plastics
- Design for simplicity of assembly
- Design for ease of disassembly
- Design for material efficiency
- Design for reuse of materials
- Design for production efficiency
- Design for product longevity

1.5 Document Outline

In developing this proposition, chapter two provides an overview of the establishment of plastics recycling in Victoria that led to the manufacture of new recycled thermoplastic products. A brief history of bending, shaping and forming timber materials in the evolution of chair design is then presented. This evidence shows a desire for complex organic aesthetics, ergonomic forms and improved production efficiencies in modern chair production that is clearly linked to the emergence of thermoplastic materials and technologies.
It is the proliferation of thermoplastics across all areas of product development, including furniture, which provides the rich material resource for this project. In establishing a practical context for the development of designs a number of international examples that combine the elements of recycled thermoplastics and design through making in contemporary chair design are also included.

In chapter three a brief discussion of plastic recycling technologies and the environmental impacts and constraints of timber supply are provided in exploring opportunities for recycled thermoplastic products in furniture design. Victorian companies involved in the manufacture of recycled thermoplastic products are then examined to provide up to date information on the materials, products and processes adopted in this project that also informs future research. These companies have created new products with implications for furniture design as a result of the recycling initiatives and opportunities developed in Victoria. They are representative of the range of materials involved in the three methods of thermoplastic recycling, open loop, closed loop and a combination of both open and closed loop practice. This manufacture of recycled thermoplastic products uses existing or adapted plastic technologies that include extrusion, compression, injection and hybrid moulding processes.

Extrusion and hybrid moulding are the processes adopted to test the proposition that the process of furniture design incorporating recycled thermoplastics produces new forms, techniques and implications for design practice.

In chapter four this development of designs is firstly presented with an outline of the methodology developed through the experience of making, and in the context of a reflective practice, that includes both commissioned and speculative design. The relationship between reproduction and innovative design is explored through the development of new furniture products incorporating mixed sources of recycled thermoplastics. The application of design processes in the context of the ecodesign strategies previously outlined is investigated. This practice is divided into two parts and expanded upon: Firstly; designs for chairs and tables adapting readymade Syntal forms, being products of domestic kerbside plastic recycling and commingle extrusion moulding. Secondly; development of the Peregrine and Bubo chair designs using mixed domestic and industrial sources of recycled engineering plastics and Repocol technology, being indicative of hybrid thermoplastic moulding.

In conclusion, the acceptance of downcycling as the natural progression for mixed sources of recycled thermoplastics is challenged in the context of the ecodesign strategies applied in this practice. These strategies are based on the practice of furniture design incorporating recycled thermoplastics. They are evident in design for reuse of constituent or component materials. They aim to demonstrate simplicity of assembly and ease of disassembly and further address material and production efficiencies. The resolution of this practice leads to designs that encompass product longevity. The distinction between ecodesign and sustainable design (Charter and Tischner, 2001) is then recognised and outlined in concert with new avenues for future research being explored.
2. Thermoplastics Recycling and Moulded Furniture Design

2.1 Overview

This overview firstly outlines the initiatives in Victoria that established the household collection system for recyclable domestic plastic waste, which continues to provide a reliable and growing source of thermoplastics for new product development. The success of these initiatives fostered the municipal kerbside collection of domestic plastic waste that was instrumental in the establishment of recycling infrastructure and which provided new opportunities for design and manufacturing.

A major impediment to the establishment of plastics recycling and the adoption of recycled plastics in furniture design was a lack of a standardised method to identify and sort different types of thermoplastics. The introduction of plastic resin coding in 1988, along with the formation of recycling infrastructure, provided a solution to this problem. This initiative is discussed in terms of its impact on furniture design and production.

The narrative then explores the links between plasticity of form, materials and furniture design. Beginning with moulded timber chair forms from the 1850s, it progresses to plastics chair moulding in the present day. It illustrates the continuum of fashioning and forming materials, and how these endeavours led to the widespread application of thermoplastic materials in contemporary furniture production, that in turn led to innovation with recycled thermoplastics.

2.1.1 Establishment of Kerbside Thermoplastics Recycling in Victoria

The success of plastics recycling in Victoria is largely the result of four initiatives, beginning with the implementation of the kerbside collection system in 1979 for Polyethylene Terephthalate (PET) bottles. The bottles were deposited in sacks or crates for kerbside pickup, and these streamed products were reprocessed into flakes and reused in the production of new PET bottles in a closed loop process. A closed loop process is defined by the reuse of a single polymer formulation in the new production of the same product. The Polyethylene caps and bases of these collected bottles were used in the manufacture of recycled plastic lumber products. The production of these mixed plastic products are indicative of open loop recycling, a process that incorporates diverse sources and types of thermoplastics in new and different products.

The second initiative was the inclusion of plastic milk bottles in the kerbside recycling scheme in 1991. The milk bottles, composed of High Density Polyethylene (HDPE), were re-moulded into pallets where the improved performance characteristics of plastics in wet and sterile environments such as food handling, saw them gain market preference over timber pallets.
Wheelie bins were also successfully moulded with recycled HDPE content. These bins supplanted the early sack and crate containers used in the initial domestic kerbside collection program, and continue to be successfully produced for a wide variety of waste and containment applications.

The entry of Visy Industries into the kerbside recycling program was the third initiative that drove plastic recycling in Australia. In the course of collecting recyclable paper and packaging materials, Visy were also collecting recycled packaging plastics. In 1997 Visy purchased a plant in Melbourne for recycling plastic milk bottles, and a year later they established a new plant at Reservoir with automated recycling of HDPE and PET into feedstock pellets suitable for a variety of re-moulding applications, including furniture.

The fourth and final initiative was the embedding of domestic and commercial recycling as a practical and viable system that fostered the collection, sorting and reuse of plastic packaging materials creating opportunities for new businesses, materials and products. The establishment of a reliable source of recyclycate encouraged the formation of a large number of local recyclers, which in turn facilitated the development of market opportunities for recycled plastic in new products (Baker, 2005).

These four initiatives were primarily concerned with the recycling of packaging plastics particularly single streams of PET and HDPE. This streaming of material facilitated efficient sorting, cleaning and reprocessing. What these initiatives did not address was an increase in the volume of other plastics (e.g. polypropylene) that were entering the recycling stream. These additional materials, which are sometimes not readily identified, are often referred to as mixed or commingled plastics. The availability of this mixed plastic resource led companies to adapt existing plastic technologies in the development of new products. Such adaptation included the extrusion of commingle waste into construction products that replicated timber materials in plank, board and post forms. In the evolution of this process outdoor and public furniture were identified as suitable product categories for development.

Expansion in the manufacture of products incorporating recycled thermoplastics was also in response to the business opportunities that these abundant and cheap materials derived from improvements in waste collection and diversion. Social, environmental and material challenges drove these initiatives, and they contribute to the development of sustainable design practice.

Whilst biodegradable refuse constitutes the largest portion of domestic waste, non-biodegradable plastics in the form of packaging and consumer products are increasingly evident in municipal waste streams (Rogers, 2005). The recognition that thermoplastics make up the bulk of plastic waste, that is reusable and can be available at lower cost to virgin material, has driven interest and experimentation in their re-manufacture and has contributed to the development of this furniture design project.
2.1.2 Impacts of Recycling Initiatives on Material Availability

The establishment of plastic resin identification codes in 1988 provided a means of identifying product compositions. In concert with the development of municipal kerbside collection services and industry support from PACIA (Plastics and Chemical Industries Association), it played a significant part in encouraging industry and consumers to manage and separate their plastic waste (Table 1).

Table 1. Recycled Polymer Materials & Resin Coding, Adapted from (Gertsakis et al., 1991)

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Code No.</th>
<th>Characteristics</th>
<th>Applications</th>
<th>Processing</th>
<th>Material Cost</th>
</tr>
</thead>
</table>
Table 1 identifies generic thermoplastic resin types, their characteristics and applications in product design. When these codes were published in Australia in 1991 thermoplastic materials already existed as significant materials in furniture production. Common forms of this production were evident in low cost seating shells and components in commercial and café seating and as cheap monobloc chairs for domestic outdoor markets (Figure 10, p 21).

2.1.3 Impacts of Plastic Production for Future Recycling

A significant expansion in plastic production and increase in recycling rates has evolved over the past two decades. The impacts that these increased product volumes, suitability of material for thermoplastic recycling and availability for innovative design are now explored by examining trends in industry production and recycling data, Table 2. Recycling has been simplified by the establishment of the plastic resin codes that in turn have added to the volume of recycled plastic material that may be suitable for furniture design purposes.

In 1989, the total Australian annual production of plastics was 694,000 tonne, of which 49,300 tonne were recycled, providing a recycling return of 7.1% (Gertsakis et al., 1991). Figures from the PACIA National recycling survey in Table 2 below show consumption of all classes of plastics produced in Australia in 2008 to be 1,525,185 tonne, with total collection for recycling of 282,032 tonne. In percentage terms recycling comprised 18.5% of total consumption.

Table 2. Australian Polymer Recycling, adapted from PACIA Report (Goldsworthy, 2009)

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Code No.</th>
<th>Consumption (tonne)</th>
<th>Domestic Recycling (tonne)</th>
<th>Export for Recycling (tonne)</th>
<th>Total for Recycling (tonne)</th>
<th>Recycling Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET</td>
<td>1</td>
<td>140 853</td>
<td>24 029</td>
<td>36 748</td>
<td>60 777</td>
<td>43.1%</td>
</tr>
<tr>
<td>HDPE</td>
<td>2</td>
<td>283 948</td>
<td>34 862</td>
<td>39 900</td>
<td>74 762</td>
<td>26.3%</td>
</tr>
<tr>
<td>PVC</td>
<td>3</td>
<td>240 112</td>
<td>7 105</td>
<td>2 095</td>
<td>9 201</td>
<td>3.8%</td>
</tr>
<tr>
<td>LDPE</td>
<td>4</td>
<td>239 589</td>
<td>43 037</td>
<td>19 958</td>
<td>62 994</td>
<td>26.3%</td>
</tr>
<tr>
<td>PP</td>
<td>5</td>
<td>235 936</td>
<td>26 336</td>
<td>14 699</td>
<td>41 036</td>
<td>17.4%</td>
</tr>
<tr>
<td>PS</td>
<td>6</td>
<td>40 714</td>
<td>5 028</td>
<td>3 675</td>
<td>8 703</td>
<td>21.4%</td>
</tr>
<tr>
<td>EPS</td>
<td>7</td>
<td>39 515</td>
<td>2 959</td>
<td>873</td>
<td>3 831</td>
<td>9.7%</td>
</tr>
<tr>
<td>ABS/SAN</td>
<td>7</td>
<td>23 140</td>
<td>5 530</td>
<td>-</td>
<td>5 530</td>
<td>23.9%</td>
</tr>
<tr>
<td>PU</td>
<td>7</td>
<td>55 710</td>
<td>8 121</td>
<td>-</td>
<td>8 121</td>
<td>14.6%</td>
</tr>
<tr>
<td>Nylon</td>
<td>7</td>
<td>17 434</td>
<td>1 227</td>
<td>-</td>
<td>1 227</td>
<td>7.0%</td>
</tr>
<tr>
<td>Other</td>
<td>7</td>
<td>208 234</td>
<td>5 851</td>
<td>-</td>
<td>5 851</td>
<td>2.8%</td>
</tr>
<tr>
<td>Totals</td>
<td>-</td>
<td>1 525 185</td>
<td>164 085</td>
<td>117 947</td>
<td>282 032</td>
<td>18.5%</td>
</tr>
</tbody>
</table>
It should be noted that these figures do not include the consumption of imported plastic products, and therefore do not provide definitive figures for the total of plastic materials in Australia nor possible total volumes available for recycling into furniture products.

Though recycling continues to be the basis of a notable product stewardship scheme the conversion into significant recycled volumes as a percentage of consumption remains relatively low. Globally, recycling rates are lower than the quantities reprocessed each year in technologically advanced western countries such as Australia, USA and the UK. ‘Over 200 million tons of plastics are produced globally each year of which, according to Greenpeace, only 3.5% is recycled’ (Fiell and Fiell, 2009 p. 28). This demonstrates the untapped potential for a global response to recycling, and the opportunities that could exist for furniture applications. What may therefore be deduced is that the opportunities in terms of a material resource for furniture design are increasing. Whilst savings of up to one third of the cost of virgin stock have stimulated the demand for recycled thermoplastics, successful reuse can see local availability of recycled PET and HDPE exceeding supply. Further constraints on local supply are the increase in export of these materials for reprocessing overseas with China being a primary destination (Goldsworthy, 2009 p. 49), and the fate of this exported material not well known.

A breakdown of plastics consumption into material longevity and types provides further illumination regarding current recycling practice and future opportunities for incorporation in furniture products.

PACIA figures in reference to the lifecycle of specific plastic types are characterised as follows:

- Short term (up to 2 years) packaging, medical, stationary products.
- Medium term (up to 15 years) electrical, electronic, furniture, automotive, transport, clothing, leisure and materials handling products.
- Long term (up to 100 years) underground and construction pipe, cable insulation and window frames.

The 2008 recycling rates for packaging (short term) are shown as 36.2% in Table 2, whilst the rate for durables that would include most furniture products (medium to long term) is shown as 8.1%. This variation in short and medium term recycling rates is attributed to product longevity and consequent limited availability of material for recycling, in addition to factors such as design for reuse and limitations in design for disassembly.

Within the packaging sector, products can be typified by short lifecycles, high product volumes, and predominant single material compositions (Goldsworthy, 2009). Products such as plastic milk bottles may therefore be reflected in higher recycling rates as a response to those conditions i.e. short lifecycles limit the degree of after market contamination, high product volumes increase collectable volumes and economies of scale and single material compositions facilitate successful reuse.
The initiatives that have embedded a culture and practice of recycling thermoplastics within Australia have also encouraged the exploration of new horizons in furniture design. Applications are now being explored for upholstery, sheet, construction and moulding materials across the spectrum of coded resin types.

2.1.4 Factors Influencing Reuse of Thermoplastics

The economic, aesthetic and production attributes of polymer materials continues to fuel an exponential increase in new thermoplastic products that may be reused at the end of their life. The link between synthetic polymer production derived from fossil fuels and the issue of declining oil supplies highlights the future limits of synthetic thermoplastic resources for product design. This situation would also reinforce a cautious approach to the use of plastic waste for energy production, where that use would result in the loss of a valuable material resource and negate the benefits that future multiple reuse may provide.

Rapid growth of urban populations has increased consumption and these new modes of consumption are being driven by short product lifecycles (Manzini, 1992b). These increases in the scale of production and consumption of plastic commodities and the consequent social and environmental issues of resource depletion and waste, underpins the process of recycling. Waste in material, economic and global terms as a loss of valuable materials for industry and commerce, is a cost to society with price impacts on goods and services, and a burden on our environment in the digestion of increasing amounts of plastic detritus.

The practice of disposing non-biodegradable waste in landfill sites, of which synthetic thermoplastics are an increasingly significant part, highlights the growing environmental implications of synthetic thermoplastic products in the waste stream. Diversification and increase of throwaway plastic products and packaging has led to problems for traditional methods of containment. The limited availability of landfill sites in urban areas has led to the higher cost of disposal. This scarcity of available land and the problems of a growing waste stream of thermoplastics polluting land and marine environments, are current issues related to the dumping and disposing of these materials (Rogers, 2005).

Landfill as a means of disposing of a mixture of organic wastes synthetic materials and technological discards may be viewed as both reactive and inadequate. This means of disposal continues to adopt the same methodologies as existed when the material buried was predominately organic and compostable. The introduction of synthetic plastics into this waste stream is symptomatic of the complex range of manufactured products which are discarded in an unconsumed state, and which do not readily decompose (Fry, 2009). Burying thermoplastic waste is indicative of a philosophy of being ‘out of sight and out of mind’, when in reality it remains very much in existence.
The accepted household practice of wrapping and mixing biodegradable organics such as food scraps with non-biodegradable plastics in the form of bin liners, bags, packaging and containers illustrates another part of this problem. In terms of recycling it adds layers of complexity for future separation, cleaning and sorting. Non-biodegradable plastics also exist in a plethora of domestic goods that at the end of life, may also be included in those same household disposal bins and routed to landfill, building on those problems of mixed organic and synthetic waste streams.

