GRC developments in Australia

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Abstract

The most popular markets for GRC are in areas of relatively low labour cost e.g. Middle East, China and Turkey. GRC manufacturers in other markets have found too often the early intent to create something different using GRC is eliminated at budget review stage. 2011 to 2014, $30 million of GRC work was removed from projects, in Sydney alone, some $20million of potential GRC work was removed from major projects 2011-2014, even though originally nominated by the Project Architect in DA documentation.

Developers and designers are always looking for quality façade alternatives to create something unique. In spite of cost difficulties, the GRC industry has made significant steps forward;

- Supplying complete panels with a 3D fair faced finish
- 3D modelling in mould manufacture to create unique surface profiles
- Using the lightweight nature of GRC to design a façade where the external skin (GRC) is not on the critical path.

The standard product market has made the biggest gains as popularity for modular construction grows;

- Bathroom floors
- Increased performance of in-ground pits
- Fire rated flooring systems

All developments have been helped by increased sophistication in design analysis of long-term creep and the increased specification of premix GRC.

INTRODUCTION

I consider it reasonable to say that glass reinforced concrete (GRC) was established in a commercial form by Pilkington Bros. in and around 1956, building on research and development work carried out by the Building Research Establishment (BRE) in the UK. Since that time there has been a huge amount of research and development work carried out in the last 60 years. However, I suggest that in terms of actual pragmatic engineering design development, as distinct from manufacturing development, there has been limited development to assist the GRC designer and manufacturer. If one reads the various papers written over the years, nearly all of them refer back to the work done by Pilkington Bros. (or persons previously employed by them). I think in particular of persons such as Messrs. Knowles, Proctor, Litherland and Oakley.

In Australia, we operate in a highly competitive market, common to the rest of the world yet. In the last decade the use of GRC has enjoyed one of its best periods of sustained growth. Architects and clients are ever more demanding in looking for something “different”. Brick, concrete, composite aluminium and glass are now considered “yesterdays’ news”. Any form of perforated/faceted material is now very popular and GRC is a perfect option. The industry has finally understood it is futile looking at GRC as a straight “like for like” alternative. To be competitive the material needs to make us of;

- A finish not achievable in another material
- Fire rating/sound rating
- Lightweight material
- This paper is split into three portions;

Developments in design
I look at current engineering design practice in Australia and ideas that we are now considering to include to increase our competitiveness and scope of work.

Developments in grc manufacturing
I look at current developments in building techniques which are improving the competitiveness of GRC in the Australian market place.

Illustrations and images of grc projects
I look at some of the stand out projects of recent years.

The Credit Lyonnais Building, Figure 1, was built in London in 1956. Three years ago the building was cleaned. At that stage the building was 56 years old. The GRC was found to be as good as the day it was erected. I suggest that the building is an inspiration, not only in design, but also an outstanding example of the all-round performance capability of the product.

Figure 1. *Credit Lyonnais Building, London (1956)*

DEVELOPMENTS IN DESIGN

In Australia, there is no doubt that this product is always produced in the context of “Design and Development”. Performance specifications prepared by consultants acting on behalf of the client too often fail to really understand the real issues of the proposed use of the material. This inevitably leads to problems at the time of tender evaluation. It is therefore important that the GRC industry educates the general market of the key issues.

For their part, manufacturers need to understand that pre-tender engineering input is vital if misunderstanding of the tender documents is avoided and a competitive edge is to be achieved in their submission.

Basic Stress

From my own experience designing and checking the design of others in GRC, I see no substantial progress from the recommendations made by Pilkington Bros. in 1956, see Figure 2a & b. In simple summary, based on a MOR of 21MPA, they discounted 50% of the strength for long-term loss of strength. Then they applied a factor of safety of 1.75 to give an allowable bending stress of 6mpa. See Figures 3a & b. Engineers must then assess stress generation at early lifting, stresses due to shrinkage in order to give a net allowable stress available to withstand permanent loads such as wind. Allowable stresses were also developed by a similar methodology for tension, shear and modulus of elasticity. The industry has developed different grades of glass to suit different style of manufacture. Further, polymers were introduced in the 1980's (Forton was perhaps the first), increasing early panel strength and allowing relaxation on previous methods of curing. In my experience through it all, the basic stress recommendations and philosophy of Pilkington Bros. has remained the benchmark.

