

# Reverse engineering: a formative method of research

Mr Blair Kuys\*, Professor Lyndon Anderson\*, Dr Simon Jackson\*, Dr Gavin Melles\*

*\* Faculty of Design, Swinburne University of Technology  
Melbourne, Australia, [bkuys@swin.edu.au](mailto:bkuys@swin.edu.au)*

**Abstract:** Design meets people's needs. In order to advance design for future needs, we can learn from our past – what has worked well and what has not. The act of reverse engineering existing products helps identify successes and mistakes that may have occurred over the service life of a product. Reverse engineering is a method of disassembling existing products to better understand their construction and manufacture. It is an analytical process of observation and documentation used to improve the design of existing products. Knowledge learnt is then considered, developed and applied to create better products.

Reverse engineering was an important component of the doctoral research study and design outcome referred to in this paper. The design outcome for this study is a timber window frame: a casement window designed as a product that exhibits the fundamental qualities of formative research highlighting the importance of reverse engineering practices to advance existing products, giving strength to timber as a sustainable material of choice for the window frame industry. Comparison studies of new and old window frames have been conducted to visually represent reverse engineering methods of research. This reverse engineering method identifies poorly constructed products, while design advancements are also developed from this process.

In the case of a timber window frame, it has been valuable research to reverse engineer older products to observe deteriorated areas. These areas have deteriorated from moisture build-up leading to rot and decay from fungal attack over a prolonged period. This is the major weakness of timber used in outdoor applications. Observing this in an old window and understanding why these problems have occurred has led to improved design solutions for innovative future products. Manufactured timber window frame, which is the result of this doctoral research, gives highest importance to energy-efficiency, sustainable materials, quality hardware and innovative design solutions to prevent rot and decay during the service life of the product. This window acts as an exemplar product for other window frame types and other timber products intended for outdoor use. The specific style of window, a casement window, was manufactured as it best highlights the areas of innovation incorporated into the design outcome derived from reverse engineering methods.

**Key words:** *Reverse engineering, timber window frame, design.*

## **Introduction**

This doctoral research has been supported by three Australian organisations. The Cooperative Research Centre (CRC) Wood Innovations, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Swinburne University of Technology (SUT). These organisations have helped set working parameters, provide funding and assist in the development of investigation.

The design outcome, an energy-efficient window frame using sustainably produced timber, necessitates technical design resolutions to ensure success within the physical design outcome. Reverse engineering was a method used in the preliminary stages of the design process to extend knowledge on existing manufacturing techniques and to understand problems that exist in current timber window frames. Traditionally the term ‘reverse engineering’ in a design discipline refers to ‘pulling apart’ the internal components of a product in order to understand its mode of functioning, and to be able to then recreate it. The term ‘reverse engineering’ in this study was used more pragmatically to ‘pull apart’ older products to identify and determine the reasoning behind deterioration in the timber frame. By doing this, reverse engineering helped develop knowledge of the fundamental design requirements of a timber window frame, providing a strong basis for improved product developments.

This method consisted of the deconstruction of existing products to understand further about the construction techniques and manufacturing processes used to create these products. It is important to learn from existing products to develop one’s understanding of how the product was created and how the product can be improved upon. This was a form of competitive benchmarking and must be noted that it is not a form of plagiarism; it is purely a design method of understanding positive and negative aspects of specific products. Knowledge learnt is then built upon to create better/more suitable products.

## **Reverse engineering influencing design**

In Australia, perceptions within the manufacturing sector about timber window frames illustrate the belief that the harder/denser the timber, the better its permanence “[Marshall, personal communication]”. Study of various timber species in this research (in literature review and actual observation) proves this perceived notion untrue, as all timber products subject to weathering are liable to rot if not designed effectively or if not treated. Design plays an important role in ensuring the longevity of a timber window frame. The avoidance of water build-up in specific areas within a window frame will reduce rot, which will otherwise be inevitable in a poorly designed timber window, no matter what timber species is used.

A significant problem that plagues timber use in outdoor applications is ongoing maintenance required to prevent fungal attack that can lead to rot and decay. This is partly due to poor construction techniques and a lack of ventilation as a result of limited design resolution for many timber window frames. Innovative industrial design solutions derived from reverse engineering existing/older products will maximise the service life of a timber window frame.