The loss of plastic material resources is not only a concern at point of disposal, but also as unrecovered waste right across landscapes and oceans. A significant contributor to these conditions is that the material life of synthetic plastics far exceeds most product applications (Fry, 2009). The low density and weight of much of this material is a positive quality in the economies of transport and trade, but this also allows them to be easily blown, carried and deposited throughout the ecosystem. Further synthetic plastics do not biodegrade, but some can photo-degrade (Bamford and Tipper, 1975). Prolonged exposure to ultra-violet light (sunlight) causes polymer chains to break down, a process accelerated by physical friction, such as being blown across the landscape or as a result of wave action. This accounts for most of the tiny flecks and fragments (nodules), present in increasing volumes in waterways and oceans (Sheavly and Register, 2007).

Reports relating to testing of complex landfill sites for leachate of toxic contamination are inconclusive in regard to plastic compositions (Kjeldsen et al., 2002). In part this may be due to the recent explosion of plastic materials and products in waste streams and the consequent time delay of more detailed studies being undertaken.

The use of thermoplastics as inseparable housings or containers for complex technological devices highlights the problem of intermixing possible toxic materials and substances. At the very least a precautionary approach should be adopted for the disposal of all non-biodegradable plastics and in that regard recycling thermoplastics into furniture products could play a role in diverting these materials from landfill.

The association between virgin thermoplastic materials and furniture design is particularly evident with a continuum of new material formulations evolving in concert with the creation of new applications, properties and products. The encapsulating of soft polymer gels in plastic chair forms, blow up chairs comprised of air filled PVC sheaths, transparent acrylic or polycarbonate chair shells, fibre reinforced single cast mouldings and the embedding of soft tactile and upholstery polymer materials within structural plastics are examples of these developments.

The impact of embedded plastic materials and components can inhibit future recycling and encourage disposal to landfill when the cost of disassembly and reuse are not primary design objectives. This issue has now been recognised with design for disassembly (DfD) as a means of ensuring that primary materials are more readily separable and available for future reuse.
Within the commercial furniture industry the practice of coded resin labelling, and marketing of single plastic formulations in chairs and chair components as recyclable has accelerated in the past decade. In terms of reuse and recycling these developments identify product compositions and point to a future when these materials may be remade.

The growing repository of recyclable thermoplastics and their relatively unconsumed status have been central to the development of design for reuse of materials and design for product longevity in this practice.

In order to gain a better understanding of these factors and other elements that influenced this research, an overview of fashioned and moulded chair designs that demonstrate the aspiration for material and production efficiencies with the aesthetics of plasticity in form is developed.

2.2 Plasticity in Chair Design

This research is allied to the development of plastics’ status as a premier moulding material across the spectrum of industrial design production and its pertinence to the furniture design industry. Furniture design links those elements of plasticity in form and material; with a lineage based in timber artisanry, the evolution of practice into plastics moulding and the incorporation of recycled plastic materials in furniture applications.

The new aesthetics that thermoplastic moulding brings to chair forms are examined in light of niche and mass production from the 1950s up to the present day. The proliferation of pliable plastic materials across all areas of product development has provided an extensive material resource that includes thermoplastics suitable for recycling and hence for the design of new products. After establishing the historical context, examples that adapt recycled thermoplastics in furniture design are presented to locate this research.

2.2.1 Developments in Moulded Chair Design

Chair and table designs have been traditionally fabricated from timber materials using established joinery and construction methodologies. Prior to the Industrial Revolution, moulded forms in furniture were typically made by craftsmen bending or carving wood in solid form. A significant advance in timber chair fashioning as a means of styling and a method of construction occurred around 1849 when Michael Thonet, a cabinetmaker, established the Thonet firm in Vienna, exclusively producing bentwood furniture. Building on his expertise of carving and bending chair and table components, Thonet was granted a patent in 1856 to manufacture bentwood chair and table legs, made from laminated veneers and later formed from solid Beech wood, using a combination of steam bending techniques and novel metal tools (Dover Publications, 1980).
This pre-eminent Thonet methodology of bentwood moulding shares many of the adjectives attributed to plastic forming behaviour, such as malleable, pliable, pliant, flexible, workable and bendable (Figure 4). Plasticity in expression of timber shapes and forms further evolved in furniture design with the process of laminating, gluing strips of wood together and encapsulating these glued strips into moulds until the glue was set. This process is also the basis for later plywood manufacture. After significant advances in the development of plywood, steel and plastics technologies during the Second World War, furniture designers embraced this new body of knowledge. New methods for joining, fashioning and manufacturing these materials expanded the boundaries of moulding in three-dimensional form, particularly evident in the development of chair shell components (Figure 5).
These new moulding techniques enabled the advancement of more complex sculptural chair forms with enhanced aesthetic and ergonomic qualities. Further they are demonstrative of new material and production efficiencies. Charles and Ray Eames in the USA and Grant Featherston in Australia epitomise these post war advances in furniture design and production. This new plasticity in chair forms was achieved by applying the processes of timber veneer lamination, plywood forming and fiberglass mat/resin moulding for the creation of custom made chair shells.

The seminal moulded plywood chair designs of Grant Featherston (1922-1995) are of particular relevance to this work. Featherstons standing within Australian furniture design is evidenced by numerous Good Design Awards, and representation in National and State collections, galleries and museums. A longstanding commission to reproduce a range of Featherston seating designs for collectors and retail markets informed this practice about chair design and complex moulding and forming of plywoods.

2.2.2 Plywood Moulding of Chair Shells

The process of making plywood involves bonding an odd number (3 ply, 5 ply etc.) of successive sheets of timber veneers at right angles to one another. This composite methodology increases stability, rigidity, and strength to weight ratios of the core timber material by providing a complex alternated and chemically bonded grain structure in flat, lightweight and efficient sheet form.

A description of laminated chair components as plastic in a formal sense has further relevance, in that the glues used to bond individual veneer sheets or ply are of themselves plastic formulations. The most common glue for these applications is Urea Formaldehyde, a thermoset (heat reactive) polymer resin. The introduction of cheap thermoset adhesives enabled the process of timber laminating to progress from labour intensive hand fabrication to efficient machine mass production. Mass production of chair componentry using fast curing heat reactive glues and industrial presses is typified by two dimensional forms incorporating separate seat and backrest components evident in Scandinavian furniture of the 1950s and 60s, and common in upholstered chair design today.

2.2.3 Featherston Reproduction

The limitations for three-dimensional shaping with veneer and plywood is inherent in the material structure, in that timber materials bend far better across the direction of the grain (the direction of least resistance) than along the grain. Whilst in traditional furniture methodology the application of water or steam can extend the limits of bending or plasticising timber materials, it remains a process of bending rather than moulding, where the aesthetics of tight radii and unconstrained three-dimensional form are not fully realised.

In comparison with plastic moulding multi-dimensional ply forming requires a laborious process of layering of sheet materials to attain a level of flexibility that still remains constrained in aesthetic form and ergonomic performance (Figure 6).
This unconstrained territory in the realm of production efficiencies is the domain of plastic materials and technology, expressed eloquently by Featherston in reference to the connection between plastic moulding, and the attainment of fluid ergonomic shaping: ‘I believe the integral one-piece plastic chair stands at the pinnacle of the furniture designer’s aspirations. Plastics and moulding technology express the synergetic challenge most eloquently. No other material so inherently speaks of body and process, offering a “negative” of the human body.’ (Featherston cited in Lane, 1988 p. 12).

Figure 6, **Contour Chair**, Featherston replica, David Burke, 2004

These limitations in plywood chair form were initially overcome by combining thermoset resins and fiberglass sheets then later by adopting thermoformed plastic seen in the Egg and Swan chairs designed by Arne Jacobsen in 1958 (Figure 7). The initial shells for these chairs were made in Styrene; these styrene forms were then fully upholstered and attached to a suitably modern steel post and cruciform leg assembly. The moulded single piece polyurethane shell in production today was only realised when the synergies of demand, cost, material science and available mass production technology coalesced. The iconic status of these designs proclaimed the arrival of thermoplastics in chair production, unparalleled in the marriage of sculptural form and efficiency of mass production (Oda, 1996).

Figure 7, **Egg & Swan Chairs**, Arne Jacobsen, 1958
2.2.4 Mass Production of Thermoplastic Chair Forms

In 1946, James Hendry revolutionised the plastics industry with his screw injection-moulding machine. Injection moulding is the most common method used for the mass production of affordable durable goods, and encapsulates those values best associated with plastic materials (Bryce, 1996).

The development of thermoplastic technology for the global furniture industry was most visible in the development of commercial designs that combined the economies of injection moulded seating with inexpensive tubular steel sub-frames (Figure 8). These modernist designs marry flexible plastic qualities with rigid and durable steel characteristics, where the practicality of economy and performance dominates ergonomic and sculptural form.

![Figure 8, Polyprop Chairs, Robin Day, circa 1962](image)

Designers such as Eero Saarinen and Arne Jacobsen recognised the potential of injection moulding for blending those economic and aesthetic qualities in plastic chair design, but were initially unable to gain the support of industry: ‘Furniture manufacturing in plastics requires very costly machinery, which the Danish market is not big enough to justify. Or so they say. But show me a plastics manufacturer who dares to take on the experiment’ (Jacobsen cited in Brainy Quotes, 2012).
The progression of thermoplastics in chair form is most notable with the Panton chair, (Figure 9). Designed by Verner Panton for the Herman Miller Company (U.S.A.), this represents one of the first examples of a single cast or monobloc design, in a structure that integrated components in a stackable plastic form. From this point in time, plastics heralded unconstrained artistic shape in chair design, with a single homogenous material integrating the parts of seat, back and legs, in a seamless, balanced and vividly coloured product.

![Panton Monobloc Chair](image)

Figure 9, **Panton Monobloc Chair**, Verner Panton, 1960

### 2.2.5 Development of Monobloc Chair Designs

The evolution of plastics technology with the development of polymer material formulations to suit monobloc construction and the economies of large production runs for an emerging global furniture design industry, were not realised until much later. Panton’s chair was initially hand made and it was twenty years after the design release that new development in plastics technology enabled feasible production. Mass production moulding of plastic furniture represented by these new sculptural aesthetics of form remained in limbo until the critical mass of market penetration and demand connected with developments in material science and rapid injection moulding technology. In relation to chair shells, labour-intensive hand laying of plywoods and fiberglass plastic composites continued to provide a means of meeting specialist niche markets.

Though designs of monobloc chairs were widely available from the 1980s, their acceptance in consumer culture mirrored the expectations of cheap, common utility that had become the hallmark of a plethora of injection moulded consumer goods. The icons of this era are the plastic outdoor chairs that now litter the environment in testament of their design for disposability.
These lightweight monobloc forms (Figure 10) are the epitome of low price, low quality disposable products because reductions in material content and large proportions of cheap fillers used in their composition significantly reduce their lifespan. As the best selling chair type in history due to the utility of form, economies of price and market availability, these examples of monobloc casting are evidence of mass production, new technology and global marketing servicing a throw-away consumer culture, and contributing to increased amounts of unconsumed plastic waste (Designboom, 2012).

![Figure 10, Monobloc Chair, circa 1980](image1)

![Figure 11, Monobloc Project, Jens Thiel, 2007](image2)

What has remained, as an aesthetic legacy of ubiquitous plastic products such as these is the large volume of poorly designed goods that reinforced the consumer perception of plastics as being cheap, poor quality, garish and disposable. The complex and cheap material compositions in such products and their introduction into the marketplace prior to the introduction of resin coding also inhibited reuse and future recycling.

2.2.6 New Imagery and Qualities in Monobloc Seating

During the 1990’s at a time of high design in the realms of art, architecture and corporate branding, plastics began to establish a new and futuristic aesthetic in the realm of chair production. The emergence of designers such as Phillipe Starck and Marc Newson signaled the development of new imagery and qualities in chair design. This presentation of plastics as desirable, elegant, amusing, chic and recyclable with the introduction of coded resin labelling did not preclude production economies due to improvements in material formulations, plastics technology and computer design.
Plastic chair production now moved seamlessly into the realm of commercial and domestic consumption, the café, restaurant, office and home. The work of Starck, a multiple award-winning designer, is notable in the context of furniture design for the development of new thermoplastic seating designs. As a designer whose work is rooted in branding and marketing of new imagery, Starck’s Bubble Club range, winner of the Compasso d’Oro award Italy 2001 (Zackheim, 2012), cleverly exploits the moulding potential of large and complex monobloc form in evoking historical precedents in seating (Figure 12).

The polypropylene Bubble Club lounge, produced by Kartell in 2000, evokes imagery of Chesterfield sofa’s or Art Deco club lounges from the 1930s. More importantly, this evolution establishes multifaceted plastic qualities of finish, form and scale in large domestic lounge furniture, traditionally the province of upholstered timber frames. The continued development of new lounge forms, surface textures and finishes suitable for the emerging crossover between indoor and outdoor seating built on existing plastic weather resistant properties, has further enhanced the public perception of quality in plastic design (Figure 13).
The marketing and branding of new plastic imagery and qualities is also evident in Starck’s monobloc Louis Ghost chair (Bernabei et al., 2011, p 449), a multiple award and best selling design for Kartell since its release in 2002. Inspiration has again been drawn from preceding upholstered timber forms to which is added new elements of plastic aesthetics with the singular use of clear polycarbonate. Futuristic and glass like qualities associated with lightness, transparency and brittleness are projected in contrast with flexible form and durable material qualities (Figure 14).

![Louis Ghost, Phillipe Starck, 2002](image1.png) ![Orgone, Marc Newson, 1998](image2.png)

 Whilst in these examples of Starck’s designs the traditional timber and upholstery structure is reinterpreted with plastic materials, Marc Newson brings the freedom of unique sculptural expression to the design of the Orgone chair. The making of such large monobloc thermoplastic forms typified by Starck’s Bubble Club lounge and the Orgone chair are the province of roto moulding, where economies of infrastructure and cheaper tooling can enable successful lower volume niche production (Figure 15).

This linking of designer branding to plastics with marketing strategies that complemented developments in material science, production technology and industrial design, created new opportunities for thermoplastic materials, as a consequence of which a proliferation of plastics has accelerated into the design of new furniture forms. This proliferation of new applications has included environmental responses in regard to the reuse of plastics that is increasingly evident in the coded labelling of virgin plastic products for future recycling.

These examples of virgin thermoplastic moulding have influenced this research as examples of leading design and also by highlighting their stance in regard to ecodesign practice. The single cast construction of virgin plastic chair shells and monobloc forms is predicated on design for material and production efficiency allied to global branding. These products are typified by the economies of lightweight, thin walled forms where the inclusion of recyclable labeling may aid future recycling. Though this single recyclable composition may reflect best industry practice it still has limitations.
The technique of screw fixing metal subframes to plastic shells commonly used in the connection of metal and steel components can be a point of failure. In the advent of surface damage or breakage of plastic components these products become redundant. Should the front leg of the Vegetal chair break (Figure 16), or the seat of the Bubble Club lounge be perforated, they are not repairable or replaceable and thus will become part of the growing plastic refuse steam.

![Vegetal Chair](image)

**Figure 16, Vegetal Chair**, Ronan & Erwan Bouroullec, 2008

Design of furniture based on construction techniques for simplicity of assembly and ease of disassembly can aid logistic economies and extend product lifecycles. The ability to reduce large or complex chair forms to smaller components is not a feature of the monobloc forms discussed but is a feature of particular value for ease of packaging, transport and delivery. Design for simple removal and replacement of components may also be adapted to provide extension to lifecycle by focusing on the structural qualities of individual parts and their means of connection. The ability to alter styling by machining or with the introduction of interchangeable or new parts are techniques that could be further exploited to achieve life cycle outcomes, that more closely reflect the significant resilient and durable qualities of thermoplastics.

### 2.3 Innovation with Recycled Thermoplastic Furniture

As outlined previously, the context of ecodesign and the practice of incorporating recycled thermoplastics are central to defining the aims of this furniture project and in marking the evolutionary course it has followed. This project is one of a design response to inform ecodesign practice, and details the pathways and opportunities that arose to explore the reuse of thermoplastics in the creation of new products.
As this project has unfolded, it has been informed by innovation and experimentation in this field. Designers have often adopted the methodology of fashioning existing materials and products into new forms. The work of Colin Reedy in the U.S.A., and Jane Atfield in the U.K. (Lofthouse, 2005) are seminal examples of furniture design practice which involved the reforming, shaping and fabricating of readymade recycled thermoplastic products.

![Image of recycled thermoplastic sheet in chair forms](image1.png)

Figure 17, **Recycled Thermoplastic Sheet in Chair Forms**, Colin Reedy, circa 1994

These early designs from Reedy (Figure 17) and Atfield (Figure 18) utilise commercial sheet products that are representative of select sources of recycled thermoplastics. The multi-coloured sheets used in these chair designs are derived from a variety of products composed of similar materials, typically high density polyethylene (HDPE), and polypropylene (PP), found in both domestic and industry waste. The speckled appearance of these materials is indicative of the variety of products and materials in their composition and the plastics technology used in their production.

