Overview of Developments and Research in Wooden Structures in Australia and New Zealand

Keith Crews
Director & Assoc. Professor
Faculty of Engineering
University of Technology, Sydney
Australia

Keith Crews has worked as a structural engineer in both private and government sectors since 1980. After completing a research Masters degree, he joined UTS in 1993. He is recognised as Australia's leading researcher for timber bridges and just completed his PhD in this area.

Summary

Despite the fact that timber is such a versatile construction material, during this last century it has significantly lagged behind developments in steel and concrete, particularly in Australia. Whilst use of timber in residential house framing has been well established in both Australia and New Zealand since the 1940's; for many years, concrete and steel were perceived as the only viable engineering materials for larger commercial and industrial structures.

However, concentrated research efforts, focused education programs and technology transfers from overseas countries over the past two decades, have facilitated the use of timber in non - residential markets. As a result, there has been considerable activity in both countries focusing on innovative development and application of timber in "engineered" structures. This paper presents an overview of various projects and initiatives that are current or have been recently completed.

Keywords: timber structures, durability, connections, education, environmentally sustainable design

1. Historical Background

Prior to European settlement, both Australia and New Zealand contained extensive areas of native forests - predominately hardwoods, which were generally high strength and high durability timbers. Indeed, the availability of such timbers and their potential for both building and military purposes was one of the most compelling, if not covert reasons behind the British colonisation of both countries.

However, the early perceptions of native Australian timbers found on the foreshores of Sydney harbour by the first European settlers, was that it was a difficult material to use and when used, it often twisted, split or warped. It was a great irony (which was soon discovered) that by sheer chance the members of the First Fleet happened to land in an area which contained what is probably one of the only patches of commercially useless eucalypt trees in temperate Australia.

On the basis of this "finding" the British formed a poor opinion of all Australian timbers, whereas in fact, they were in the midst of a virgin continent of trees, which in many ways were unexcelled throughout the world. Unfortunately this ill-informed opinion has tended to characterise so much of how development and use of timber has occurred in the Australian environment.

As a result of these difficulties it wasn't long before the early government started sending out search parties to look for other areas in an effort to find suitable timbers as well as of course land for cultivation. One of the early timbers so discovered was the Sydney Blue Gum which was found to be a stable timber, hard, free of blemishes and was described as being far more durable than English Oaks. Soon Flooded Gum, Blackbutt, Grey Gum, Yellow box and Spotted Gums were also found. It was discovered that after careful seasoning, these fine timbers had many building uses.

One of the most important timbers of all for the early settlement was the Australian Cedar, which was found in 1790 in areas adjoining the Hawkesbury River (some 50 km north - west of Sydney). This timber has close and evenly spaced grain, is easily worked, and has a warm red / brown colour. It soon became popular for every type of work, from fencing to house framing, and in joinery and furniture. Unfortunately, this timber was greedily and indiscriminately felled in order to build and furnish the houses of early New South Wales. This turned out to be a short term profit exercise which resulted in total depletion along the banks of the Hawkesbury River by the early 1800's.

Similar exploitation of native timber characterised the British colonisation of New Zealand. This situation was further aggravated by the need for agricultural land and vast tracts of forest in both countries were subjected to clear felling in order to create farm land. In New Zealand, the drive for agricultural land decimated most areas of native forest - to the extent that few areas of such forest now remain.

1.1 Perceptions of Timber in Australia

It appears that because of the unhappy early experiences with timber in building construction, the first European Australians developed an aversion to timber for use in permanent buildings. Timber was perceived to be only acceptable for use in temporary and makeshift structures where there was no other "permanent" alternative [1]. As the colony developed it was seen as a mark of respectability to build in stone and masonry, a fact which reflected the Georgian Architectural tradition from Great Britain.

Whilst timber played an important part in many of these homes it tended to be hidden rather than expressed as part of the visible structure of the building. In 1838 the Building Act of Sydney came into force. The result of this legislation was to encourage masonry construction and restrict timber to use in internal applications only, such as for joinery and staircases.