In 2015, I suggest it is time design engineers made greater use of material testing in general, age testing analysis in particular for different applications as well as coupled with more detailed investigation of optimizing design stress for different methods of manufacture and glass content.

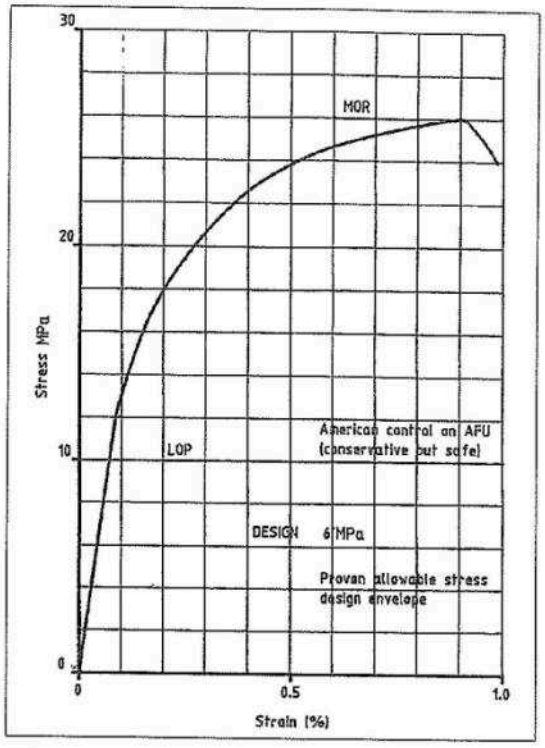

Figure 2a. *Stress strain curve. Original Pilkington Design Guide 1979*

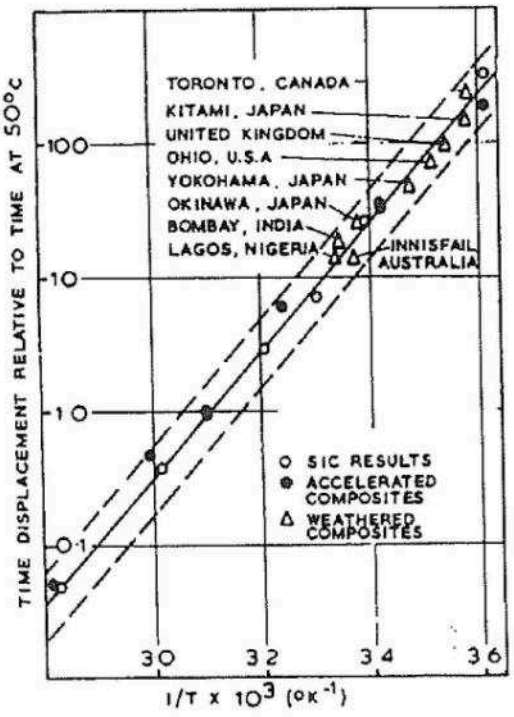

Figure 2b. *Extract from The use of accelerated aging procedure to predict long-term strength of GRC, Litherland, Oakey and Proctor, C&CA. Vol II, 1981*