Visual documentation

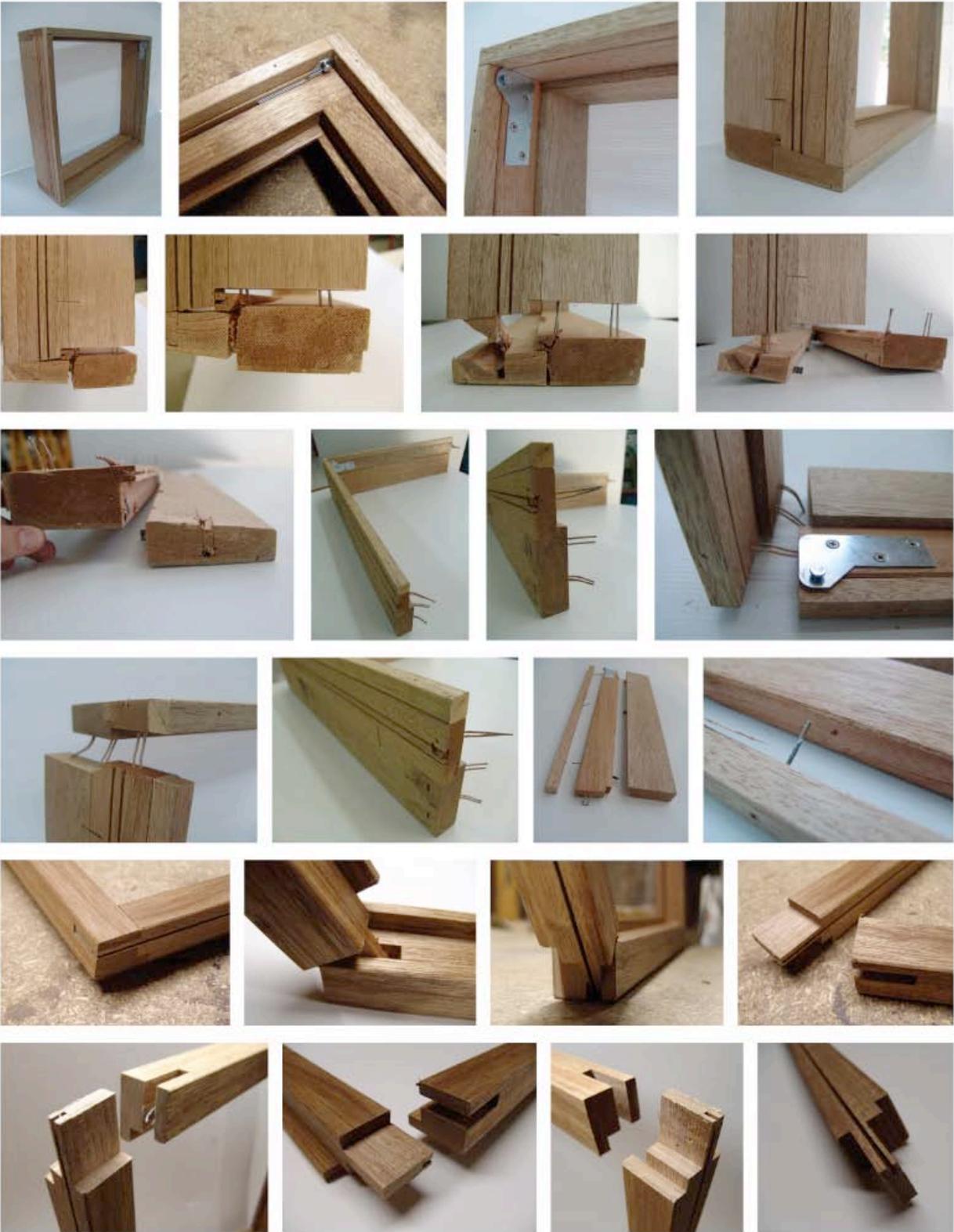


Fig 1. Visual progression of the reverse engineering process.

Reverse engineering as a formative method of research was one of many approaches used in the product development process for this research. It was the most important research method used to better understand the reasons why older timber window frames deteriorated over their service life. Observation and analysis led to elucidation of construction flaws and design faults that may not have been realised if existing products were not reverse engineered. To design a successful window frame, an understanding of the industry and all design considerations is required to satisfy future needs for this industry. The planning process considers product development opportunities according to many sources, including suggestions from industry, existing product research (literature review), current product development teams, and benchmarking of competitors (reverse engineering). [1]

Reverse engineering is a useful tool for understanding how a product operates and it is not uncommon. However when working with a traditional material such as timber intended for outdoor use, it is imperative to ensure design is at the forefront of innovation to maximise the service life of the product.