In rural areas timber still tended to be used particularly in farm buildings where many such applications have survived until the present time. It was in the fringe areas of settlement and country areas that "a host of fine timber structures were erected that were unique of their kind, outstandingly simple in their construction, ideally suited to their function and beautifully in harmony with their environment. They were bold, strong, forthright and masculine, no nonsense buildings, reflecting the same self-reliance, the initiative, the common sense, the courage and the understanding of the men who built them." [2]

Farm service buildings became the architectural climax for Australian timber structures. Large buildings, huge shearing sheds, large wool sheds, etc became a sign of rural prosperity and many of these were constructed across Australia. Interestingly with these, developed new forms of building construction (most notably post and beam construction) and over a period of time more sophisticated techniques were used as designers and tradesmen began to understand how to work with Australian timbers.

1.2 Timber in the 20th Century

By the commencement of the first world war, many of the older "crude" rural buildings were giving way to the march of “progress”. Building frames were no longer made from poles of hardwood, but were built from thin skeletons (frames) of imported Oregon sticks nailed together as plate studs, braces, and trusses. At the end of the second world war, timber was essentially relegated to the domestic market, using small dimension timber. The only continuing use of large section timber and poles in structural applications, tended to be in bridge and wharf construction. Timber became hidden behind external skins of brickwork, and internal linings of plasterboard.

Whilst there have been some fine examples of timber bridges, wharves, woolsheds and houses over the past 200 years of European settlement, these examples in Australia are relatively isolated. Timber has been generally perceived by designers as a “temporary” and unreliable material - despite the fact that most of these timber structures have performed satisfactorily for well over 100 years! The effects of this perception were also reflected in New Zealand to some extent, although the seismic activity of that country and the poor performance of unreinforced masonry under such conditions, meant that timber construction was more generally accepted.

Australian architect Barry McNeill believes the problem of a lack of expertise in architectural and engineering design of timber goes back to the first European settlement in Australia 200 years ago. McNeill observes that architects and engineers "Did not develop for Australian conditions a tradition of design that would guarantee performance, as occurs in traditional timber architectures in Switzerland and Scandinavia in particular" [3].

1.3 Fundamental Issues for Designers and Specifiers

Whilst it is recognised that timber played an important part in early buildings in Australia as an overall tradition, its roots have been somewhat lost and it was not until the emergence of the so called "Sydney School" of Architecture in the 1960's that timber was once again recognised as an appropriate and honest material, which when expressed in structure harmonises with the Australian environment. By the early 1980’s a number of key areas, each with their own set of problems and constraints were identified as acting together to strongly influence the development and acceptance of timber design and usage for large spanning, non-residential construction in Australia and New Zealand [4]. These can be broadly categorised under four main headings:

1. Understanding Material Characteristics and Structural Performance
2. Production and Marketing
3. Environmental Considerations
4. Education, Research and Changing the Design Professions

The combined effect of these factors was perceived to undermine designer confidence in timber as a reliable and valid structural material. The material performance of timber is of key importance to engineers, architects and designers. There are many problems that have occurred in existing timber structures that have arisen out of a failure to understand the nature of the material and how it should be best utilised.

A number initiatives were commenced to address these issues, leading to the first Pacific Timber Engineering Conference in 1984 as one of the first significant forums where these issues were addressed and the process of building "designer confidence" began. Much of what has happened since flows from this initial conference - focused on creating confidence in timber as a reliable structural medium. The abilities of manufacturers and fabricators and the structural performance of engineered wood (timber) products, is now generally well founded and supported by extensive product testing, marketing, quality control and laboratory research.

In general terms, current development of timber in engineering applications focuses on the following areas:

1. Management of Infrastructure - such as bridges and utility poles
2. Design Innovation - Education and Application
3. Durability (including Fire Resistance) and Reliable Performance for service life

Examples of each of these development areas are presented in the remainder of this paper.

2. Management of Infrastructure

Despite the fact that timber has often been perceived as a "temporary" material, it forms a major part of the physical infrastructure in both Australia and New Zealand - particularly for transport (bridges) and power distribution (utility poles). The myth of replacing timber bridges and timber poles with more "permanent" materials such as concrete and steel was exposed in the late 1980's and early 1990's, when the reality of the situation was finally faced by asset managers. In that context significant funding was provided by both government and industry to undertake research and development work with two major emphases:

1. Development of high performance, reliability based systems using new timber to rehabilitate, repair, upgrade or replace existing structures
2. Development of reliable assessment techniques to quantify structural performance using non destructive evaluation (NDE) technologies

A number of papers in this conference present international developments concerning timber bridges (including two that specifically detail developments in Australia). About $4m has been spent on research and development of timber bridges in Australia over the past 10 years and the result is that high performance decking systems for both replacement and repair of deteriorated structures are now available, that compete with alternative materials on both and structural performance.