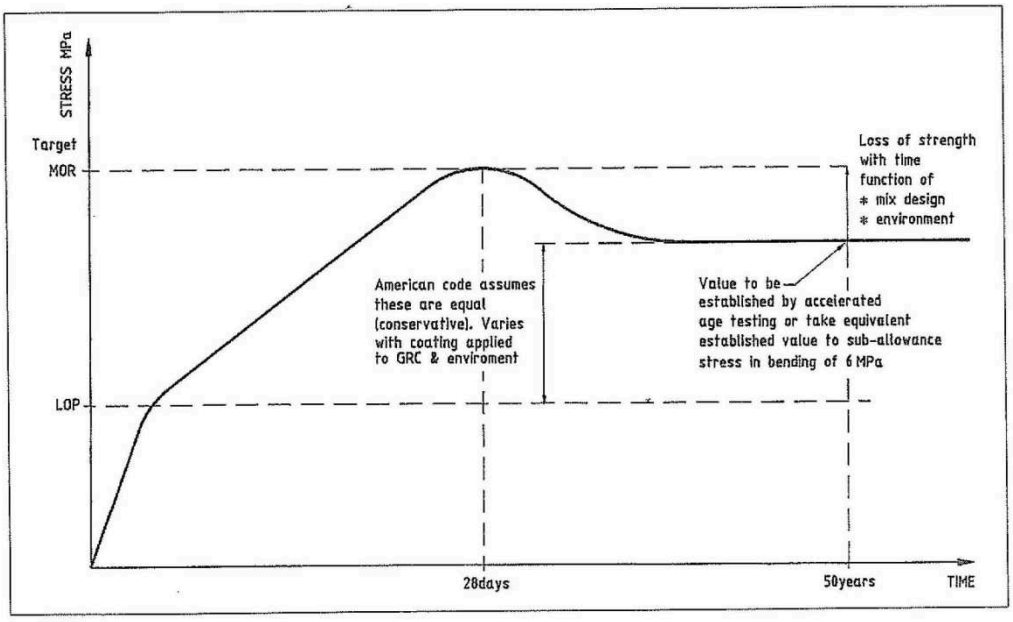

Figure 3a. *GRC loss of strength with time. Extract for the Australian Code of Practice for GRC*

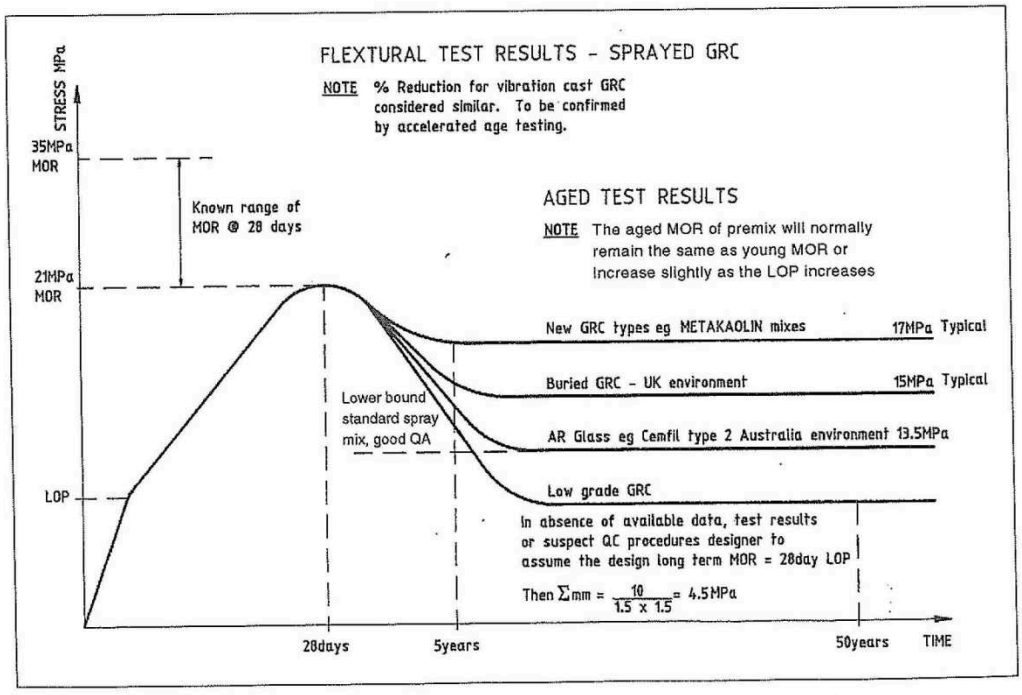

Figure 3b. *Comparison of results for typical GRC mixes. Extract for the Australian Code of Practice for GRC*

Limit State Design

I graduated in 1975 when limit state design for steel and concrete was just entering the market place. I appreciate the value of limit state design for steel and concrete but fail to do so for materials with no real "plastic" range e.g. GRC, wood and aluminium. The limit state option was included in the Australian Code to conform to modern trend but only after we ensured that a limit state design gave the same design solution as an allowable stress design. Earlier attempts to introduce the concept resulted in an overnight downgrading of the strength of the material.