**Comparison study**

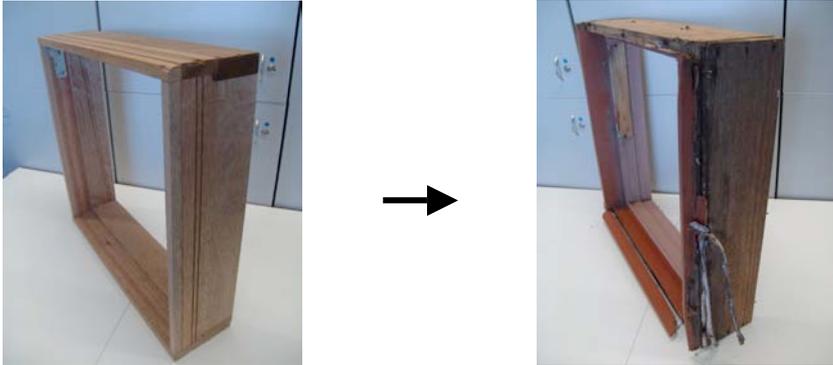


Fig 2. Deterioration of the outer frame of a casement window.

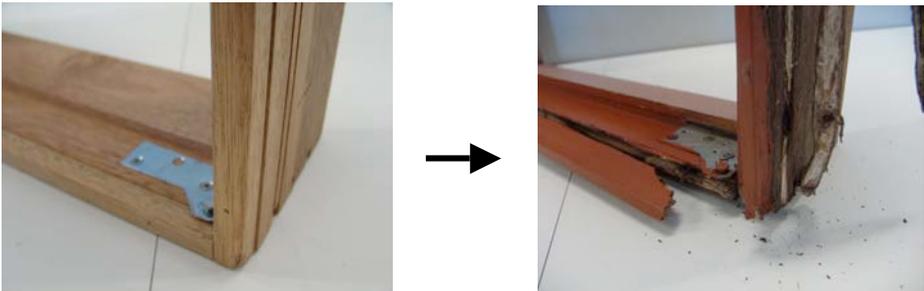


Fig 3. Deterioration between the jamb and the head of a casement window.

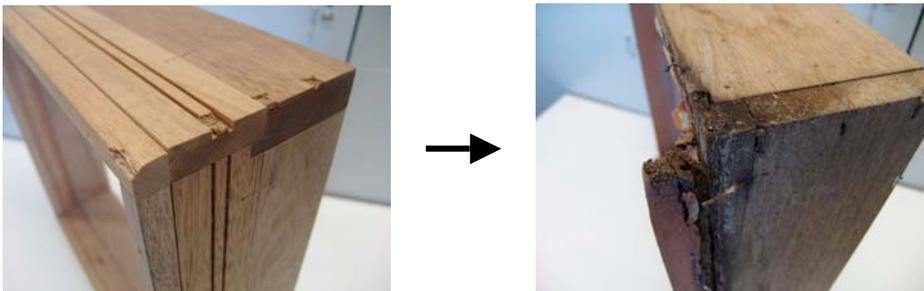


Fig 4. Deterioration between the window mould and the jamb of a casement window.

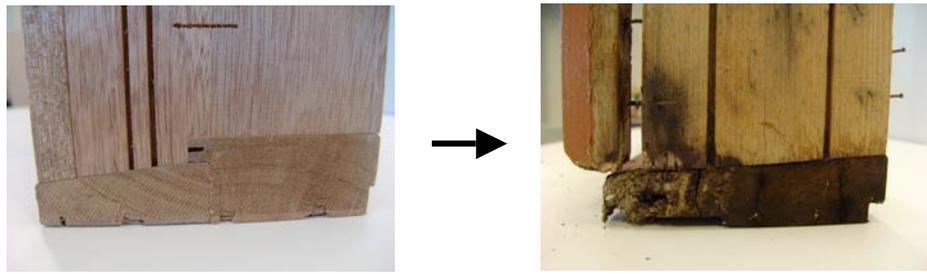


Fig 5. Deterioration of the sill and jamb of a casement window.