![Image of RCP2 Chairs](image2.png)

Figure 18, **RCP2 Chairs**, recycled thermoplastic sheet, Jane Atfield, 1995

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3 Images of recycled thermoplastic sheet moulded and fabricated for furniture applications courtesy of Colin Reedy, 2012.
The melding of similar though different material constituents is a hallmark of processes such as compression press moulding. This technology has been exploited by companies such as Smile plastics in the U.K. in the production of recycled thermoplastic sheet forms with unique aesthetic characteristics (Smile Plastics, 2007). Sources for these materials include plastic banknotes and mobile phone casings (Figure 19).

Figure 19. **Recycled Thermoplastic Sheet Products.** Smile plastics, circa 2007

Within Australia recycled thermoplastic sheet materials composed of HDPE and PP in single homogenous colours (as a result of injection moulding technology) have been available for furniture design since 1997, with the establishment of the Unimould Company in Melbourne. These categories of sheet materials are eminently suitable for fabrication with existing joinery techniques and where heat forming and heat welding methodologies can be exploited.
In terms of furniture production, the higher cost of transforming recycled thermoplastics into sheet materials relative to timber composites such as plywood and MDF can inhibit economies in production other than at a specialist or niche level (Figure 20).

The importance of this area of endeavor may be more clearly appreciated in educative and innovative outcomes, where invention allied to plastics recycling has a new story to tell. The examples from Germany (Bär + Knell, 2012), share those innovative outcomes in expressing the ethics of recycling and the innovations of process. The chair depicted is composed of recycled sheet sourced from advertising displays. This novel and idiosyncratic approach to the reuse of plastic materials in furniture applications exists largely in the realm of art galleries and bespoke practice (Figure 21).
The recycling of packaging plastics in the form of PET soft drink bottles used in the Navy chairs (Figure 22), is indicative of the breadth of technologies and recycled thermoplastic materials that may be used for chair production. These replicas of an established design are produced in the USA in a collaborative venture with Coca Cola a major producer of PET bottles and Emeco, the company that produced the original Navy chair in fabricated aluminium (Emeco, 2012). The economic production of large volumes of disposable PET bottles is the result of rapid blow moulding technology where pliant, transparent and durable material qualities are sought in ultra lightweight, thin walled packaging products. This transformation into brightly coloured and structurally robust chair forms is far more complex than simple recycling of bottles and includes reformulation of the PET with additional colourants and fibres that may inhibit future recycling.

![Figure 22, Navy Group Chairs, Emeco, 2010](image)

Whilst the production of the Navy chairs may not allow for recycling, the re-use of PET is evidence of the adaption of disposable and pervasive products into durable sophisticated furniture forms that can better embody the inherent longevity of thermoplastic materials. Whilst Papanek, McDonough and Braungart recognised the value of keeping recyclable plastics separate by type (as demonstrated in these chairs), they emphasise the problems associated with the process of plastics recycling.

### 2.4 Summary

The development of innovative recycled thermoplastic furniture highlights how, through the action of designing new forms, techniques and qualities can be developed that contribute to the practice of recycling. The establishment of recycling initiatives in Victoria with kerbside collection of consumer plastic waste and coded resin labelling of thermoplastic consumer products has been shown to provide a rich material resource for new product development.
The impacts of increased plastic production and their diverse applications has also been explored in regard to their unconsumed state in waste streams and the problems that established methods of disposal can generate. The ability to productively utilise thermoplastic waste can be compromised by complex formulations, possible toxic ingredients and the practice of embedding dissimilar materials in product compositions.

The central theme that links these issues of thermoplastic waste and recycling with furniture design is the progressive expansion of thermoplastic materials into the realm of contemporary chair production. The desire for enhanced aesthetic, ergonomic and production qualities of moulded form in chair design gave rise to early monobloc production and cheap disposable products.

Thermoset polymers combined with fiberglass were evidenced in the early furniture designs of Eames and this remains a method used today in small sectors of the furniture industry, although more evident in larger applications such as boat fabrication. The successful integration of thermoform polymer formulations with the technologies of mass production resulted in the global marketing of moulded furniture, seen in the seminal designs of Robin Day.

The acceptance of plastics within this international marketplace has been further explored through the development of complex moulded furniture that moves beyond utility and the commonplace into new realms of functional and aesthetic expression. The aesthetics of futuristic form in chair design have been cultivated with the marriage of notable international designers and leading manufacturers. This aesthetic is embodied and typified by the work of Starck and Newson in virgin thermoplastic chair production. Inclusion of contemporary indoor domestic settings is evidence of practical and fashionable market acceptance in the province of advanced and affordable virgin thermoplastic moulding.

The recycling of thermoplastics into new materials marks the emergence of innovation as expressed in the development of these materials as a source for furniture design. These new products are evident in international bespoke practice. The commercial moulding into seating forms with products such as the Navy group of chairs is an example of the growing presence of recycled thermoplastics in the global furniture marketplace. A response to the proliferation of plastic production evident throughout current consumer culture has been shown with this use of recycled thermoplastic materials in innovative furniture design.

In the following chapter this subject of innovation with recycled thermoplastics is reviewed with a focus on new products developed in Victoria. A brief comparison is made between the properties of kiln-dried timbers and recycled thermoplastic products that replicate their form and applications. This comparison is provided in reference to the seminal part that timber has played in furniture design, and the current constraints on timber supply for future commercial production. The developments of new and exciting products derived from commingle and mixed source thermoplastics in the Victorian marketplace is then examined to better understand the potential and application for innovative design.
3. Recycled Thermoplastic Production

Innovation in the Australian marketplace is now explored with a review of Victorian companies engaged in the development and manufacture of recycled thermoplastic products. The companies studied are based in Victoria; a sitting complemented by the historical development of recycling initiatives and established plastics manufacturing capabilities. An examination of these key companies seeks to explore the diverse recycled thermoplastic materials and processes that may provide the grounds for practical experiments based in furniture design.

The diversity of compositions and forms now available for furniture practice that are commercially viable provides further evidence that the process of recycling thermoplastics has created new and valuable materials. That plastic can mimic other materials (Tonkinwise, 1998) has been widely exploited with the use of recycled thermoplastics in the replication of timber, a material that is seminal to the history of furniture design. This suitability of thermoplastics to replicate traditional furniture materials, whilst retaining plastic qualities of mouldable shape and impervious finish, has also included those essential qualities of cheap and readily available resources necessary for successful industry adoption.

The products of this review include specific polymers that replicate timber materials and have potential for furniture design. Existing furniture construction techniques used in these products include joinery methods and hardware that have been adapted and developed to aid processes such as design for simplicity of assembly and ease of disassembly. This review is also undertaken to observe how plastic qualities of shape, form and finish are transferred to recycled thermoplastics and establishes whether new and valuable forms are created in their development. These activities provide a springboard for later experiments and designs.

The development of new plastic technologies has expanded the diverse applications for thermoplastics across the spectrum of plastic consumer goods. The adoption of these technologies in concert with the establishment of recycling infrastructure and the ability of recycled thermoplastics to be remade has created fertile prospects for furniture design.

3.1 Recycling Technologies and Opportunities for Furniture Design

The adoption of new plastics recycling technologies in Australia, such as separation by colour, can be effective and reliable for sorting of plastic waste streams for applications such as furniture. Transparent products such as PET bottles can be automatically sorted using transmitted light systems, whilst reflected light systems can be used to sort products such as opaque LDPE milk bottles (Rtt-Steinert, 2006). Both clear and opaque short term plastics in the form of single use containers exist in large volumes in household rubbish and can be easily identified and readily sorted using such automated systems with success rates in the order of 80 to 100% (Rtt-Steinert, 2006).
The significant labour costs involved with manual sorting in developed economies are reflected in the reliance on automated recycling technologies for economic diversion from dumping and landfill.

In the medium to long term lifecycles of durable plastic products there are similarly high product volumes but significantly lower recycling rates. This range of products is typified by complex material and component compositions that are more problematic for sorting and streaming technologies (Goldsworthy, 2009). At the end of life, this complexity can further inhibit separation of materials and components for recycling. It is with these more complex products with intermixed components that ease of design for reuse becomes critical in providing the opportunity for economic recovery and reprocessing into new products, such as furniture. A qualitative comparison between the properties of timber and products that incorporate recycled thermoplastics is provided in Table 3.

### Table 3. Comparison: Kiln Dried Hardwood and Recycled Thermoplastic Products

<table>
<thead>
<tr>
<th>Property</th>
<th>Hardwood</th>
<th>Modwood Decking</th>
<th>Syntal Products</th>
<th>Replas Products</th>
</tr>
</thead>
<tbody>
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<td>+</td>
<td>+</td>
<td>++</td>
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<td>Rot Resistance</td>
<td>0</td>
<td>+</td>
<td>++</td>
<td>++</td>
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<tr>
<td>Insect Resistance</td>
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<td>++</td>
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<td>Chemical Resistance</td>
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<td>++</td>
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<td>Stain Resistance</td>
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<td>++</td>
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<td>Warp/Cup Resistance</td>
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<td>Comfort</td>
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<td>Dimensional Stability</td>
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<td>Heat-Slump resistance</td>
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<td>Installed Longevity (exterior)</td>
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Scale : (- - Very Poor, - Poor, 0 Average, + Good, ++ Very Good)

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4 David Burke 2011
The properties outlined in Table 3 are based on property requirements for furniture and construction applications. The consequences of changes within the furniture industry, especially limitations of timber supply and the rise in moulded plastic products may be seen as fortuitous for plastics recycling and the development of new recycled plastic materials and products. This comparison of hardwoods and products incorporating recycled thermoplastics is illustrative of the new qualities recycled plastic materials bring to the furniture and construction sector.

The key advantages of materials with thermoplastic compositions are their resistant qualities to environmental conditions affecting material degradation and their good forming and bending characteristics. Advantages of hardwoods relate to machining, finish, glue adhesion and tensile strength that is a significant property in providing a breadth of structural applications. The similar form, application and fabricating qualities of these timber and plastic materials provided the impetus for experiments with woodworking tools and machinery within the practice of furniture design.

### 3.2 Supply Constraints on Timber Resources

During the past decade wood plastic composites for decking, furniture and screen boarding have been one area of significant market expansion (Smith and Wolcott, 2006). Ever growing commercial pressures on forestry worldwide and a growing appreciation of roles forests play beyond those of providing material for building and construction has played a pivotal role in these developments. Environmental values that encompass the health and diversity of ecosystems are now evident in the establishment of large public forest reserves (Bengston, 1994). When added to a diminishing forestry resource, these factors are a constraint on the future supply of timber materials for construction and furniture purposes.

As old growth forests have become more depleted, the range and availability of diverse timber species for furniture design has also diminished. In Australia, commercial species common a century ago such as Silky Oak, Walnut, Black Bean and Huon Pine are now protected in public reserves and unavailable for commercial furniture production (Erskine et al., 2005). The depletion of forestry resources has seen a parallel diminishing of available log scale and consequent sawn sizing. Where once lumber widths in the order of 250 mm to 350 mm and lengths in excess of six metres were readily procurable, they are now less common across all areas of wholesale timber supply.

In response to these constraints on supply, new and different materials such as recycled thermoplastics are increasingly being used to replicate traditional timber forms and applications. Though timbers and recycled thermoplastic products that replicate them have similar qualities as shown in Table 3, the differences that are also demonstrated require the development of new techniques and practices for successful incorporation into furniture design.
3.3 Thermoplastic Processes and Furniture Production

Having examined the establishment of plastics recycling, Victorian companies that utilise recycled polymer feedstock were studied. Allied to the development of businesses predicated on polymer recycling are incremental advances in plastic recycling rates, increasing demand and application for recycled plastic products, and the emergence of diverse manufacturing methods for their production. The businesses studied are presented as models of effective recycling practice, representative of a breadth of manufacturing process and a diversity of recycled thermoplastic materials and products. The variety of moulding processes includes extrusion, injection, low compression and hybrid moulding.

The established methods of machining and moulding of solid and plywood timber materials in furniture practice has synergies with the forms and application of recycled thermoplastics products being developed in Victoria. These synergies have led to experimentation with the readymade products that replicated solid timbers and processes that could be used to replace plywood moulding of chair shells. The other examples of Victorian recycled thermoplastic production provided; give a more general overview, having either established product applications in furniture components or potential for innovative furniture design.

3.4 Extrusion Moulding

The reuse of mixed thermoplastics in Victoria was initially defined by the replication of timber products where design inputs and product development were limited to simple round, square and rectangular extruded sections. At this basic level recycled thermoplastics are still extrusion moulded into posts, planks and stakes, by companies such as Australian Composite Technology (ACT), Close the Loop (CtL) and Repeat Plastics.

These extrusion methods commonly produce a heterogeneous dark material in the spectrum of grey, black and green, though a wide variety of coloured and textured outcomes are possible, dependent on the mixture and processing of source material and the moulding technology involved.

Extrusion moulding of commingle plastic products was adopted as a means of diverting mixed and contaminated domestic plastic waste from landfill. This plastic waste was considered by municipal councils to have little value in relation to: the rising physical and environmental costs of landfill solutions, the amount of material contamination or the degree of processing necessary to render it reusable. Therefore it was often provided for free by local councils, as part of their domestic waste collection services and its reuse subsidised as a means of initiating new recycling ventures. The establishment of these new ventures now forms the basis for the following study of Victorian companies and the recycled thermoplastic products they manufacture.
3.4.1 Smorgan Plastic Recycling - Syntal

Syntal recycled plastic lumber products developed by Smorgon’s at their plant in West Footscray from 1985 to 1992 was based on an existing internationally patented extrusion process and developed product lines. These products included speed humps, bollards, marker posts and a variety of shapes and forms replicating solid timber boards and profiles that were trialed and incorporated in furniture products.

A range of standard round, square, rectangular and oblong steel sections were adapted by Smorgon’s as off-the-shelf mould tools welded to the outfeed of the extruder. This tooling formed the shape of the extruded plastic in replicating basic timber forms; posts, slats, planks and beams.

Extrusion remains a viable and necessary process for recycling the lowest grades of plastic recyclate for two critical reasons. Firstly, it does not require separation of the mixed plastics enabling processing without the additional expense of manual or mechanical sorting and cleaning. Secondly, the process successfully accommodates a degree of contamination in the form of paper labels, ring caps and metallic particles (Smorgon, 1990). Such a rudimentary process complements the domestic kerbside collection systems provided by local councils, where a range of mixed recyclable household waste was deposited in recycling bins. These bins also contained mixed glass, metal, paper and coded plastic products used in the normal cycle of household consumption, and as such also contain other residual contaminants.

In respect of providing fully uncontaminated sources of these materials, the system is imperfect at both the point of collection and subsequent processing. Plastics that are not coded and problematic to recycle in this system such as bottle caps, or containers that may hold residues after being emptied exist in such small amounts that they may be successfully encapsulated in the extrusion. Similarly minor residues of metal, glass or paper remaining after separation that are small enough to fit through the materials screening can also be successfully encapsulated within the extruded products. These commingle plastics were economically formed into lumber substitutes and custom moulded products in a variety of forms especially suitable for outdoor applications, where the significant material longevity and moisture resistance of plastic materials was utilised.

The properties of Syntal, include resistance to rot, chemicals, weather and bacteria. Unlike wood, Syntal does not splinter, and was projected to have a lifespan in the order of 50 to 100 years (Smorgon, 1990). It is essentially maintenance free, and as such could be installed in any exterior situation. This advantage can be extended to include the range of tropical wet and humid to artic conditions, in contact with seawater or aggressive chemicals where timber installations would have a relatively short life.

The Syntal brand disappeared from the marketplace in the early 1990’s when Smorgon’s sold their plastics recycling business. Australian Composite Technology and Repeat Plastics in Melbourne have adopted this extrusion methodology and the production of posts and planks.
3.4.2 Australian Composite Technology (ACT) - Plasmar

The diverse recyclate used in current ACT production includes black plastic sheeting from the building industry, carpet waste, engineering plastics from a variety of sources including Materials Recycling Industries (MRI) electronic waste, packaging and other miscellaneous plastic waste (ACT, 2012). ACT produces a similar product range to Syntal, using an equally rudimentary extrusion process to accommodate diverse recycled thermoplastics. This product range consists of round and square section post forms, available in 1800 mm, 2400 mm and 3000 mm lengths, being typically grey/black in colour with a roughcast surface finish. A large market for these products is the agricultural fencing industry, particularly in vineyards, where its comparative pricing to treated pine, lower leachate toxicity, recycled credentials and longer lifecycle has seen demand outstripping supply.