Types of GRC
For many years I suggest, most manufacturers dismissed “Premix” as very much a junior option to “Spray”. Yet in Australia today, I suspect that volume sales of Premix GRC exceed Spray GRC by perhaps 3:1. Self-compacting Premix GRC has enjoyed an ever increasing market share in Australia. Power Sprays Limited exclusively supply two of the largest companies in Australia. An MOR uni-directional reading of 16mpa is regularly achieved and this gain in strength has made a big contribution to the development of standard Premix products.

Australian “Spray” GRC is found to reach strengths of 32MPa with the use of polymer additives. Standard spray mix will readily achieve the high 20’s. It continues to be the product used for the large architectural panels but is now being assisted by innovative developments such as pre-stressing. Increasing focus is being directed towards addressing the significance of possible saturation of a GRC products. Focus is given to the need to seal all faces of the product at a low moisture content. The nature of the load application, the size of the load application and its effect upon fibre bond in the matrix is also considered.

Aged Testing
In spite of a huge volume of research work on this issue, I suggest that the best reference document is still “The Accelerated Ageing Procedures to Predict the Long Term Strength of GRC Composites” by Litherland, Oakley and Proctor. As we become more sophisticated, with different mix design, so we need a benchmark to relate to a proven methodology. Many may not realise the highly professional diligence of Pilkington Bros. in testing the GRC in different environments, see figure 1. Pilkington established a stock of standard coupons and then proceeded to age test those in a variety of environmental conditions and then relate to age testing to create an appropriate mathematical model. As a simple summary, “maintaining a coupon of GRC at 75ºC for 28 days is equivalent to 20 years exposure in the UK environment”.

Figure 2 shows how the Australian Code of Practice has been set up to encourage GRC designers to make greater use of material testing to suit different mix, different location and different use. I expect to see real benefit from research and development work in this area in the coming years.

Curing
Over the years, I have been directly involved in the design and manufacture of GRC in the USA, Australia, Singapore, Qatar, Abu Dhabi and the UK. My Middle Eastern clients have no concerns with curing and seem to have no problems long-term. Back in 1984 in Australia, at least one manufacturer would maintain the products in a controlled environment, spraying them with water on a daily basis for at least 7 days. In 2015 in Australia, the product is generally kept in a controlled environment for 7 days but no one to my knowledge spends time wetting the product. Polymer mix is by no means universal.

Clearly the need for care is much greater with GRC on a steel frame than it is for GRC with integral GRC ribs. To my knowledge the use of steel frames with GRC in the Middle East is virtually non-existent which is a good thing considering their standard practice in curing. Much greater attention should be spent with regard to sealing the product and controlling moisture gain in the product that is currently exercised.

Use of Continuous Fibre
In the 1980’s, I undertook a number of tests with GRC panels designed using continuous strand fibre on the back of integral GRC ribs. Experimentation showed a 25% increase in strength on those panels without the continuous glass fibre. Clearly this is of significant economic value.

Use of Reinforcement in GRC
At the 2011 Conference in Istanbul, research and development work relating to the use of steel reinforcement in GRC was tabled. I believe great care is required with this idea. I am firmly of the view that its use should be limited to bars of limited length in areas of high stress, principally relating to de-moulding and possible induced stresses due to transportation. We need to differentiate between reinforced concrete and GRC. We need to remember that we do not have the aggregate in the GRC to set up the micro-cracking to distribute the effects of shrinkage. The idea that we can create reinforced GRC ribs 3 or 4 meters long behind a face skin of 12mm is proven to lead to issues with "panel bowing" and face skin cracking. I have successfully used reinforcement to strengthen the GRC skin local to fixing points to control stress levels when the panels are lifted, typically at 18 hours of age.

GRC Wall Formwork Panels
At the 2011 Conference in Istanbul, an excellent presentation was given regarding the development of floor to floor GRC wall panels as permanent formwork for the creation of an interior structural concrete wall. At the time, the issue of differential shrinkage between the GRC and the new concrete wall behind gave me cause for concern. Since then I have looked at mathematical modelling of the issue and reached the conclusion that so long as the timed shrinkage performance of the GRC material relates as closely as possible to the forthcoming shrinkage of the structural concrete wall behind, no concerns need arise. This dissipation of the high early shrinkage will allow easy matching of subsequent GRC shrinkage to the concrete behind.