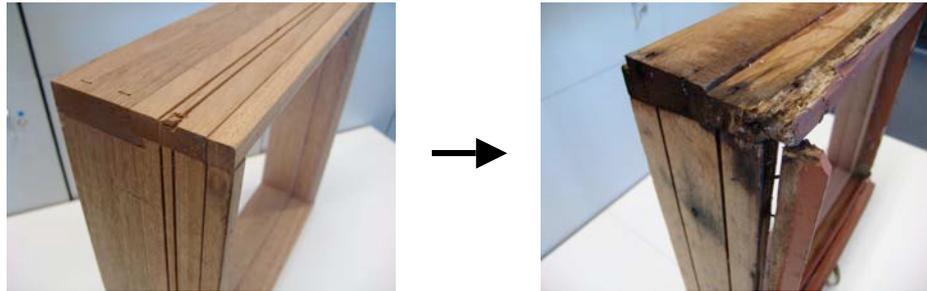


Fig 6. Deterioration of the head and jamb of a casement window.

The design outcome is giving highest importance to energy-efficiency, sustainable materials, quality hardware and innovative design solutions. The manufactured product for this research is a casement window frame that acts as an exemplar product for other window frame types. The outer frame of all windows designed in this research is the same in design and manufacture; it is the inner frame that differs depending on specific window types. A casement window has been manufactured as it best highlights the areas of innovation the design component of this research contributes.

The casement window developed for this research has been designed to expel water and reduce the pressure of wind entering the frame. Reverse engineering highlighted major areas of rot and decay that were consistently seen on many product examples. One of these major areas was the window sill, which is subject to constant weathering. Eighteen old window frames were collected for this study and used in the reverse engineering process. It was interesting to note that on nearly all window frames deconstructed and analysed, the sill projected past the face of the window. This caused unnecessary exposure to the timber and in some cases causing rot and decay and in all cases resulting in severe weathering (UV degradation). This is one example where the method of reverse engineering influenced the final design. The design of the window sill was therefore derived from this study and does not project from the face of the window so water cannot sit on the sill; any water that hits the glass is allowed to drain completely away from the window. It also reduces the chance of weathering. The function of the sill is not jeopardised as an external sill is to conduct the water that runs down from the window away from the window, and to cover the wall below the window and exclude rain from the wall.

Another successful example of how reverse engineering influenced the final outcome was in the joint design for the outer frame of the timber window. Many products ‘pulled apart’ and examined were constructed using

simple butt joints that did little to extend the life of the window frame. A butt joint is a weak construction joint and is formed when one timber member runs into another with no interlinking details. These joints are usually glued and nailed to fix each member together and are prone to movement. This movement creates small gaps within the design allowing moisture to build up leading to rot from fungal attack.



Fig 7. Timber deterioration between a weak butt joint due to water penetration.

Blind mortise and tenon joints were also observed during the process of reverse engineering older products. These joints are more secure than a butt joint but considerable damage was observed due to internal moisture having no escape path when trapped within the joint.

This fundamentally changed the outer construction of the window frame and ‘through’ mortise and tenon joints were used. A ‘through’ mortise and tenon joint allows water to pass through the joined components when necessary. The reverse engineering analysis of this area proved that if a ‘blind’ mortise and tenon joint is used there is an increased possibility of water being trapped within the joint, leaving the window frame prone to rot and decay.

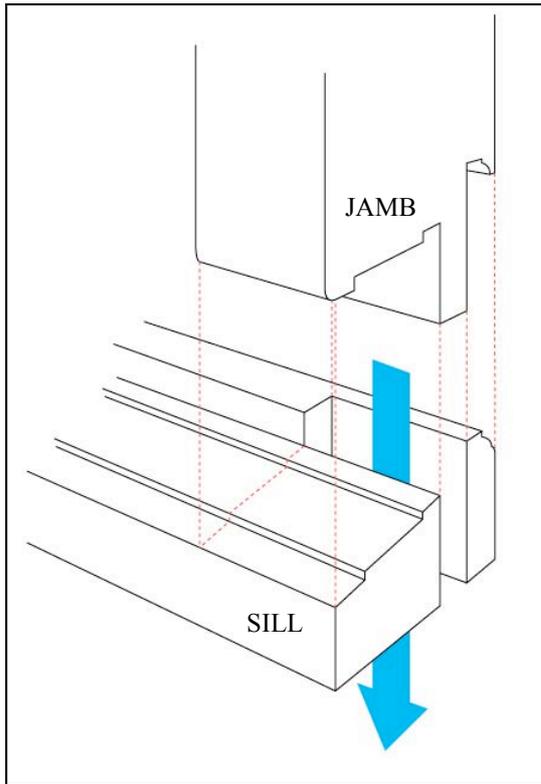


Fig 8. A 'through' mortise and tenon joint designed to prevent water being trapped between the sill and the jamb.