Whilst commingled polymer products may be the least favoured outcome for recycling plastics, such methodology, when linked with compression and extrusion technologies, are a substantiated means of remaking or containing these materials. They may therefore provide a solution to the accumulative problems of mixed plastic waste whilst also providing a rich source of material for activities such as furniture design.

The familiar replicated timber forms, coupled with the ease of fabricating with standard woodworking machinery, provided a natural starting point for experimentation with these recycled thermoplastic products. Experiments with Syntal provided the genesis for this research in exploring the proposition that the process of furniture design incorporating recycled thermoplastics produces new forms, techniques and implications for design practice.

3.4.3 Close the Loop (Ctl) - eWood

Ctl, based in Campbellfield, Victoria, have developed a unique thermoplastic extrusion methodology based on containment and extraction of contaminates and toxic residues (Ctl, 2008). The production of eWood (electronic waste wood) in a closed loop process is at the forefront of producing a valuable material from the polymers in generic printer cartridges and casings.

These printer components are composed of mixed styrene engineering plastics such as general purpose polystyrene (GP-PS), high impact polystyrene (HIPS) and acrylonitrile butadiene (ABS) recognised for their superior engineering qualities of durability, toughness and surface finish, and which are typically more highly valued in the chain of coded commodity plastics. The following description from the Ctl technical data demonstrates a holistic approach to recycling, where the waste toner and foam residues contained in the cartridges are also utilised in the process to provide pigmentation for the end product. ‘It is characterized by high stiffness, high strength and a glossy waste toner powder and PU foam. The eWood is pigmented using a master batch (or colour concentrate) based on waste toner powder and PU foam.’ (Scheirs, 2005 p. 2).
The market success of CtL has much to do with the constant supply and significant volumes of recycled printer cartridges being collected at point of sale. Hazardous substances in this electronic waste include brominated flame-retardants that are a significant barrier to safe recycling practice. To address this problem, CtL have developed processing and technology for feedstock that draws off brominated fire retardant residues safely. The existence of such toxic materials within plastics can be a reason against recycling them (Tonkinwise, 1998), but the evolution of research and development in this instance has validated the ability to extract, capture or encapsulate those toxins with new technology.

By utilising this waste material in a closed loop process, the superior performance characteristics of engineering plastics, longevity and tensile strength are incorporated into the eWood products. eWood is also marketed as a safe alternative to Radiata Pine impregnated with CCA (Chromated Copper Arsenate timber preservative, an insecticide and fungicide used to prolong the life of Radiata Pine), which is recognised as a potential source of leached environmental pollution (Scheirs, 2005).

The process developed by CtL also mechanically removes any metal particles as part of the automated sorting operation, whilst encasing contaminant residues in the extruded plastic lumber composite. This robust sarcophagus like encasement of contaminates admirably suits the long lifespan of eWood in fencing, animal enclosures and furniture previously the province of native hardwoods and CCA treated Radiata Pine (Figure 23).

Figure 23, **Furniture using eWood**, CtL, 2007
Whilst a comparison between recycled plastic lumber and treated Radiata Pine would suggest a range of improved characteristics, it raises issues of ‘like for like’ comparison. Radiata Pine represents the lowest denominator of construction and furniture timber in Australia being the most common plantation resource, the cheapest and representative of the lowest engineering grades. It is typically graded in the order of F5 to F9 in a code where comparative Hardwoods are rated F18 to F22 as a measure of their superior engineering span and tensile qualities.

In further assessing the properties of eWood for furniture construction, it may be limited by a tendency of harder thermoplastics to fracture across a section of form, due to sharp and concentrated pressure or shock loads. This can occur where fixed by mechanical fasteners to a frame, and is in contrast to the pronounced resistance to fracture inherent along the grain of timber materials and their ability to withstand concentrated pressure and shock loads.

The engineering qualities of eWood are enhanced by removal of any contamination that may promote structural defects. The CtL process removes metal contamination from the cartridges by magnetised extraction; firstly, as any metallic contamination can be abrasive and damaging to the expensive and complex moulding machinery; and secondly, as a source of possible safety problems with post production machining or fabrication and consequent performance defect issues. The trend in production of printer cartridges with embedded metal components can adversely affect CtL’s ability to transform this waste stream. This practice is symptomatic of design economies negating the improved material and social outcomes that design for ease of disassembly and separation of material components can provide. Such embedding practice may have the consequence of valuable material loss and pose further potential for leachate contamination in landfill.

In comparison with the commingle thermoplastic materials created by the Syntal and ACT processes, eWood has improved engineering qualities though it shares very similar methods of extrusion manufacture. The former are representative of diverse domestic waste plastics in an open loop cycle, and the latter is indicative of select post consumer waste in a closed loop cycle.

3.4.4 Modwood Technologies- Wood Plastic Composites (WPC’s)

The evolution in plastics recycling is now producing new and valuable materials and product lines which fit more comfortably between the extremes of mixed and contaminated material sources (Modwood, 2010). Developments in plastic lumber and specialist sheet materials have continued and intensified and are now two areas of significant promise for furniture design.

Australian hardwood timbers traditionally sourced from old growth forests and used for furniture and construction purposes are increasingly sourced from plantation stock (Love et al., 1999). In concert with limits on availability for commercial purposes due to the increase in old growth forest reserves and impacts of deforestation, timbers are now typically processed in kiln-dried form as opposed to air-drying favoured in traditional furniture practice. These factors have diminished the diversity and availability of commercial timbers that in addition to increased uniformity can include loss of structural performance and material longevity in exterior applications.
Comparatively wood plastic composites (WPC’s) suffer little of the pronounced defects or limitations of timbers, especially in applications requiring ongoing maintenance. They are not prone to problems of insect attack or significant moisture uptake associated with wet weather and marine environments, due to the natural resistance of plastics to water penetration. The success of these products in the marketplace has grown significantly during the past five years as evidenced by the entry of new businesses offering WPC board for decking and furniture products (Figure 24).

The difference between WPC and commingle products is the selection of single code thermoplastics and their mixing with wood fibres. This engineering of WPC materials allows more detailed and complex moulding with features such as ribbing, non-slip surfaces, hollow section profiles, brushed and timber grain finishes. Increasing the fibre content with wood particles can also increase the rigidity of the material to counteract slumping, a property pronounced with heat exposure and common with early Syntal materials in replication of solid timbers in outdoor furniture.

![Figure 24, WPC in Furniture, Botton @ Gardiner, 2011](image)

Modwood Technologies was the first Australian company to produce and market wood plastic composite products, launching its first decking range in 2001. A basic formulation consists of approximately 55% recycled wood fibre (by product of Radiata Pine processing), 35% HDPE plastic (typically sourced from recycled milk bottles), with 10% additives and stabilisers. These additives include ultra violet stabilisers to provide added protection from the effects of sunlight exposure and tints to supply a range of colours and shades. The extruded Modwood range includes three timber plank look-alikes in red, brown and beige with a grey providing a neutral alternative (Modwood, 2010). The current product line includes solid boards in widths up to 137mm wide and 32mm thick.
In comparison with timber boards the plastic composites have a softer surface and feel with the added advantage of being splinter free, providing a more comfortable alternative in decking and seating applications. The inherent flex in these materials adds to these qualities and also allows for gentle curvature and radii not possible with solid timbers, and may suggest an increasing sophistication of application in future furniture design.

The ability to replace and enhance timber resources with plastic and plastic wood composites should not be underestimated or dismissed as mere downcycling (McDonough and Braungart, 2002). It can provide advantages in diverting demand pressures from diminishing forest resources, while further creating the development of a new class of materials with the possibility of inherent and fabricated attributes superior to the timber forms they replace.

### 3.4.5 Repeat Plastics – Replas

Repeat Plastics Australia (RPA) was formed in 2001, being the amalgamation of two companies active in post consumer and post industrial waste processing during the 1990’s. The extensive product range is composed of 100% recycled plastic in the form of blended HDPE, LDPE and PP. Within the post consumer materials, extraneous matter such as product labels can constitute up to 3 to 4% of the mix. In order to overcome issues of slumping and warping in their range of products a minimum thickness of 40 mm is currently required (Repeat, 2010).

As with the examples cited to date, the product focus is typically replication of forms the province of solid timbers. Posts, rails, slabs, boards, pickets, bollards, and beams are produced as singular items or form the building blocks for installations such as outdoor furniture, traffic management, park and marine projects. More complex mould tools have also been developed as shown in the robust sub-frames (Figure 25) that point to more innovative outcomes.

![Repeat Plastics Outdoor Furniture](image1)

**Figure 25, Replas Outdoor Furniture, Repeat, 2011**

The value of plastic moulding is exploited in the shaping and forming of details within the mould tool so that decorative features in timber equivalents previously made with repetitive processing such as fluting, decals, rounding or trenches are formed in a singular process. The 100% plastic content in these products allows complete and sustained immersion in water where WPC materials are less inert and subject to some degradation of the wood particles in such extreme conditions.
With the evolution of plastics technologies and greater emphasis on separation, recovery and availability of single plastic types, a new generation of recycled plastic products was being created as demonstrated by the Hume setting (Figure 26). This public setting consists of three separate and replicable elements, table, bench and chair. The design is dominated by site and function. Robust single piece forms are modelled in a modernist manner devoid of any extraneous ornament or fixings. They incorporate straightforward elements of ergonomic form and shape for user comfort with structural design for longevity in outdoor sitings.

![Hume Picnic Setting](image)

**Figure 26, Hume Picnic Setting, Repeat, circa 1995**

The production of these pieces demonstrates sophistication beyond the simple extrusion moulding used to form posts and planks, though vestiges of those forms are evident in the square section posts that anchor the table top, bench and seat. The development of mould tools for this furniture setting demonstrates the progression from simple readymade geometric steel sections in the production of extruded commingled forms, to custom designed tools more reminiscent of those employed in injection moulding.

### 3.5 Injection Moulding

The plastics recycling processes examined so far have focused on extrusion manufacture, which is appropriate for the production of forms that can accommodate a degree of contamination and or intermixing of materials. The most common method of producing plastic furniture products is injection moulding, a process which lends itself to rapid and complex replication of form, typified by high volume thin walled products which contain economies of form, scale and cost.
It is interesting then to observe that this method has also been adopted for forming recycled thermoplastics into sheet materials. The imagining of recycled plastic products to replicate existing materials, in this instance plywood, chipboard, and medium density fibreboard (MDF), targets joinery, building and construction applications with standard sheet sizes of 2400 mm x 1200 mm and thicknesses from 6mm to 25mm.

3.5.1 Unimould & Plaspanel - Recycled plastic sheet

Unimould was the first Australian producer of these recycled plastic sheets in the mid 1990’s using technology and infrastructure imported from the USA. The core of this plant was a large piston injection-moulding machine linked to four large aluminium tools to accommodate standard 2400 mm x 1200 mm sheet production.

Unimoulds production included smooth and stippled non-slip finishes in single pigments of green, grey and white with special colours limited by commercial volumes of suitable stock being available. Recycled HDPE and PP from post industrial and post consumer sources provided the feedstock and panels were produced up until 2003 when the plant was dismantled and sold. The infrastructure that remained was purchased by the Builda Panels Company and material is now produced under the Plaspanel trademark (Builda Panels, 2006). The current Plaspanel colour range is indicative of market growth with single pigmentation in black, grey, off-white, beige, yellow, orange, red, green, blue and select colours on request. Applications are found in industries as diverse as agriculture, building, construction, furniture, manufacturing, marine and materials handling. This methodology also incorporates the reuse of panels, off-cuts and material waste in a closed loop system.

Whilst methods of cutting, shaping and fixing in joinery and construction are similar for both panel forms, it is the additional suitability for seamless welding and heat bending that enhances applications for recycled thermoplastic panels in furniture design. Plastic welding technology is available from portable hand held heat guns through to commercial computerised systems, with the welding rod being composed of the same plastic formulation as the sheet being fused, further aiding future recycling.

Figure 27, Recycled Thermoplastic Sheet, designs, David Burke, circa 2005
The prototypes and concepts developed above (Figure 27), specifically targeted plastics welding. Internationally these panels are available in a wider variety of forms, with speckled colour finishes being indicative of mixed source formulations as shown in the early furniture designs of Reedy in the US and Atfield in the UK. These board materials are especially suitable for large constructions, and whilst many furniture concepts have been exhibited, successful conversion into commercial production is hampered by high material and fabrication costs in comparison with timber composites.

3.5.2 Reln Plastics

Reln Plastics were a pioneer in the Injection moulding of recycled polymers in Australia. The wide range of products largely produced from polypropylene or polyethylene targets commercial and domestic drainage, agriculture and water management sectors. Of all the polymers used by the plastics industry, PP and PE have the most viable second-life application and are the most easily sourced from the waste stream (Reln, 2007).

On a visit to Reln’s production facility in Sydney (2003), the use of recycled thermoplastic was illustrated by the closed loop production that incorporated reused milk crates, of which they are the original supplier. This development of taking back products at the end of life provides a material stream of known composition and potential, at a discount price to production in virgin plastic. Dependent on market price and availability the savings can be in the order of 30%.

A major issue in the production of new plastic products from recycled sources surrounds the aesthetics of colour. Typically the intermixing of a range of colours results in darker shades and black being formed. Overcoming this problem has been assisted at Reln by their ability to stream and select sufficient quantities of recycled plastics according to colour, through sorting of similar shades for re-colouring, and by establishing black as the standard for products where colour is largely irrelevant. Due to the large scale of their plastics business, Reln are also able to fully select and utilise all of their in house plastic scrap to achieve desired colour and product outcomes (Figure 28).

Figure 28, Recycled Thermoplastic Grates, Reln, 2003
Their products that are sited in ground such as sewerage and water tanks, piping, grates and worm farms are typical of items where colour is not a primary requirement of marketable function. Where colour is a requirement for branding as with proprietary milk crates, or where its function is to match, complement or differentiate form, the establishment of a closed loop system enables the selection and sorting of recyclate to produce specific colours seen in the grates.

This issue of re-colouring recycled thermoplastics for furniture applications can be possible when sufficient quantities of suitable material are available in the colour of choice, or in a form where they can be readily re-coloured with additional pigment. Plastics in clear, white and light colours are therefore most suitable if the colouring of plastics follows that of basic paint pigmentation. The chemical diversity within plastic types and the numerous additional performance enhancements including ultra violet stabilisers, flow agents and flame-retardants further complicate this process.

As a consequence of possible chemical complexities, and the additional compounding when recycled thermoplastics are derived from varied sources, a simpler commingle solution of known types fused together is often the starting point for recycling operations.

3.6 Low Compression Moulding

The recycled thermoplastic sheet samples depicted in figure 29 are typical of outcomes based on similar coded recycled thermoplastics from different sources being melded together by pressure which results in the constituent plastics being identifiable by colour. Typically these outcomes are produced by low compression moulding in the production of sheet materials, as distinct from more homogenous and dense commingle extrusion or injection moulding.

Figure 29, Low Compression Moulding, sheet samples, 2007
3.6.1 Design Flow – Matrix Products

Design Flow manufacture a range of lattice, screens, pickets and panels under the Matrix trademark (Figure 30). An innovative process for moulding panels has been developed in-house that combines low cost mould tools with hybrid technology made possible by concentrating on improving the flow characteristics of recycled PP and HDPE (Designflow, 2008).

The range of plastic lattice, screens and pickets is combined with galvanised and powder coated steel rails and posts, to form a complete fencing system for retail through established hardware and building outlets. Design Flow is indicative of emerging plastic businesses that strive to reduce their overheads and increase their economic advantage by the adoption of less capital-intensive plant and infrastructure in combination with lower cost recycled feedstock. Whilst reuse of suitable PP and HDPE is possible in quantities close to 100% of content in most of their products, market availability and competitive pricing of recycled material fluctuates with demand and periodically leads to substitution with virgin sources.

An advantage of this niche production is the ability to offer customised options in terms of material, sizing, colour and finish. An exciting example of custom innovation has been the production of sheet materials composed of recycled plastic bank notes. The resultant sheets exhibit a greater surface hardness and scratch resistance than other recycled plastic sheets, consistent with a higher level of HDPE in the mix, plus hardener additives in the bank notes used to improve their durability.

These sheet materials have a distinctive appearance drawn from the colour range in the notes. This quality is more clearly evidenced in the low compression production of panels comprised of recycled British bank notes (Figure 19, p 26), where the imagery embodied in the notes is clearly retained in the recycled plastic sheets. The reuse of such thermoplastics with embedded visual qualities can add qualities of aesthetics novelty and exclusivity for applications in furniture such as bar tops, cafe tables and decorative panels that increase their marketable premiums.