Pre-stressed GRC
At the 2011 Conference in Istanbul, I presented details of a design in GRC utilizing pre-stress which I used in 1992 to design sun-hoods for the Adelaide Australian Tax Office. The building is now 23 years old and there has been no need to retention the pre-stressing bars since installation. The bars were left deliberately "un-bonded" to give the option of future stressing. I noticed recently that a company in America is now actively promoting pre-stressed GRC and feel this is the appropriate future of GRC with regarding to reinforcement rather than "Reinforced GRC".

Fire Rating
The excellent fire rating characteristic of GRC is too often ignored by designers responsible for the concept development of a building. This is an education process which we are pursuing in Australia to increase the market viability of the product. I am not aware of fire testing work undertaken in China but certainly testing continues in America and the UK, tests certificates readily being available for testing as recent as 2008.

"GREEN" Buildings
In the last 4 years this has become a major issue on all substantial commercial and Government buildings. GRC is well placed to make a positive contribution in this regard and is something in which the market in Australia is pursuing vigorously.

DEVELOPMENTS IN GRC MANUFACTURING

The principal interests of the prime manufacturers' of GRC in Australia can be summarized as follows;

Manufacturers Of Architectural Cladding Panels & General
Asurco Contracting Pty Ltd – 1180 Old Port Road, Royal Park, SOUTH AUSTRALIA, 5014
Precast Concrete Brisbane – Factory 3, 94 Lipscombe Road, Deception Bay, QUEENSLAND, 4508

GRC Environments Pty Ltd – 100 Chestnut Street, Richmond, VICTORIA, 3121
Minesco – 15 Hewitt Way, Tullamarine. VICTORIA, 3043

Manufacturers Of Drainage/Services Pits
Mascot Engineering Group – 37 Tarlington Place, Smithfield, NEW SOUTH WALES, 2164

Manufacturers Specializing In Planter Boxes
Quatro Design – 6 Kay Street, Murwillumbah, NEW SOUTH WALES, 2484
Manufacturers Specializing In Modular Construction
Precast Concrete Brisbane - Factory 3, 94 Lipscombe, Road Deception Bay, QUEENSLAND, 4508
GRC Environments Pty Ltd – 100 Chestnut Street, Richmond, VICTORIA, 3121

Manufacturers Specializing In Kitchen And Vanity Benchtops
Domcrete – 28/29 Coombes Drive, Penrith, NEW SOUTH WALES, 2750
(and many others throughout Australia)

Use of Structural Steel Framing
10 years ago, steel frame GRC panels accounted for 90% of the architectural panel manufacture in Australia. It still remains the preferred style of manufacture for one or two of the manufacturers. I make no apologies for say that I do my best to convert every tender design solution from steel frame to integral GRC rib. The principal reasons for this are;

- Cost of the steel frame being a sub-contract to the manufacturer.
- Nearly every GRC job in Australia has to travel large distances and the potential damage caused to steel frame panels far exceeds those with integral ribs.
- Positions of bonding pads on the face skin are often obvious to close inspection
- The complications created by potential locked in stress between the steel frame and a GRC skin

The trend to GRC on a steel frame was started by the Americans. As you will be aware, a steel frame building has always been the preferred method of construction in the USA and therefore the creation of steel frame GRC was a logical solution. I suggest that the steel frame panels are still the only solution where one contemplates panels which are greater in either height or length of 5 meters. Four years ago I designed panels 10m x 3.4m with a 1.5m return, which I would never contemplate with a ribbed GRC solution. As much as there are advantages dealing with site tolerances, I am convinced that generally the ribbed GRC is a better commercial solution. Clearly others will disagree and there is no doubt that there is a place for both in the market place today.

Two Sided Fair Face Panels
Around 1996, I became involved in the design of large perforated panels for the Ceremonial Court in Doha, Qatar. See figure 23 . This was a design by Arup UK which was rejected by the local manufacturers as being impossible. I was brought in as an independent expert and the panels were built to the same basic design by Redco Group WLL. The concept was to build the panel in two halves and then join them together. Any consideration of a steel frame was impossible because of the large perforations. I designed the panels using computer modelling of the perforated shape. The two halves were joined together by stainless steel pins. They are a spectacular use of GRC.