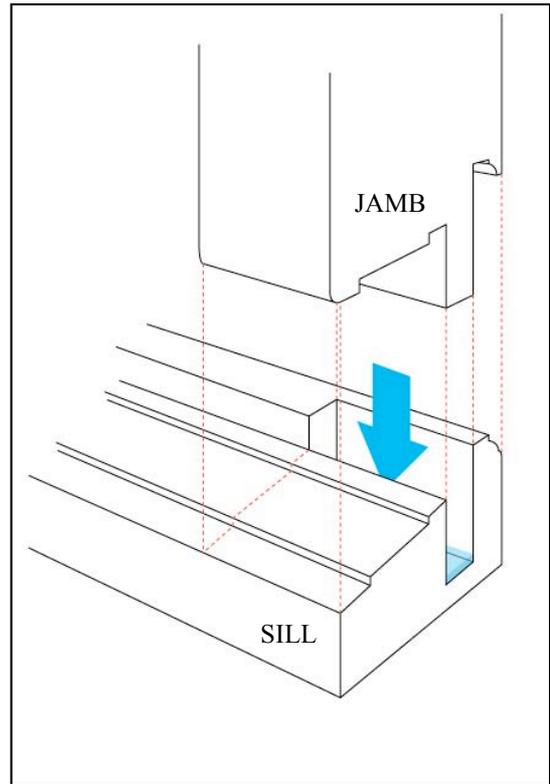


Fig 9. An example of a 'blind' mortise and tenon joint. This was eliminated as a design option due to the liability of water being trapped within the joint cavity.

A clear observation of one cause of deterioration after analysing the reverse engineering process was the delamination of surface coatings to the timber. These coatings act as a protective barrier from weathering and a majority of older windows that were 'pulled apart' and examined had evidence of delamination predominantly around right angled edges. This creates thin wall sections of the coating applied to the timber where one angle meets another, exposing the timber to water damage and UV degradation. This analysis has shown that it is essential for all right angled edges on a timber window frame to have at least a 3 mm radius. Paints and stains do not adhere to sharp corners identifying the need for a radius so the surface coating has an improved performance.



Fig 10. A visual example highlighting the importance of incorporating a radius on a right-angled edge.