Figure 30, **Sheet & Lattice**, Design Flow, 2012
3.7 Hybrid Moulding

3.7.1 Recycled Pipe Manufacturers (RPM)

Recycled Pipe Manufacturers (RPM) have exploited the longevity of recycled thermoplastics in outdoor applications, a property improved with in-ground positioning where the degrading effects of sunlight and exposure to the elements are eliminated (RPM, 2012). This property has been central to their development of low pressure piping solutions, such as drainage and flood irrigation pipes in a range of diameters in the order of 300 mm to 600 mm and up to six metres in length.

These recycled thermoplastics are sourced from post consumer waste consisting of high-density polyethylene (HDPE) found in milk bottles, milk crates, agricultural black poly pipe and detergent bottles. Being sourced from a single plastic type enables weld jointing and custom fabrication to extend the product range into agricultural water and feed troughs that are readily fabricated by splitting pipe forms lengthwise and welding end caps (Figure 31). The scale of these products and their means of custom fabrication contain unique possibilities for large-scale furniture installations which are identified for possible future exploration.

Figure 31, Recycled Thermoplastic Pipe, RPM, 2003

3.7.2 Wharington International - Repocol

Wharington have taken a novel approach to fusing or melding recycled thermoplastics such as ABS (Acrylonitrile Butadiene Styrene) to produce furniture components and interior design products under the trade name Repocol (Wharington, 2012). They produce a range of lounge, tub, task and cafe chairs where the Repocol componentry is primarily treated as a substitute for traditional ply shell forms, and as such is intended to be covered with upholstery treatments.
This methodology is shown in the Repocol shells upholstered and adapted for commercial seating by Schamburg@Alvisse (Figure 32).

Wharington have moulded recycled plastics since the 1980’s by adapting existing chair moulds and developing low cost sheet steel tools. This is an extension of their expertise in engineering customised steel fuel tanks, containers and fittings for the long haul trucking industry.

These custom steel tools are fabricated in two parts, being joined with mechanical bolt and nut fastening. The methodology for re-moulding recycled thermoplastics demonstrates an innovation with process and technology. Unlike injection moulding where feedstock is fully melted, homogenised and injected into tools, this is a hybrid technology. It involves blowing the pelletised recyclate into a static mould. The mould is heated in a gas-fired oven and pressed or mechanically tensioned to provide pressure. Consequently the point of melt and flow is finely balanced with the pellets being fused or melded rather than fully melted. In completed form the parts retain the formative pellets that may distort in areas of greater pressure or heat and exhibit a pixelated appearance throughout (Figure 33).
The resultant parts are also characterised by imperfections with minute pores and cracks apparent in the surface of the moulded parts. To overcome any structural weakness components are significantly thicker and denser than similar virgin plastic parts, typical wall thickness of chair shells, correlates to similar plywood components being in the order of 12mm thick, to compensate for the imperfect fusing of the polymers.

During the mid 1990’s local furniture design businesses such as MAP and ISM Objects collaborated with Wharington to produce a range of new furniture products using the Repocol process. In addition to chair shells and café tables formed from recycled ABS plastics, the use of transparent plastics sourced from recycled car tail light lens was undertaken. Whereas the recycled ABS was derived from a variety of sources such as computer casings and household appliances, and hence was an amalgam of varied opaque coloured pellets, the ‘Madam Ruby’ lamp produced for ISM was moulded from a singular stream and type of semi transparent thermoplastic recyclate (Figure 34).

The lamp was available in two colours, with the recycled plastics being derived from tail light lens (red) and indicator lens (orange). The use of recycled thermoplastics for the lamp shade combined with the process of fusing the pellets produced a novel crazed appearance to the shade form, which when lit from within further fractured and intensified the quality and form of the light. This innovation and the highlighting of pixilated form shown in the ‘Placy’ table (Figure 35), demonstrated the possibility of new material qualities being created from recycled polymers that remains a fertile area for new designs.
The Repocol material is not unique in form, similar outcomes are evident in a variety of recycled plastic materials utilising PP and HDPE in pressed sheets and moulded products, where the pellets are fused rather than fully melted and blended. Samples of recycled plastic products in Europe such as the seat and back components developed by Bär + Knell based on a 1950 Egon Eiermann chair design mirror the appearance of mottled form indicative of outcomes from the Wharington process (Figure 36).

Figure 36, **Egon Eiermann SE 68**, replica Bär + Knell, circa 1996
3.8 Summary

This chapter has outlined the opportunities, products and applications developed thus far for recycled thermoplastics in Victoria. These thermoplastic products replicate existing material forms and especially solid timbers and wood composites across a broad spectrum of applications. This began with forms such as planks, posts and boards that was followed by panel and sheet materials and finally shows the development of more complex moulded forms.

In regard to the methods adopted for production of these forms, the processes of extrusion, compression, injection and hybrid moulding have been explored. Within Australia injection moulding of recycled plastic furniture was not found to exist at the beginning of this study but it is a technology now incorporated into commercial furniture practice in the production of sub-assemblies and components\(^5\).

The evidence for market acceptance of recycled thermoplastics exists in the local manufacture of products that have been adapted and developed in furniture designs. Transformation into marketable furniture through replication of traditional outdoor timber designs, development of new designs and the moulding of more complex shapes points towards further new developments with recycled thermoplastics. Within Australia the Repocol hybrid moulding process developed by Wharington has been accepted as a viable alternative to plywood chair shells for upholstery purposes as seen in the commercial seating designs of Schamburg and Alvisse, and as a material for further innovation shown in the designs of ISM objects and MAP.

In the following chapter use of Syntal readymade extrusions derived from domestic commingle waste recycling, and the application of Repocol moulding technology in the use of recycled engineering thermoplastics, will be applied to the design of furniture. The proposition that the process of furniture design incorporating recycled thermoplastics produces new forms, techniques, and implications for design practice will now be developed through the action of furniture design.

\(^5\) Site visit, Camatic Commercial seating, 2011.
4. Methodology and Development of Furniture Designs

In the following chapter the processes adopted and the outcomes delivered will demonstrate that recycled thermoplastic products need not be derived from single products or single polymer formulations to be products of significant quality and value. Systematic reflection on this practice will incorporate ecodesign strategies considered relevant to furniture design. These strategies include: simplicity of assembly, ease of disassembly, material and production efficiency, reuse of constituent materials and longevity of product lifecycle.

The body of this self-directed research into furniture designs that incorporates recycled thermoplastics is evident in two distinct periods. The formative period in the development of new furniture designs began in 1989 as part of a design competition initiated by Smorgan Plastic Recycling exploring new applications for their readymade Syntal products.

The second part of this research was initiated in 1999 as a result of the opportunity to develop recycled thermoplastic chair shells. This development opportunity was influenced by the ongoing reproduction of Featherston plywood chair forms and by the marketing and sale of local and international chair designs. Anecdotal evidence and intelligence gained through these commercial activities provided insight into the growing applications for thermoplastics in chair design and provided focus for experiment and development of designs incorporating recycled thermoplastics.

This chapter firstly discusses research as a methodology used to explore the design of furniture in this project and then details the experiments into two categories of recycled thermoplastic materials, described in preceding chapters and outlined below.

1. Commingle thermoplastic products in extruded post and plank forms derived from mixed sources in domestic and industrial waste streams. Detailed in design, experiment and prototyping with Syntal readymade forms for desk, chair and table components.

2. Mixed engineering grade thermoplastics from domestic and industrial waste streams moulded with the Repocol hybrid process. Detailed in formative design works, commission of the Peregrine mould tool and the production of innovative chair designs.
4.1 Methodology

Through this research, a systematic building of knowledge has occurred that includes knowing about design through furniture making, its evolution in history and the development of technology, techniques and materials in a self directed practice (Downton, 2004). The method adopted in this research began in reflection on design, and the amalgam of craft, furniture design and commercial production.

The strategies adopted in this ecodesign practice also informed the reflective process. It encompassed the issue of the use of finite resources in relation to materials and product development. This project began by examining joining methods to simplify assembly and disassembly of components, and as a means of separating constituent materials for future reuse. The building of knowledge about an ecodesign framework has been influenced by the use of thermoplastics in furniture design. The economies of production and complexities of form that thermoplastics have established in contemporary furniture production led to posing the question about whether those qualities are transferable to recycled thermoplastics. In order to answer that question making with recycled thermoplastic products was followed by further reflection and study of local production.

In the process of reproducing Featherston designs, the framework for a set of ecodesign strategies was further developed. This example of commercial commission was built on iconic designs and an existing body of knowledge. Making these replicas influenced the development of ecodesign strategies in relation to the history of chair design, fabrication of moulded plywood chair shells, construction of solid timber sub-frames and their means of connection to chairs. Building on the body of knowledge gained through making, reflection in the activity of doing and on its outcomes assisted the development of a new range of lounge chairs that further demonstrate this ecodesign framework.

In the moment of making with Syntal, and later the Featherston reproductions, reflecting within the making resulted in the creation of both intended and unintended outcomes. The act in design, described as ‘reflection in action’ (Schön, 1991, p. 62), or as a part of ‘doing design’ as expressed by Strappers (Michel, 2007, p. 81), is central to the method of this research. As a result of doing through drawing, the physical action of sketching freehand on a large scale was a method intentionally adopted to encapsulate the broad sweep of linear form. The process of product development began with formative study, sketching outlines, defining patterns, making templates, constructing prototypes and then marketing the results. Each step of this process has provided the opportunity for reflection followed by evaluation. The outcome of this evaluation has provided the framework identified as encompassing design for simplicity of assembly, ease of disassembly, material efficiency, production efficiency, reuse of materials and product longevity.

This research has contributed through design (Schön, 1991), by marketing of products through Rivet furniture, Exhibition in Australia (Chrysalis 1999 and Furnitex 2000, Melbourne; Designing Minds, Adelaide, 2000), International design competition (IDRA award, 2001) and Publication (Glover et al., 2001) and The Ecodesign Handbook (Fuad-Luke, 2002).
4.2 Furniture Designs with Commingle Thermoplastics

This research has built on the knowledge and experience gained in adapting existing recycled thermoplastic products and exploring new opportunities for the reuse of these materials for furniture design. Experiments with Syntal, in the form of commingle recycled thermoplastic posts and planks begin this examination of recycled plastic qualities through the practice of making. Syntal posts and planks are now explored as a substitute for solid timbers in furniture applications, where the method of construction mirrors that of traditional furniture practice with posts being fashioned into leg forms, and with planks being used for seat slats and in the construction of table tops.

Established work with knock down construction and separation of componentry patented with the ‘Socket’ design provided the platform for new methods of connecting chair and table leg components (Figure 38, p 53). Experimentation with lathe turning of commingle plastics led to the discovery of a new visual aesthetic for what had previously been described by Papanek as a ‘dark grey, rough textured’ material.

4.2.1 Preliminary Designs

The intent to create and develop new designs for commingle plastic extrusions arose upon reflection of how product lifecycles may be extended, and how a new aesthetic may be developed for these products of domestic waste. The exploration begins with preliminary designs to extend the lifecycle of chairs.

In developing techniques for extending the lifecycle of chairs, mortise and tenon joints were explored and identified as a structural technique that may be adapted and applied. These joints (Figure 37), are a traditional and strong means of joining timber components in furniture joinery (Walton, 1970), whose breadth in application is further demonstrated in historical architectural construction (Seike, 1981).

Figure 37, Mortise & Tenon Joints. (Seike, 1981, Joyce, 1983)
This exploration of sustainable outcomes in furniture specifically targets the primary elements that link leg structures to frameworks, in response to issues involved in the repair of broken chair parts (Figure 38). Those issues can include the practical or economic viability of performing repairs, and the disposal of an otherwise sound product due to a single component failure. The objectives in developing component solutions to these issues also included singular and separable parts that may facilitate the extension of product lifecycles, promote the re-fashioning of products and aid future recycling or reuse of materials.

This method of connection is an integral part in the history of design and the making of timber chairs and tables and formed the basis for new designs. This exploration of connection led to the design of robust steel joining components.

Figure 38, **Socket Chair Designs**, David Burke, 1989

These components incorporate the principles of design for simplicity of assembly and disassembly that in turn were applied to achieve material and production efficiencies. As a result of reflecting on this method of making, steel was used as an integrated sub-frame and a means of component joinery that facilitated the replacement of parts for repair or alteration. This technique is extended in this project through linking recycled thermoplastic forms with custom designed metal components to facilitate these primary connections of chair shells to legs, and table legs to tabletops.
The initial recycled thermoplastic extrusions produced by Smorgan Industries under the Syntal trademark replicated simple timber forms (Figure 39) that are no longer available but similar extruded products are now made by Australian Composite Technologies under the Plasmar brand. These two examples of commingle extrusion reprocessing have the material resource, methodology and product lines in common. The subtle differences that may exist between them have only been discernable in respect of the roughcast finish. The Syntal products exhibited a homogenous rough furred finish, where samples of Plasmar have included a surface finish akin to geological core samples. In relation to the designs developed for Syntal, and given that the same or similar profiles exist; it is assumed that they are interchangeable (Figure 40).

Smorgon Industries, as part of their efforts to expand applications for their Syntal product range, initiated a design competition in 1991. As part of this competition a selection of Syntal samples were supplied to the designers involved so that they may become more familiar with its characteristics.
These samples were used to perform a variety of hand tool and machine tests that were evaluated and form the basis for new designs. A design concept was produced for an outdoor table and chair setting for this competition, a siting that complemented plastic qualities of longevity and weather resistance. This marks the beginning of designs and experiments with commingle extrusions, and builds on earlier work initiated within the parameters of ecodesign practice.

The drawings show Syntal planks and boards incorporated into the dining setting. Fabricated aluminium sub frames were designed to connect components and provide the means for simplicity of assembly and disassembly. These designs did not progress beyond initial concept drawings, but they provide reference for later experiments with commingle post forms (Figure 41).

![Figure 41, Syntal Competition Designs, David Burke, 1989](image)

### 4.2.2 Self Directed Process

The unused Syntal products left after this competition occupied the workshop with such material presence as to demand consideration, if for no better reason than they were a constant reminder of a material of value in their readymade post and plank forms. Within the parameters of timber furniture and building construction, machined round posts are evidence of additional commercial value as a result of the extra labour and secondary turnery process involved in this shaping. In terms of primary material value, the woods preferred for turning purposes are typically sourced from higher grades of straight and tightly grained timbers.

Timber turnery produces a rounded form that incorporates a refined method of truing by removing the rough outer surface in a precise manner, more akin to skimming than cutting. It is also a method of polishing, detailing, shaping and decorating achieved through precise slicing, gouging and skimming in the removal of material that can result in new aesthetic and practical qualities.
The aesthetic qualities contained within Syntal were first exposed when truing the end of a post to make a precise round tenon for fitting inside a metal tube. Having incidentally revealed this surface quality the potential for exposing it more fully with turnery was realised.

The first experiment with turnery of Syntal was performed with standard wood lathe and hand held wood turning chisels. Prior to turning it exhibited a homogenous roughcast grey surface quality as previously described, the colour being the result of intermixing of diverse sources of coloured plastics. A round billet of leg proportion was sawn to length. The billet was mounted lengthwise on the lathe and a gentle straight taper was turned from tip to toe.

What resulted was an appearance akin to polished granite in its intermixing of feldspar, quartz and mica, a predominant dark grey surface imbedded with small plastic particles across the spectrum of white to black with some silver flecks from metallic sources. A pair of these leg forms was turned complete with a collar detail on the thicker portion of the billets for mating into aluminium tube sections (Figure 42). The leg assemblies were completed with insertion of standard off-the-shelf adjustable feet and mounted onto the custom made Pegasus desk (Figure 43, p 57).

Figure 42, Syntal Turning, post & aluminium collar, David Burke, 1989

Design of these legs was the result of discovery through making (Schön, 1991), without planned drawings but with precedent of a method of joinery and a conscious plan to make leg components complement a developing furniture piece. The observation that when turned on a woodworking lathe these commingle extrusions exposed unique visual qualities, led to reflection on applications that formed the basis for new designs.

The largest available section in recycled plastic post form was 100 mm in diameter and this sizing itself offered new opportunities to produce single piece components. Similar dimensions in timber have historically been the standard for wooden table applications where the addition of turned detail and shape can create new forms. Large dimensions in commercially available timber for turnery of post forms have become increasingly rare for furniture applications. This limitation in availability is due to issues such as the impacts of a long history of logging, the establishment of large public forest reserves, reduction of commercial plantation cycles and changes from long duration air drying to short cycle kiln production diminishing suitable feedstock, as previously outlined.
Existing table designs that incorporated recycled thermoplastic materials were focused on the outdoor market and public spaces. In these applications the aesthetics of dark coloured roughcast materials were lesser considerations than weather resistance, longevity or the environmental credentials embodied in the recycling and reuse of plastics.