Since that time, working in conjunction with GRC Environments in Australia, we have created a number of outstanding panel designs using the same concept e.g. Australian Catholic University, See figure 4 and also Flinders Street, See figure 5 both in Melbourne.

Integral Colour Panels
In 2011, the project Museum of Contemporary Art (MCA) Sydney, See figure 6 , had five or six different coloured GRC panels, all of them nominated as integral colour. At the recommendation of Precast Concrete and myself, we ensured that the panels were also stained to offset colour variation due to hydration and to allow for covering up any panel repair due to a possible accident during erection.

Even with an integral stain, the variance for a number of the colours was still significant. No one will be surprised that the most successful colour was white. However, since that project I have successfully completed a number of projects in the same way with GRC Environments with increased success and we recommend the stain “KEIM”.

Secret Fixing of GRC
On any project, price and program dominate the attitude of the builders in Australia. The ability to seal a building and therefore erect the exterior GRC cladding away from the critical path is of enormous value to both the façade contractor and the main contractor. Working with Precast Concrete and GRC Environments, we have developed fixing systems that enable large panel erection utilizing fixings, all of which are hidden within the final envelope of the building. We would recommend this to all manufacturers as a very strong marketing advantage for the product. It makes use of the lightweight nature of the material because clearly the nature of the fixings required is much less significant than that required for reinforced concrete.

Drainage Pits and Planters
I first started working with Mascot Engineering in 1984. Over the last 30 years, their business has grown to the point where they supply right across all the states of Australia, these days based in a highly automated new manufacturing facility in Smithfield, Sydney. All their product is made using Self-Leveling GRC, working in conjunction with PowerSprays UK and various glass fibre suppliers. Use of their product has grown to include heavy civil engineering applications such as Sydney Container Parks and the Greta Rail Repair Facility in NSW. They exclusively use Premix GRC. See figures 19 and 20 .

I first started working with Quatro in 2010, see Figures 15 and 16. They have focused on standard and non-standard Planter Box project. They generally use Spray GRC which is obvious when one looks at the complexity of the shapes they create.

Modular Building
The focus of the building industry for the future is very much directed towards modular construction. I am currently involved in a project in Perth where 84 different modules are being built in China to be combined into a high class residential development in North Coogee, Perth. Each of the units is different. There is virtually no straight forward stacking of the units. Generally, across the industry, there is a lot of co-operation between Australian and Chinese companies in this regard. One large company in Melbourne has in recent years focused upon building only bathroom units. The units are complete, see Figure 14. They are totally fitted out and are simply inserted into the building around them. There are at least three major building companies now focusing on this style of manufacture and it presents many exciting opportunities for the GRC manufacturing industry. See figure 13 for a typical simple GRC floor panel.

3D Computer Generated Product
I refer to the following outstanding projects, Figure 17 Geelong Library and Figure 18 West Kiera Shopping Centre by Asurco. I also refer to Figure 22 Swinburne College by Minesco. The extra-ordinary complexity of the geometry would have been created with extreme difficulty 15 years ago. When I worked with Glenn Industries, see figure 10. 37m high

Merlion Statue in Singapore, this was created to an accuracy of +/- 75mm with huge dependency on the skills of the sculptor. In 1999, see figure 21, again working with Glenn Industries the Body Zone sculpture in London was built to an accuracy of +/- 5mm. The mould exactness and sharpness of detail on the ACU Panels, Figure 4, Flinders Street Figure 5, Airlie Bank Figure 6 and in particular the GRC Feature Wall, Figure 8, highlights the huge advantage now enjoyed by the GRC industry in creating very high class product.