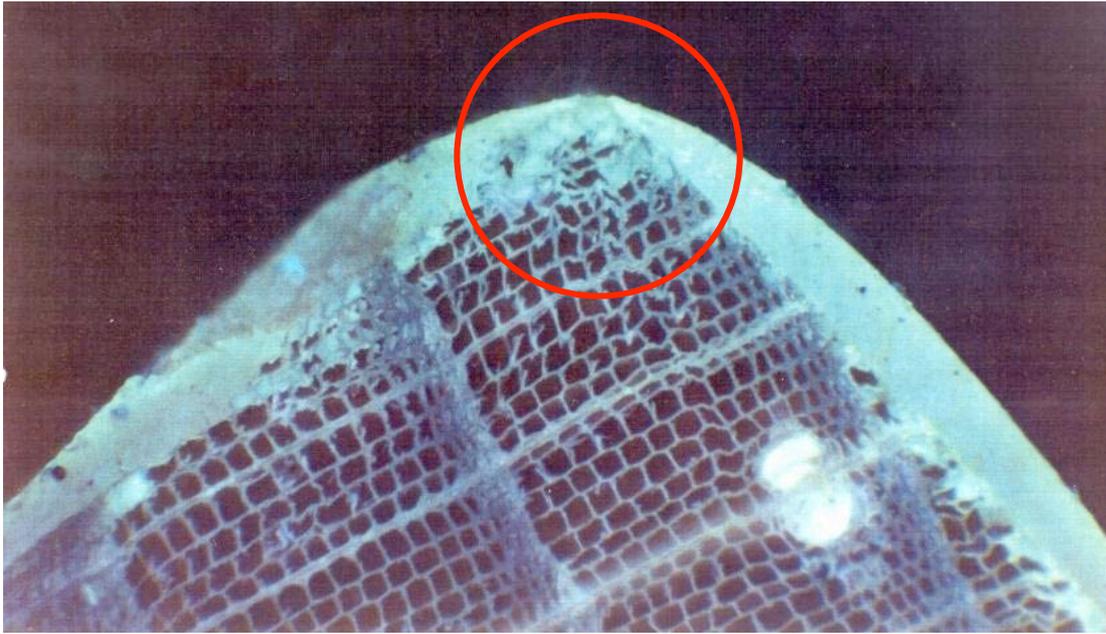


Fig 11. A microscopic view of European Redwood (*Pinus sylvestris*) highlighting the importance of design in reducing sharp edges and allowing coating systems to perform better (British Research Establishment.).

The significance of design for a timber window frame is to ensure water is not trapped in areas it cannot escape from and to make sure the window is well ventilated. Trapped water arises frequently in poorly designed timber frames due to a lack of internal circulation and poor joinery. Air movement within a frame allows internal trapped moisture to dry and evaporate. Therefore, a constant flow of circulated air within the internal substructure of a window frame will evaporate any trapped moisture, which if ignored, will inevitably result in rot. This is the role of good design.

Reverse engineering formed one component of this doctoral research and was a useful means in creating a better understanding of the product that was to be designed. When all elements of the design process come together a successful advancement of what already exists is possible.

Fig 12. Digital CAD rendering: sectional view of the casement window designed for this research.



## **Conclusion**

An extensive understanding of innovative manufacturing techniques specific to timber window frames, sustainable forest managements and sustainable timbers were all major components of this research. By utilising this knowledge in a practical advancement on what already exists, a sustainable window frame has been created that will last longer, and perform better than existing products of similar materials.

The inquiry process for this doctoral research was iterative [2] and was one of many design methods conducted to develop knowledge in the area of timber window design. Knowledge was developed over an extensive period with many industry partners through direct contact and conversations. This research method, specifically with window frame manufacturers, developed knowledge in many different areas exclusively to the manufacturing of window frames. This knowledge identified areas of successful practice, such as quality construction techniques and high standards in manufacturing and design. Unsuccessful practice was also identified, mainly in poor joint designs that did little to eliminate water infiltration into poorly constructed areas within a window frame.

Sustainability was another key driver for this research. Unsustainable practices were of great concern as a large percentage of manufacturers use hardwood timbers that are becoming scarce and are harvested from poorly managed forests. Poor construction techniques also contributed to these. This negative practice, which is completed to save time and money in manufacturing, contributes to product obsolescence, as the service life of a window frame can be drastically reduced. Poorly constructed timber window frames are prone to fungal attack and therefore rot and decay, deteriorating the timber over a period of time.

Positive sustainable practices were identified and knowledge gained in this area formed significant elements for this design research. Sustainable design consists of using suitable timbers that have appropriate properties to withstand prolonged weather exposure, and which are harvested from well-managed plantations and native regrowth forests. Intricate design details for the overall construction of a timber window frame must be satisfied to ensure that joints repel water and that air is able to circulate throughout the frame. This will prolong the service life of a window frame to compete with competitive materials such as PVC and aluminium.

This iterative process of inquiry sets out to eliminate the negative and promote the positive aspects associated with the design and manufacture of window frames. This extensive evaluation of the window frame industry helped construct design guidelines that were used as a base for innovation. Successful, well-resolved design is the key in bringing back the confidence of consumers and positioning timber as the sustainable material of choice for the manufacture of window frames, both in residential housing and commercial building construction. The underlying problem is that currently Australian manufacturers underestimate the power of design in the construction of timber window frames. This leads to poor air circulation within internal elements of a frame, as well as poor joint designs that allow water penetration in small gaps and crevasses within the timber construction.

Reverse engineering helped advance design, positioning timber as a sustainable material of choice for window frame manufacturing. Research in any discipline should create a greater good and sustainable solutions should underpin the moral values of all research outcomes in this field.

## **Acknowledgments**

Mr Lotars Ginters. Swinburne University of Technology.

Dr Voytek Gutowski. CSIRO Division of Materials Science & Engineering.

Mr Jamie Marshall. Patron Windows. Australia.

## **References**

[1] Ulrich, K. and Eppinger, S. (2002) *Product design and development*. McGraw-Hill, New York.

[2] Downton, P. (2003) *Design research*. RMIT University Press, Melbourne.