As a result of these insights a plan was developed to design and make indoor furniture prototypes that built on the improved aesthetic qualities gained through turning Syntal. The outline of that plan is as follows: Explore a new aesthetic with roughcast recycled plastic post extrusions through turnery machining. Design new connecting components to join leg forms to tabletops that may facilitate ease of assembly and disassembly.

4.3 Pegasus Desk

The Pegasus desk was the first design prototype that incorporated Syntal legs (Figure 43). The desk was commissioned by the South Australian Timber Corporation (SATCO) to demonstrate the diversity of applications for a new structural timber composite called Scrimber. This manufactured board was composed of Radiata Pine thinnings that were bonded with heat reactive urea formaldehyde glue. The primary application of Scrimber was to supplant the importation of Oregon timbers as structural members for the building and construction industry.

Figure 43, Pegasus Desk, David Burke, 1991
The B-2 stealth bomber, an aircraft whose body was constructed from carbon fibre, inspired design of Pegasus. Scrimber has associations with plastic process in that it was the result of heat and press moulding and included thermoset glue in its composition. The textural qualities of Scrimber and its development from what had previously been waste timber thinning’s had synergies with the appearance and recycled nature of Syntal.

The composition of both materials is revealed when the outer surface is removed and the undersurface polished; when the depth of structure and melding of constituents is exposed. The combination of these two materials was intended to empower a storyline that would encourage debate about new aesthetic material qualities, recycling opportunities and design for reuse of materials.

4.3.1 Review

The discovery that turned and polished Syntal had the appearance of polished stone was unexpected. It was expected that the miscellaneous nature of the recycled plastic waste and the homogenising inherent in extrusion processing would produce a dark grey and amorphous outcome as suggested by Papanek, McDonough and Braungart. Polished stone is highly valued in many building, construction and furniture applications, both for its robust physical and refined aesthetic qualities. The polished Syntal outcome has a similar appearance to polished granite but with the relative softness and malleability of plastics. Structurally the mixing of disparate plastics, fibre and metal particles adds rigidity to Syntal, but regardless of this commingle composition it remains highly mouldable.

The size of the robust tenon turned on the Syntal leg is the result of removing a minimum of surface material without going deeper into the core where pores may affect the quality of the join (Figure 47, p 62). This provides structural integrity and adds to the lifespan to the join, which in turn reinforces the long lifecycle that the material is capable of sustaining.

These initial experiments demonstrated the potential for application of Syntal in furniture. In further exploring the proposition that the process of furniture design incorporating recycled thermoplastics produces new aesthetic and structural form, new techniques for machining and implications for the development of furniture components, a novel innovation in table design is presented.

4.4 Erinundra Tables

Existing table settings that incorporated Syntal were copies of traditional timber designs for public outdoor furniture, (Figure 48, p 63). Typically these settings were in public spaces where the aesthetics of dark coloured roughcast materials were lesser considerations than weather resistance, longevity and the environmental credentials marketed in the recycling and reuse of plastics.

The initiation of the Erinundra project was influenced by the methods of construction and connection for leg components that were already in development. Design of the connecting component was of aesthetic and structural importance due to its intended visibility and function.
The resultant steel connectors were meant to invoke a sense of proportion and permanence. The diameter of the steel tube is intentionally smaller than the inserted leg to create a waistline in emphasising this form and juncture.

An industrial aesthetic is adopted for the shaping of the legs in contrast to the organic form of the timber top. This industrial aesthetic is carried into the processing of the recycled plastic in the creation of perfectly round and smooth tubular forms. In the first exploration of turning commingle plastics the task was performed manually on a wood lathe, but in order to finely control this process and produce crisp detailing this turning was commissioned using an automated metal lathe. Automation of this turning process was also undertaken to reduce material waste and improve manufacturing economies within the confines of furniture production (Figure 44).

In regard to the design of the timber tops, a new approach was explored to meet the attributes of form and finish for indoor applications, while also reinforcing recycling and reuse of materials. The structural design incorporated the practicality of a platform for attachment of the leg components to the underside of the tabletop with a technique that would assist disassembly.

A premium furniture timber, Blackwood, was chosen for the tabletops. These tabletops were composed of boards machined from a salvaged log discarded after forest harvesting, to explore the aesthetic values of discarded timber material and to emphasise reuse of materials. Traditional design of the table sub-frame was reinterpreted, inspired by solid plank door construction, where the sub frame members are laid flat to the planks, thereby providing a slim profile, whilst also connecting the planks and providing a flat surface for hardware attachment (Figure 45, p 60). The method of slot screwing in creating lateral slide between the sub-frame and top, allowed for the differential of expansion and contraction between these elements.
With the exception of the tabletop that was fabricated as a permanently jointed and glued whole, all of the other components are readily separable into their constituent materials through means of standard mechanical fixings. Reworking of this traditional frame door construction also resulted in ergonomic benefits of an increase in legroom and the ability to create a lower working surface (Figure 46). The two Erinundra tables produced consisted of three elements: a solid Blackwood plank top, fabricated steel jointing components and turned Syntal legs.

The aesthetic contrast sought in the design was between the natural variegated grain structure in a premium timber top and the moulded, synthetic plastic qualities of an industrial machined form.
The steel components reinforced this material contrast in providing a physical separation between top and legs. A balance was sought between the structural constraint for table stability and a sense of permanence without over engineering components or using oversized materials. A long serviceable lifespan was aimed for in the combination of simplicity of assembly, robust knock down components for ease of disassembly and quality of material reflected in appropriate scale and substance.

The available stock of Blackwood for the tops was fully used in the construction of two tables with minimal material wastage. This outcome is apparent in the first table with the uncut board lengths being featured. The rough cutting of these boards to length by chainsaw prior to milling is preserved and highlighted in more organic form by staggering the board lengths. The second top has neatly trimmed ends in forming a perfect rectangular form normally associated with table shaping. Both tables are narrow by conventional standards in expression of their intended use in constrained spaces, bijou houses or flats, where they may also be aligned against a wall to save space or have dual use as side tables.

Finish treatment on the tabletops consists of multiple coats of linseed oil applied to a point of saturation. The excess of each coat was removed with a dry cloth and the oil was then allowed to dry prior to recoating. This quick and simple oiling procedure was repeated daily over a period of two weeks prior to finishing with beeswax polish. The turned commingle plastic legs are similarly finished with oil and wax, though the inherent oil content within the plastic negates the need to regularly repeat this process.

Though this procedure is labour intensive in comparison with clear lacquer spray finishing commonly used in furniture production, it does not require future labour intensive removal and re-application. An expeditious twice yearly oil and polish is considered sufficient on both timber and plastic surfaces to retain a depth of patina, ensure material longevity and enhance resistance to staining.

4.5 Design Overview

The mass of the Syntal legs is comparable in mass, dimension and weight to solid timber used in similar application. Selection of Syntal leg diameter for the desk was 65 mm but at this size and in a large desk application it exhibited a tendency to flex under load. As a result of this experience 100 mm diameter was chosen for the later table designs to improve structural rigidity. Further refinements to the sizing made by the removal of the roughcast surface were kept to the bare minimum in achieving a trued form and defect free finish, and in dimensioning for insertion into the steel tube components.
Examination of the end section of Syntal and Plasmar posts shows that the extrusion technique for these products results in pores within the material. These pores become physically visible in the centre of the material and decrease progressively outwards, so that the outer surface layer is typically defect free, as illustrated (Figure 47). This feature of commingle extrusions influenced the amount of material removed in truing the legs, and the depth of cut used to produce the collar jointing.

The adaption of readymade Syntal posts has further practical value in terms of structural and engineering qualities. A single heavy-duty coach screw is fixed through the steel connecting plate into the end section of the Syntal post. This fixing is achieved without any pre-drilling (a process that would be necessary with timber) due to the lower densities in the core of these large extruded plastic forms. This feature aids assembly efficiency and simplifies future knock down capability.

Figure 47, **Syntal & Plasmar Posts**, end sections

The combination of a slim profile solid timber top with the substantial mass of the Syntal legs provided an unforeseen outcome, in that the weight of the legs provides self-leveling of the table on uneven floor surfaces. The recycled plastic has a softness representative of plastic materials, and incorporates a resistance to grip, a feature that aids the sliding of the table across floor surfaces and reduces the possibility of damage through scratching, scoring or marking.

This resistance to grip also assisted the ease of movement of the table single handedly, a positive feature given that both tables were intended to be used as both side and dining tables which would require their repositioning, and in circumstances when assistance may not be available. These qualities, found as a consequence of making and of use, help support a proposition of new and unforeseen values in furniture applications.

The concepts for chairs and table design developed for the Syntal design competition were informed by first hand experiences machining and fabricating Syntal that had been collected in a variety of post and plank forms. Knowledge was also gained from visual inspection, handling and a range of basic tests. The Syntal was tested for bending, deflection and breakage under load and through performing simple hand tool and machine trials.
This experience was also informed by available product data and the anecdotal knowledge that slump and bending of unsupported planks resulted from prolonged exposure to sunlight (Figure 48).

![Syntal Picnic Setting, St Leonards, 2012](image)

Visual inspection of the surface exhibits a rough fibrous texture with even single colouration in each piece across the spectrum of dark grey to green in a range of stock profiles. The visual aesthetics of Syntal and Plasmar are undeniably limited, though if considered neutral as representative of a range of grey then they could be successfully combined with more vibrant colours and materials. It was from this perspective that the interplay with structural connectors made from polished aluminium was explored in the initial chair and table drawings and in the Pegasus desk design.

Production efficiency was initially a major consideration in leaving the appearance unchanged. The only secondary processing involved in the realization of the preliminary designs was cutting material to length or shape. The ease, with which Syntal may be cut and drilled, combined with excellent fixing qualities due to its material density and resistance to splitting, complemented this application. The technique of treating round profiles as tenon joints which could be friction fitted was intended to enable simplicity of assembly and ease of disassembly within the context of future material reuse.

The qualities of these rough cast materials were explored in terms of function and structure. The plastic material properties of weather resistance and the transference of those properties to recycled thermoplastics make outdoor furniture applications an obvious starting point. The flex and tensile properties of Syntal were incorporated in the preliminary designs with the use of thin slat profiles for the chair seat, back and armrest components. Deflection of these components in the action of seating was intended to provide a more comfortable seated experience in comparison to harder surface and limited flexural qualities of solid timber alternatives.
4.5.1 Aesthetic Qualities

The development and focus on Syntal and Plasmar post forms for furniture leg components was a result of the discovery of new aesthetic qualities being exposed when the posts were turned and polished. This refinement of form and finish has been a result of the machined transformation from roughcast to polished finish for indoor furniture applications. The adoption of woodworking turnery and the established production efficiencies contained in that technique have been shown to be transferrable to Syntal and Plasmar. The progression in changing the material for the connecting components from aluminium to steel was undertaken to achieve different aesthetic outcomes available with paint and powder coat finishes. Production efficiencies are also enhanced with the more economic material and fabricating costs of steel componentry.

It has been established that the content of commingle extrusions can be as various as the multitude of thermoplastic materials found in domestic and industrial waste to which small particles of thermoset plastics, metals, synthetic or organic materials may be successfully encapsulated. Within the constraints of resin code identification growing ranges of similar though disparate thermoplastic formulations exist. In terms of colour, form and texture the extrusion of thermoplastics produces a wide range of readymade products that can be roughcast and grey as in Plasmar posts, or smooth and colourful as shown with Replas outdoor furniture designs.

The aesthetic quality of consistent and vibrant colour is limited by this intermixing of recycled thermoplastics when no selection criteria are applied to achieve those ends. Intervention through selection by type and colour or adding pigments (master batching), can provide more reliable colour outcomes, which are evident in the material selection and homogenous appearance of Replas products. The constraints of material thickness in extrusion moulding of commingle thermoplastics are particularly apparent in terms of achieving refined, thin section forms. In consideration of these limits the improved structural qualities of these thick sections was exploited in the development of designs.

4.5.2 Production Methods

In addressing the aim of production efficiency the existing moulded Syntal forms were identified as feasible products for the application of methods used in timber furniture production. In timber tables and chairs a plethora of established methods and associated hardware exist for separable joining of components. With the introduction of recycled thermoplastics into this product composition a new methodology was developed to foster simplicity of assembly, aid production efficiency and achieve a long product lifecycle.

Knowledge of machinery, processes and hardware facilitated production efficiencies. Fashioning of Syntal was undertaken by hand with existing woodworking tools, woodworking machines and automated lathes. Saws were used for cutting material to length, drills for boring fixing holes, lathes for truing and surface skimming and the turning of tenon joints. Existing screw methods were also used to efficiently connect the leg assemblies to the solid timber tops.
The choice of readily available steel tube in a complimentary diameter to suit insertion of chair, desk and table legs was the basis for the Syntal designs. A minimum of secondary processing to achieve a tight fit highlights the aim for production efficiency. In the evolution of these leg designs, altering the aesthetics of finish and form of leg components through turnery was undertaken. A minimalist approach was adopted with production turning as it was found that only a small amount of material needed to be removed to change the surface from roughcast to a trued and polished finish. In relation to form and aesthetics this efficient lineal removal of the rough surface provided simplicity of shape and polished finish perceived as suitable for interior décor.

Dramatic reshaping on the lathe would question the means of achieving this end. Extrusion moulding of recycled commingle plastics represents remaking in its most basic and economic form. The infrastructure, machinery, technology and tooling required in the hand or automated turning of commingle thermoplastic posts is minimal compared to the prerequisites for injection moulding of similar products.

4.5.3 Alternate Techniques

The Hume setting (Figure 26, p 40), demonstrates the efficacy of more complex moulded shapes, when mixed sources of selected recycled thermoplastics such as HDPE or PET are extruded into large roughly cast mould tools. A roughcast surface finish, thick rudimentary forms and slow production remain hallmarks of this technique. To achieve both polished finish and complex form economically, expensive polished steel tools, combined with high pressure moulding in the form of injection or low compression moulding, is requisite.

This is not to say that such possibilities for greater variety of form and finer surface finishes using extrusion methodologies have been fully explored, but in order to achieve new shapes and polished finishes with the method of extrusion moulding, secondary machine processing is required. The opportunities for new form and finish could extend to robotic milling to improve production efficiency. Such machining and shaping of extrusions is limited in surface penetration with pores being a feature within the core of these materials.

In addition to experimentation with smooth, defect free finishes machinery and technology could also be applied to score the surface, imbed characteristics or add materials that may highlight the tactility of surface. The unique irregular embossed surface of recent Plasmar post extrusions is an example of novel appearance and tactile feature. In comparison to timber surfaces where machined processing and finishing is a means of expressing grain, feature and colour it is also a means of neutralising rough cuts, surface imperfections and splinters, which may cause discomfort or injury in furniture applications. Recycled thermoplastics components, by nature of their plastic composition, have a softer, splinter free surface that could be further explored functionally and aesthetically.
4.5.4 Product Lifecycle

Within the parameters of material reuse, the design of furniture for simplicity of assembly and ease of disassembly demonstrates outcomes that facilitate extension of product lifecycle. Adaption of the method used in mortise and tenon joinery provides a robust device for ease of connection and separation of components. This method aids replacement of the same components, enhances packaging and transport efficiencies and provides opportunities for restyling or alteration in the form of new componentry in extension of lifecycle. It also provides the ability to separate constituent materials by type a feature that aids recycling or reuse at the end of product life.

In summation the application of recycled thermoplastic components is enhanced by furniture designs for interior siting where any degrading effects of environment or weathering are minimal. The qualities of longevity, formability, ease of fabrication and machining are qualities that are retained in the process of recycling.
4.6 Furniture Designs with Recycled Engineering Thermoplastics

This section of the research is predicated on the potential for recycled engineering thermoplastic materials to be production moulded into more complex furniture products. Where fabrication by turning (machining rotating material) and milling (machining with a rotating tool) were undertaken in adapting readymade extrusions, the primary quality of moulding recycled thermoplastics is now explored with the development of new chair designs.

The technology developed by Wharington in Melbourne to utilise recycled ABS thermoplastics for the process of moulding into chair shells, has been reviewed. This method of moulding provided a solution to the limitations of the established practice of plywood fabrication used in the production of the Featherston chair shells. The sintering technique of fusing recycled engineering plastics demonstrates new aesthetic and fabricated qualities in the creation of shell components. The superior fluidity of form achievable through moulding recycled thermoplastics and the potential it provided for reuse of materials at the end of product lifecycle complemented the ecodesign objectives of this research.