ILLUSTRATIONS AND IMAGES OF GRC PROJECTS

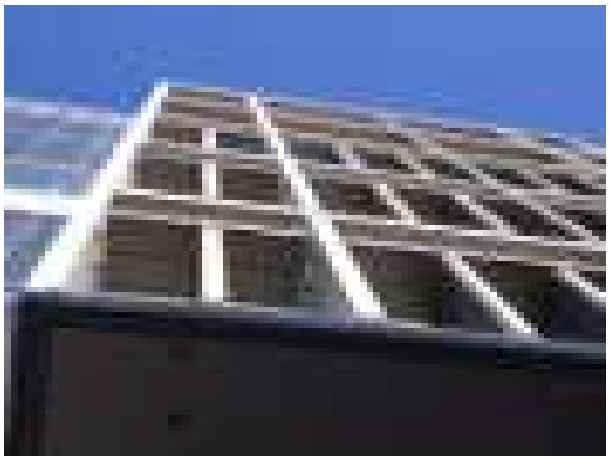

Figure 4. *Australian Catholic University, Melbourne (2012)*

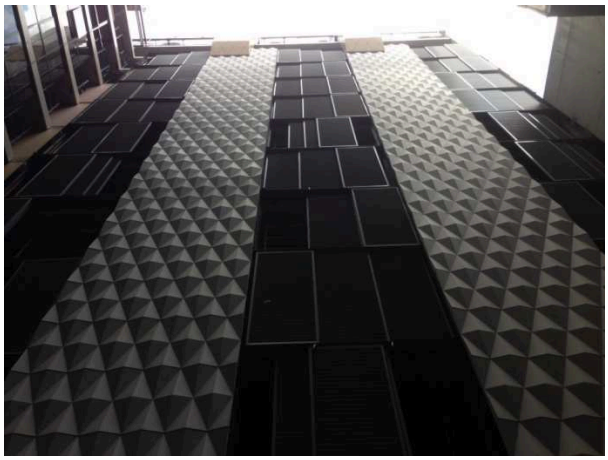

Figure 5. *Flinders Street – Offices, Melbourne (2013)*

Figure 6. *Airlie Bank Lane South Yarra, Melbourne (2012)*

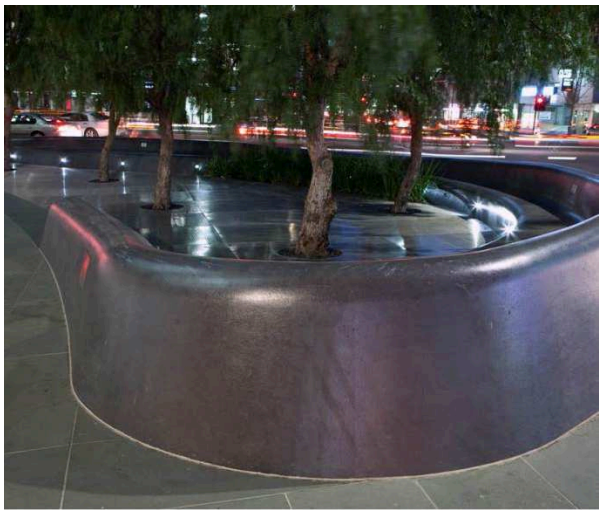

Figure 7 . *Street Furniture, Melbourne (2014)*

Figure 8. *Feature wall in private home (2012)*

Figure 9. *Museum of Contemporary Art - MCA (2012)*

Figure 10. *Merlion-Santosa Island, Singapore (1996) Free Form*

Figure 11. *Monument Park, Melbourne (2015) Workshop*

Figure 12. *Monument Park, Melbourne (2015) On-Site*

Figure 13. *Bathroom Floors – Typical Panel*

Figure 14. *Bathroom Floor – Complete module being craned into building*

Figure 15. *Quatro – Planter Box – Example of range*

Figure 16. *Quatro – Luxury Home in Bellevue Hill, Sydney (2012)*

Figure 17. *Asurco - Geelong Library, Geelong (in progress)*

Figure 18. *Asurco – West Kiera Shopping Centre, Wollongong (2013)*

Figure 19. *Mascot Engineering A Typical Pit*

Figure 20. *Mascot Engineering The Range (1984)*

Figure 21. *Glenn Industries Body Zone, London (1999)*

Figure 22. *Minesco, Melbourne Swinburne College (2014)*

Figure 23. *Redco Group WLL Ceremonial Court, Qatar*