Where earlier exploration began with readymade forms that replicated existing timber materials, this part of the investigation begins with recycled engineering grade thermoplastics that have been reprocessed into pellets for remoulding purposes. These pellets, though sharing the same resin code identification, have been derived from a variety of products such as computer housings, automotive trim and domestic appliances. They contain similar plastic properties of hardness, durability and melt point, but contain different master batch additives that are seen in the variety of melded pellet colours.

4.6.1 Preliminary actions

These recycled thermoplastics and the opportunities they provide for moulding were the foundation for a new range of chair designs. This development was a direct response to extensive practical experience in making plywood chair shells and the recognition that the amalgam of materials and irreversible processes involved in the Featherston method of plywood production constituted a future environmental problem. The combination of embedded screw fixings and glue bonding of layered pattern construction inhibited future recycling efforts and the processes of natural decomposition.

Evolution from using plywood to recycled thermoplastics for chair shell moulding offered solutions for environmental outcomes through the ability to separate and contain materials in a closed loop cycle. Reducing the amalgam of materials in the Featherston plywood shells to a single thermoplastic moulding that is fully recyclable within the confines of that single technology (closed loop cycle), could improve the outcomes for simplicity of assembly and future material reuse.
The shape and fluidity of form inherent in the moulding of plastics also enhanced potential for sculptural aesthetics in the commercial production of chair designs. Exposure to the explosion of virgin thermoplastics in chair production during the 1990’s, informed this practice through the physical demonstration of the scope of aesthetic and structural qualities being developed for new designs. In conjunction with the coded resin labelling and promotion of these thermoplastic chair forms as recyclable, it pointed to a future in their reuse and further opportunities in the development of a practice based on ecodesign strategies.

4.6.2 Reflection on Featherston techniques

This project to design chairs that incorporated recycled thermoplastics was influenced by a practice in the manufacture by commission of Featherston lounge chair designs from 1991 to 2006. The shells for these chairs were fabricated by a method of shaping, glueing and fixing alternate layers of bending ply in rudimentary plywood moulds (Figure 49). A sub frame consisting of four turned legs was jointed and glued to rails in formation of a cruciform assembly that was then fixed to the plywood shell. The resultant compositions posed a number of problems for end of life disposal. Though constructed for longevity of service, when finally discarded they could not be disassembled and represented a problematic amalgam of timber, plywood, lacquer, glues and a myriad of second layer screw fixings.

Figure 49, Featherston Shell & Mould Tool, David Burke, 2006

Reflection on this plywood method of construction led to the development of a speculative brief, based on experience gained through design and making chairs. This brief included design for simplicity of assembly, as the methodology used in fabricating the Featherston shells was physically laborious and expensive.
Design for ease of disassembly was identified for production economies and improved material outcomes in relation to future reuse and recycling. Design for production efficiency was to be addressed by limiting the range of materials and processes involved.

In terms of aesthetic and structural form the Featherston chairs are representative of 1950’s plywood design that has been superseded by the opportunities for greater fluidity of form, structural efficacy, economies of material use and production technique available with thermoplastic production. The combination of a cruciform timber sub-frame and tapered timber legs cradling the plywood shell is indicative of the structural technique, material selection and turnery shape popularised in this post war style. Environmental considerations of reuse or recycling were outcomes largely unrecognised at that time in mainstream social debate and the production of furniture.

Construction of the original Featherston chair shells developed from hand laying of separate glued veneer patterns, clinched with furniture tacks, to alternately staggered plywood patterns hand fixed with tacks. Casein glue provided the bonding agent in this original method and the whole process, including the cutting of the veneer and ply patterns to shape, was labour intensive.

In the late 1980’s Featherston shells were replicated with standard three-ply patterns bonded with poly vinyl acetate (PVA) glue and clinched with staples driven by compressed air guns. The solid timber sub-frames were replicas of the originals in shape and method of screw fixing the sub-frames to the plywood shells. This production methodology was progressively changed and adapted from personal experience (Figure 50).

Figure 50, Contour Chair, Featherston replica, David Burke, 2006
4.6.3 Adaption of Featherston Techniques

Firstly, the mechanical method of fixing the plywood patterns in forming the chair shell was altered to screw fixing with a battery powered screw gun. Though a slightly slower procedure than stapling, screw fixing provided extra clamping force to the consecutive ply layering, resulting in a higher quality fabrication and the elimination of poorly bonded or reject shells.

The use of standard three plys also created issues of effective material use and breakage of the individual plywood patterns when laying them into the mould. Two methods were used to alleviate breakage: Wetting of the plywood at critical bending points and positioning of patterns vertically to the length of the plywood sheets. These changes maximised the bending characteristics of two of the three constituent veneers. The process of vertically laying out patterns proved particularly wasteful as it produced significant amounts of offcuts.

Further reflection on this technique resulted in changing the type of plywood sheet material from three-core ply to two-core ply. This provided material economies as patterns could be more readily nested due to the superior bending characteristics of two-core ply resulting in the virtual elimination of waste due to breakage. Plywood usage of two and a half standard sheets per chair shell was halved; sheet price reduced by one third, and improved bending performance resulted in faster layup times.

Similarly a reassessment of the timber sub frame led to a new bolt and ‘T nut’ attachment of sub frame to plywood shell and a slight increase in the thickness of the timber cruciform components through which these bolts penetrated. These changes improved the structural efficacy of the sub-frame and its connection to the plywood shell. They were initiated to improve production economies and extend product lifecycle without compromising the aesthetics of shape or form in the reproduction of these iconic pieces. These four main adaptations of the original method of construction improved the simplicity of assembly, material usage, production efficiency and structural efficacy of the Featherston designs.

4.6.4 Bubo Chairs

The technique used to produce a new range of lounge chair shells was adapted from the method used to make the Featherston Contour chair shell, though in all other respects the design was intentionally its antithesis. In shape these new shells exhibit a curvature of rounded form and gently flowing and circumscribing linearity more reminiscent of Jacobsen’s ‘Egg’ chair than the traditional ‘Wing-back’ form from which the Featherston design drew its inspiration. The design of a new sub-frame included separate rolled tube steel legs that provide the dynamics of cantilevered structures supporting the shell rather than a static cradling sub-frame. The change in sub-frame material from timber to steel also led to the development of readily separable knock down forms with the custom design of robust steel bolt and plate fixings.
Designing these Bubo chairs began with full scale sketching on a large wall mounted board that resulted in a penciled outline reminiscent of the drawing above (Figure 51). The outline was based on a notion of two intersecting and encompassing circular shapes that developed from a process of physical engagement with the full size drawing. This building of form was composed of overlaid and refined arcs and intersections that did not simply define finished measurement, but rather provided the parameters of aesthetic shape and ergonomic scale. The drawing was then used as a guide for the making of templates from which a full size prototype was made.

As previously discussed, the full size prototype of the Bubo shell was constructed using the same plywood methodology developed in the reproduction of the Featherston chairs. It included eight oversized plywood patterns, four seat and four back, which intersected and overlapped to form the armrests. These patterns were layered in the mould tool and tacked together with screws. The sinuous linear edge that circumscribed the shape from the front of the seat, over the armrests, into the waist, then around to the top of the backrest was then reduced and refined. Sighting this sinuous line from every viewpoint and remarking its path by drawing, taping and painting refined the shape and completed the modelling.
The screw fixings were then removed and the patterns recut and shaped to form a set of templates (Figure 52).

![Baby Bubo Templates, David Burke, 1996](image)

From these templates new plywood patterns were cut and a final glued and screw fixed prototype shell was made in concert with adjustments to the mould tool so that it firmly cradled and contained the shells. The resultant shape was grounded in the interplay of circular construction enveloping ergonomic considerations that included generous seat dimensions, supportive back and forward flowing armrests (Figure 53). These features were intended to engender physical qualities of rest, relaxation and reflection. Definition of the shell was also intended to emphasise its powerful structural composition, and this feature is given prominence with the attachment of the back legs almost perpendicular to the shell in expression of suspension rather than the cradling support of the Featherston sub frames.

![Baby Bubo Ply Shell, David Burke, 2004](image)
The Featherston chair shells were narrow across the seat providing a firm form hugging fit and this dimension was the first change made in expression of a more expansive form. In addition to increasing this dimension, prescribing gentler curvatures and forward flowing arms for the bubo designs created a more informal lounging platform that enabled comfortable positioning across as well as in the seat.

The brief also focused on the processes of separation and replacement of major components. In total it culminated in the design of the bubo shells, construction of templates, design and fabrication of the mould tool for shell production and the development and commission of new designs for the fabrication of steel leg components. The aim to fully address the brief in light of modelling, production economies, separation and reuse of materials revolved around being able to find an alternative to the described method of plywood construction. Though the bubo shells were envisaged as being composed of a single cast recycled thermoplastic moulding that embodied all the elements in this brief, a viable solution was not initially available.

4.6.5 Bubo Production Design

Construction of an open female mould and a fitted male plywood prototype were developed in tandem, being informed by the experience of scale and process in the making of moulds for fabricating plywood chair shells (Figure 54). External shaping of the prototype and ergonomic dimensions were refined in repetition of this working method.

Figure 54, **Bubo Mould Tool**, David Burke, 1995
Reflection on the structural qualities of this shell construction led to a new concept for leg forms and their method of attachment. The intersection of seat, back and sides was considered as an area of great reinforcement and rigidity when fully integrated into a single form in the plywood prototype, as could be the case with a moulded plastic shell. In the bubo shells, these intersections were too tightly radiused to bend plywood around, and therefore were break points in the patterns that required an introduced joining element to bring them together.

![Figure 55, Bubo Shell Ply Detail, prototype, David Burke, 1995](image)

The design for a stamped and bent metal insert, screw fixed to the ply at this juncture transformed these plywood shells into structural sub frames to which individual cantilevered legs could be clamped (Figure 55). This quality, which is visually reinforced with the suspended orientation and physical attachment of the back legs to the shell, is demonstrative of these structural qualities.

The shape of the legs references the geometry of the shell, in defining arcs of rolled tubular steel, of which the front and back forms are identical pairs for economies of manufacture and ease of replacement (Figure 56).

![Figure 56, Bubo leg Components, sketches, David Burke, 1995](image)
A smaller occasional chair that shared the same mould was also developed and these Bubo chairs were successfully marketed throughout Australia with fully upholstered treatments designed to complement the moulded ply shells.

Figure 57, Bubo Chairs, David Burke, 1996

4.6.6 Peregrine Mould Tool

The opportunity to produce recycled thermoplastic shells for these designs continued to be explored, and these endeavours were realised in 1999 when Wharington was commissioned to construct a steel mould tool from which shells composed of recycled thermoplastics could be produced. Wharington has an established business model for producing furniture products from recycled engineering plastics under the Repocol brand. Their preferred application for Repocol was promoted by Wharington as a replacement for plywood upholstery shells in chair components - an application admirably suited to the development of the bubo chairs.

A major consideration in the undertaking of this project was the cost of a new plastics moulding tool. The decision to progress therefore instigated a review of designs and procedures that resulted in extending the parameters to include a family of chair forms and new upholstery methods. The creation of a family of chairs was concentrated on maximizing the benefits of the metal mould that is central to the process of plastics forming.
These benefits were identified as design outcomes that may broaden product and market options by providing a larger base to amortise the costs associated with mould construction.

The design work began by drawing a larger form with pointed wings at the extremities of the headrest and the seat so that a process of cutting and reshaping that form could resize it to create a family of chair shells. The reworking of designs was also aimed at building on the nesting characteristics developed in the bubo chair, being that ability to efficiently stack the shell components, which was envisaged in the initial development of separable leg structures (Figure 58).

![Figure 58. Peregrine & Bubo Repocol Shells, nesting shapes](image)

The final templates for the metal mould are illustrative of a large winged form, inspiration for which was drawn from the mating pair of Peregrine falcons that had incongruously made the top of the Rialto skyscraper in central Melbourne their nesting site. These fibreboard templates were used by Wharington as the basis for fabricating an articulated hollow mould that parted along the perimeter of the winged form. These two sections were mechanically fixed together with threaded bolts and mating nuts along the part line, which when fully tensioned added compressive force to the moulding process.

Two options were considered to achieve the aims of resizing the Peregrine shells: firstly, the introduction of blocking pieces into the mould tool to limit the scale or shape of the moulding, and secondly, post forming of the plastic shells. The post forming method was adopted in the shaping of the prototypes, using sheet templates as a guide for cutting the recycled plastic shells with a jigsaw and finishing with hand tools.

The resultant prototypes were produced in five variations of shell shape, and a further two iterations were produced with the design of new upholstery treatments and leg assemblies.
4.7 Peregrine & Bubo Repocol Designs

4.7.1 Peregrine Chair

This prototype utilised the shell in its largest shape, as it is formed in production within the steel-moulding tool. It is from this Peregrine moulded form that a further five shell variations were created by adopting a technique of refining shape with hand machines and tools (Figure 59).

Figure 59, Peregrine Chair, prototype, David Burke, 1999
4.7.2 Peregrine Office Chair

The full size Peregrine shell attached to a standard gas lift mechanism and five star base on castors produced the following adaptation, that was intended for further upholstery development (Figure 60).

![Peregrine Office Chair](image)

Figure 60, **Peregrine Office Chair**, prototype, David Burke, 1999

4.7.3 Peregrine Upright Chair

This shell was reshaped to produce a squared form for the backrest in conjunction with a shortened seat profile. Upholstery treatment includes removable leather seat and lumber support cushions. The stainless steel legs were elongated in a more forward inclination to facilitate easier exit for the elderly (Figure 61).

![Peregrine Upright Chair](image)

Figure 61, **Peregrine Upright Chair**, prototype, David Burke, 2000
4.7.4 Bubo Chair

The Repocol Bubo chair was post formed from the full size Peregrine shell using board templates as a guide for hand machining and shaping. It is a prototype indoor-outdoor variation, with internal stainless steel cap plates for leg attachment (Figure 62).
4.7.5 Baby Bubo Chair

This Baby Bubo design was also post formed to shape from board templates. The Peregrine shell was further resized to produce this shape using a jigsaw and hand tools. This smaller occasional style was a further indoor-outdoor prototype with powder coated steel legs and internal leg caps (Figure 63).

Figure 63, Baby Bubo Chair, indoor - outdoor prototype, David Burke, 2000
Upholstery treatments for the original Bubo designs were based on existing practices of glueing and stapling foam padding and fabric coverings to plywood shells. Buttoning the fabric covers was initially explored as a means of facilitating the future separation of fabrics and foams from the plywood shells. The development of a chaise longue saw this enabling of separation of upholstery materials taken a step further with a loose fabric sock stretched over the form with a zipper on the underside, allowing it to be opened up and peeled off for cleaning, repair or replacement (Figure 64).

Figure 64, Bubo Upholstered Ply Forms, David Burke, circa 1997

The technique of using zippered covers, Velcro attachments and foam inserts for the separation of upholstery elements is further explored in the development of the Peregrine chairs.
4.7.6 Peregrine Lounge Chair

Upholstery development for the Peregrine lounge chair was composed of four major parts: separate seat, lumbar and back cushions and a single piece fabric cover that fitted over the shell. Each of these three cushions had zips on the back to allow for easy removal and replacement of covers and foam inserts. The cushions were held in place and positioned with Velcro fastenings and their positioning disguised the physical attachment of the outer covering to the plastic shell. The method of fitment of fabric to the shell drew from automotive upholstery trimming wherein the exposed ends of the fabric are pressure fitted into plastic sleeves, which provided a means of fitting and removal without additional mechanical or glue fixings. A new stainless steel leg design was developed to complement this winged shape. An ottoman design was also added in extension of the lounge chair form (Figure 65).

Figure 65, *Peregrine Lounge Chair*, prototype, David Burke, 2000
4.7.7 Peregrine Occasional Chair

This evidence of post forming of the shell included reducing the height of the back and the length of the seat. Prototyping also included the further development of a new upholstery treatment attached with Velcro fasteners to the internal face of the shell, and the use of angular stainless steel leg components to complement the new shaping (Figure 66).

Figure 66. Peregrine Occasional Chair, prototype, David Burke, 1999

The upholstery of the Peregrine occasional chair demonstrates a further adaptation of form and process to facilitate separation of parts and attachment to recycled plastic shells (Figure 67). The seat and back cushions were separate elements that formed a single visual component. They were shaped to grip the edges of the plastic shell, in providing additional positioning and support.
The pixilated surface texture of the Repocol shell is contrasted in relief to the fashioned upholstery components. Zips again provided the means of removing covers, a process which also facilitated changing the composition and densities of internal foams for means of comfort or replacement.

Figure 67, **Upholstery Development**, occasional chair, David Burke, 1999

The prototyping of new upholstery options led to a re-evaluation of the potential applications for these chair designs. The positive properties of plastics that made it suitable for outdoor furniture (resistance to moisture and relative stability of form and structure with exposure to weathering agents) had not previously been explored with lounge chair designs using the Repocol process. Given the growing trend for outdoor entertainment and the expansion in plastic seating to suit that purpose, adaptations of these designs were developed.

These adaptations included the forms achieved by size reduction and reshaping. They highlighted the Repocol shell by reducing and removing the upholstery, thereby expressing the aesthetic quality of the recycled thermoplastic. Whilst these shells are predominantly a mixture of black, grey and white to reflect of the car trim and electronic goods housings from which they are derived, they also contained small amounts of brightly coloured pellets found in a variety of consumer products. The process inherent in this method of sintered moulding results in a pixilated amalgam of these fused pellets that is intentionally contrasted with a plain upholstery colour (Figure 67).
The design of new stainless steel leg structures for the Peregrine chairs was also developed with this indoor-outdoor crossover in mind (Figure 68).

The original bubo legs were composed of powder coated mild steel and shared the same method of construction as the stainless steel alternatives developed for the Peregrine chairs. The choice of steel for the construction of these components was also based on established infrastructure and method for its successful future recycling. The leg components consisted of rolled and bent tubular forms welded to circular plates. The plates had a centered hole matching the diameter of the leg tube so that it may be passed through this opening and welded on the inside face of the plate to form a seamless external join. Three countersunk holes were pre-drilled in a triangulated pattern on the plate to maximize the spread of bolted attachment through the Repocol shell. A matching internal circular steel plate with corresponding hole positions for welded nut attachment was fixed in position on the inside of the shell (Figure 69).

The bolting of these mated components formed a robust clamp assembly sandwiching the Repocol shell firmly in position. The rear legs which cantilevered off the back of the plastic shell were also positioned beside the point of intersection of back, base and side of the shell to maximize a connection of structural integrity where the greatest shear loads occur.
The front legs, by comparison, were positioned inset from the seat edge of the shell. This siting under seating loads adds a cushioning effect by promoting inherent material flex with structural tensile strength being provided in the curvature of form. The resolution of these designs incorporating Repocol thermoplastics is now complete.

### 4.8 Summary

In summary, it is demonstrated that, by applying a methodology to the making of furniture designs that incorporates recycled thermoplastics, new forms, techniques, and implications for design practice are produced. This making of furniture designs describes a method where the physical acts of drawing; machining and fabricating are the genesis of new designs. These acts have been described as sketching outlines, defining patterns, making templates, building prototypes and reviewing designs that lead to a resolution in new designs. Within this process the elements of more formal research are intertwined. Study of design history in relationship to connecting furniture components, moulding chair designs and the development of new products, materials and processes, has in this research focused on thermoplastics and recycling.

Beginning with the readymade products of Syntal or Plasmar, and through a process of reflection, followed by the application of hand woodworking skills that progressed to machine cutting, turning and milling, it has been demonstrated that these recycled commingle thermoplastics can be simply and economically transformed into practical furniture components with unique aesthetic qualities.

Similarly, by review and reflection on the making process involved in reproducing the Featherston designs, the incorporation of Repocol recycled thermoplastic into new furniture products with unique qualities, has been developed. This development includes the design of a new form as the basis for production of a mould tool and the application of hand and machine skills in the production of a family of chair forms. Further developments have resulted in the design of new leg assemblies and upholstery treatments that complimented the resolution of new chair designs.

The aim of this research has been clearly stated as a design investigation into the use of recycled thermoplastics for furniture applications in the Australian market. This investigation has challenged the proposition that thermoplastics may only be successfully recycled into products of significant value when separated into single polymer types. It is within the context of ecodesign practice that the objectives of simplicity of assembly, ease of disassembly, material efficiency and production efficiency in furniture design have been explored. Achievement of these objectives also provides a platform for longevity of lifecycle and future material reuse. The conclusions to this body of research will now be presented in the final chapter.
5. Conclusion

This thesis demonstrates that the process of furniture design incorporating recycled thermoplastics produces new forms, techniques and implications for design practice. The relationship between complex materials and new products is unfolding in the context of plastics recycling. These factors are supported by industry and anecdotal evidence of the growing diversity in material formulations and progressive development of product applications for thermoplastics, that continue to feed a recyclable resource. In this chapter, the proposition that thermoplastics may only be successfully recycled into products of significant value when separated into single polymer types will be answered through reflecting on the key aims of this research through design. These aims are:

• Design incorporating recycled plastics
• Design for simplicity of assembly
• Design for ease of disassembly
• Design for material efficiency
• Design for reuse of materials
• Design for production efficiency
• Design for product longevity

In contributing to ecodesign practice in Australia, this research concludes that commingled recycled thermoplastics have been successfully adopted in chair and table applications. Material and production efficiencies for these products have been achieved through the development of fabricating techniques, connecting systems, component design and production methodologies that aid simplicity of assembly and ease of disassembly. In concert with applied machine and moulding technologies, this research also substantiates constructive reuse of source materials, and shapes the conditions that enable material reuse at the end of product lifecycle.

The development of this design practice is predicated on the reuse of materials that are a by-product of the successful implementation of the kerbside collection scheme in Victoria, which initially targeted recyclable PET and HDPE in the form of soft drink and milk containers. The adoption of resin coding by the plastics industry in Australia further accelerated recycling opportunities by providing a clear means for identification of plastic products for effective material streaming. The culmination of these recycling initiatives is also providing a growing repository of mixed plastics that may not be readily identifiable for coded sorting, or that may be altered to the extent that replication into the same or similar products is inhibited.
This research demonstrates that recycling and reuse of these commingle or mixed thermoplastic materials, does not necessarily result in downcycling; that is, the lowering of material values as some have argued. On the contrary, there are significant and different aesthetic and material qualities in recycled commingle and mixed stream thermoplastics that have been developed for furniture design. As a result of this study, it is demonstrated that recycled thermoplastics are a valuable commodity, in that they contain novel aesthetic properties and have significant applications for remaking and remoulding into furniture products.

In traditional methods of timber table construction and contemporary chair production, that combines plastic shells with steel sub-frames, established techniques and associated hardware exist for separable joining of components. In this research, new products and techniques for connecting recycled thermoplastics in desk, table and chair forms were developed to foster simplicity of assembly, aid production efficiency and achieve long product lifecycles. The conclusions drawn from this research are validated by expanding the applications of these new forms, and through development of techniques that demonstrate implications for ecodesign practice.

5.1 Design Incorporating Recycled Thermoplastics

This practice demonstrates the effective reuse of commingle thermoplastics sourced from domestic kerbside collection and mixed engineering thermoplastics, derived from diverse consumer products in furniture design. New desk and table designs have been created that incorporate commingle thermoplastics in leg components fabricated from Syntal and Plasmar readymade extrusions. The design of a new mould tool for use with Repocol hybrid moulding technology has resulted in the successful production of moulded chair shell components. These components are the basis for new lounge and occasional chair designs that incorporate mixed sources of recycled engineering thermoplastics.

5.2 Design for Simplicity of Assembly and Ease of Disassembly

A new range of forms and techniques for connecting furniture components has been developed and implemented for desks, tables and chairs.

The desk and table designs consist of three primary elements: a structural timber composite top, fabricated steel connectors and turned recycled thermoplastic legs. The design of the connectors is central to facilitating the means of simplicity of assembly and ease of disassembly. These components provide fast and robust fixing for joining and separating the primary top and leg elements. Established woodworking techniques of turnery and mortice and tenon joinery have been adopted to assist this process. Jointing shape in straightforward tubular forms has been developed for ease of connection and future knock down capability.
The plastic quality of slip (reduced resistance in the insertion and removal of leg parts) aids this simplicity of assembly and ease of disassembly. The use of single robust bolts for attachment of the steel sockets to the plastic legs also removes the need for permanent glue bonding of timber leg and sub-frame assemblies as used in traditional methods of timber construction.

In contemporary chair production the method of joining separate fabricated steel leg structures and moulded plastic seats with mechanical fixings is established practice. This method, developed for simplicity of assembly and ease of disassembly, has been transformed and resolved in designs that incorporate recycled thermoplastic chair shells and add to handling, storage and transport efficiencies. The innovative design of individual leg clamps that sandwich, rather than cradle, the chair shells was developed as a result of reflection on existing designs and through experience gained in making. The design of these leg clamps provides new means for simplicity of assembly and ease of disassembly of chair components. The further development of new methods for fitting, fixing and separating upholstery materials reinforces the application of a holistic approach to linking the interconnected components in chair designs.

5.3 Design for Material Efficiency

The readymade thermoplastic posts were recognised as being of complementary scale and mass for use in desk and table design. Available stock lengths and profiles were intentionally selected to maximise efficient cutting to length and turning to shape. The aesthetic and structural qualities of Scrimber and premium Blackwood timbers have been complimented by careful thicknessing and cutting of boards to minimise material waste and in the development of a thin structural profile. Design for material efficiency was also achieved in fabrication of off-the-shelf aluminium and steel sections to create new leg connecting components. The combination of these simplified structural elements removed the need for traditional post and rail construction.

In reflecting on the efficacy of the Repocol hybrid moulding process adopted for chair shell production, issues relating to material thickness and quality of finish were left unresolved. Construction of the Peregrine shell necessitated a thicker wall dimension and consequent larger material usage than comparable virgin plastic moulding. This technique was applied to ensure structural integrity and product longevity. The quality of surface finish aptly described as ‘a half cooked cake’, is caused in part by the mixing of disparate forms of recycled engineering thermoplastics. Though sharing the same broad resin material code, they may have different melting points and different compositions as a result of master batching for specific product applications. In conjunction with low pressures being applied to the mould tool, a homogenous flow of material remains partly realised with resultant imperfections being evident in surface crazing, miniscule voids and incomplete fusing of constituent pellets.
These imperfections are more pronounced in large lounge chair shells, and this is a factor that has influenced their application as sub frames for upholstery treatments. In comparison with the off-cut waste produced with plywood moulding of Featherston and Bubo designs, use of plastics moulding technology uses only that amount of material necessary to create required form. The method of cutting down the plastic Peregrine shell to produce different forms though creating offcuts produces material that can also be productively recycled.

5.4 Design for Reuse of Materials

In respect of design for reuse of materials, recycled commingle thermoplastics may be limited by diversity of material composition. Similarly mixed sources of engineering thermoplastics may be limited in reuse. Possible third-party contamination in the form of chemical additives and the existence of foreign material particles, due to the increased handling and imperfect systems for their extraction, can limit the scope for future recycling and re-moulding. Alternatively, keeping these materials in closed loop systems enhances future opportunities for successful recycling.

Reuse of materials in this research is aided by the design of separable leg and connecting components and simple mechanical systems of connection. These techniques promote fast and effective means of reducing these designs into single material types. In chair design Velcro upholstery fixing, adoption of automotive fitting methods and zippered covers for upholstered elements are all part of this resolution.

5.5 Design for Production Efficiency

Extrusion moulding is a plastics technology that is typified by rudimentary forms, thick sections and limited detailing. These constraints are a result of the inherent limitations in this method being mated with low cost mould tools. The products of this methodology are economic and structural substitutes for timber resources that have been efficiently remodeled to add new aesthetic and design attributes in desk and table applications. Assembly has been simplified and streamlined with new component design and method of construction.

Within the context of chair production, the fabrication of sheet steel moulds and the technique of sintering recycled thermoplastics provide low cost opportunities for product development. Conversely, the sintering of pellets in fabricated steel sheet mould tools is a slow process with production turnaround expressed in the order of units per day rather than units per hour.

The methodology of designing a particularly large chair form and physically resizing that shape in the creation of new scale and form provides efficient means of creating a range of products in bespoke practice whilst also amortising tooling costs. Production efficiency is further enhanced by the design of interchangeable leg and shell components and simple mechanical systems of connection.
5.6 Design for Product Longevity

Factors that extend product longevity in table design are evident in structural composition, premium hardwood timber tops and sturdy steel and thermoplastic components. Longevity is reinforced with powerful mortice and tenon joinery, durable methods of bolt and screw construction and application of a penetrating and easily maintained finish.

Longevity in the chair forms has been addressed with the design of a durable clamping method for connecting legs to shells. In concert with the design of new upholstery forms and processes it forms a platform for ease of repair, refurbishment and replacement. Considerable aesthetic and ergonomic judgement was also applied in the development of designs in an effort to foster an appreciation of form in that it may also result in improved product longevity.

5.7 Future Directions

In the process of exploring recycled thermoplastic materials, certain limits have been identified in regard to production economies and material efficiencies, but these are considered as resolvable. Further research has been undertaken in Australia and overseas to investigate those limits and to study new possibilities for the moulding of recycled thermoplastics.

Within Australia, microwave moulding was explored through commission of the Industrial Research Institute at Swinburne University (IRIS) in 2000 and 2002. Experiments and further research at IRIS suggest that industrial microwaves could provide an alternative means of moulding recycled thermoplastics. Although results at this stage are inconclusive, they provide a potential direction for future use of recycled thermoplastics.

Overseas research was undertaken in Europe (2000 & 2001) exploring the means of improving the sintered Repocol process and studying alternate means for moulding recycled thermoplastics. Marketing in Europe and Japan was also undertaken for the Peregrine and Bubo designs. A request from Japan for container pricing of Repocol designs was not proceeded with due to reasons of commercial in confidence but is evidence of anecdotal demand.

The initial research in Europe was embarked upon in partnership with Kiel Industries, specialists in Roto-moulding of recycled thermoplastics. This investigation included a site visit to the Recover consortium in East Germany where injection moulding of recycled thermoplastics for the production of pallets for material handling was observed. Visits to Dieffenbacher Industries, who specialised in the production of hydraulic compression moulding technology, and Deuschle, fabricators of steel mould tools for mass production moulding of plastics, were also undertaken. The observations and conclusions drawn from this further research are as follows:
1. Recover has developed a hybrid injection moulding technology which utilises recycled commingle thermoplastics in the mass production of pallets. These pallets exhibited a complexity and intricacy of moulded homogenous form in scale suitable for furniture production.

2. Dieffenbacher has an established production of low compression press technology that, in concert with Deuschle tooling, could produce Peregrine shells that retained the pixilated appearance of sintered form without any bonding imperfections. A millimetre of plastic thickness per hundred tonne of pressure was the expressed rule of thumb. It was projected that a 10 mm wall thickness for the Peregrine shell would therefore require pressures of one thousand tonne.

3. Compression moulding of recycled thermoplastics in the form of products as diverse as bank notes, mobile phone casings and gum boots into sheet materials has been developed by Smile plastics in the U.K. Adaption of this methodology for furniture products, with the introduction of more complex mould tools, could extend the parameters of novel aesthetic outcomes.

These conclusions drawn from microwave experiments and overseas research suggest the pathways and potential for further work in the future. Whilst strategies and techniques to integrate environmental considerations into this body of work consistent with ecodesign definitions were adopted, the broader aspects of sustainable design with a comprehensive analysis of impacts throughout the lifecycle, more rigourous market analysis or redesign that may question the need for these products remain areas for future research.
5.8 Summary

This project began with the development of furniture designs incorporating recycled commingle thermoplastics in the form of readymade products. As a result of the research carried out in this project, it is concluded that different selection criteria for commingle material streams, the design of new mould tools and experiments with different moulding technologies, could provide rich outcomes for ecodesign practice in Australia.

Furniture design incorporating recycled thermoplastics is in its infancy but the need for viable solutions to address the problems of resource depletion and growing volumes of plastic waste will generate further research and experimentation. Such future research into recycled thermoplastics and innovative furniture design based on reflective practice, as demonstrated in this project, or based on sustainable principles (Charter and Tischner, 2001) could also provide new and valuable insights and results.

This project has successfully incorporated commingle and mixed sources of recycled thermoplastics in new furniture forms through the application of ecodesign strategies. These strategies of design for simplicity of assembly, ease of disassembly, material efficiency, reuse of materials, production efficiency and longevity of lifecycle have been demonstrated through the development of new furniture forms, methods and techniques. The implications for design practice that these forms, methods and techniques demonstrate, show that recycled thermoplastic products need not be derived from single products nor from single polymer formulations to be products of significant quality and value.
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