2.1 Timber Utility Poles

The Australian and New Zealand work on timber poles has focused on two areas:

- characterization of pole properties, sourced from plantations
- evaluation of NDE technologies appropriate to determining the condition of in-service poles

Timber Utility poles represent a significant component of power distribution infrastructure in both Australia and New Zealand, which has often been taken for granted. There are an estimated 5 million timber utility poles in Australia – with a current net worth of about $10 billion. The average usage of power poles in the three eastern states of Australia, is approximately 60000 per annum, with a total average annual cost of replacement of approximately $18 million. Most of these poles are timber.

With the introduction of Asset Management philosophies the early 1990's it was recognised that optimising design and assessment criteria using a reliability based philosophy and improved knowledge of the residual strength of poles, could potentially increase the level of asset reliability whilst reducing new pole costs. Significant potential savings in asset maintenance are also possible by refining inspection and development of more accurate methods of assessing in-service poles [5].

It was within this context, that two major complementary projects were developed in Australia for assessing the strength of new poles and remaining strength of in-service poles. The first project was initiated by the Electricity Association of New South Wales, for assessing commercial NDE technologies which could be applied to predicting remaining strength or residual life of utility poles which were perceived to be at or near the end of their service life. This has involved removing some 350 poles from service and undertaking NDE assessment using 20 different technologies (including ultrasonics, x-ray, and intrusive methods), after which all poles were removed and destructively tested to assess actual strength and failure characteristics.

The second project comprises both ingrade testing of new poles and selective testing of in-service poles; with results from the latter also being used to quantify strength degradation effects. This project is supported by the Forest and Wood Products Research and Development Corporation, NSW and QLD Electricity Associations and Queensland Forestry Research Institute was developed in Australia. The aim is to characterise the design properties of new poles from regrowth and plantation sources, and develop tools for assessing the remaining life of in-service poles.

2.2 The Need For Reliable Strength Assessment

For poles in service, the power supply industry needs to maintain a high average reliability against pole failure whilst extracting the maximum value from these assets. For this balance to be achievable it needs to have available to it pole evaluation techniques and procedures at least able to:

- always classify correctly any pole with inadequate strength.
- only infrequently condemn poles with adequate strength.

This might be all that was required if maintenance of a line was the only objective. If however, the purpose of testing is, for example, to assess a pole or line for its potential to carry a greater load then it would also be necessary for the systems used to give a dependable indication of remaining strength. It would be useful too, if they facilitated reasonable estimates of remaining life - at least until methods become available which can be shown without doubt to control degrade in the critical zone(s) for the term of the ensuing cycle.

Since the 1980's most network managers have relied upon assessment systems which presume that the remaining strength of a pole is proportional to the modulus of the cross section of the sound wood surviving in the critical plane (assumed at or just below the ground line).

The current industry "best practice" is to determine the section modulus of a pole by periodic drilling, to determine the extent of degradation and remaining sound wood. The annulus of sound wood is then assumed to be an average thickness and the section modulus "Z" is calculated, based on this assumption. The bending moment capacity of a pole at the ground line is the "Z" value multiplied by the characteristic strength of the wood in bending "f'_b" - commonly assumed to be a constant value of 80 MPa.

Unfortunately, both the variability of wood strength and the inherent errors in determining the section properties contribute towards a high level of uncertainty in predicting the bending capacity of a particular pole. Thus whilst the "section modulus" method was unquestionably a significant step forward from previous practices, it still has deficiencies; - recognition of which has sustained interest in finding alternatives.

2.3 Background to NDE R&D Project:

Over a period of many years a variety of non destructive evaluation or testing devices, some already in use in other applications/countries, have been proposed or trialed for the inspection of timber poles in Australia. Until recently, none of these has come into routine and general use in the industry, despite some serious attempts to achieve this end. Furthermore, there had been no opportunity to correlate predictive outputs from any of these NDE systems, against the real strength and critical section properties of timber poles, established by full scale destructive physical testing.

In the absence of such information, the necessarily subjective judgement of asset managers and inspection personnel tended to be that the unfamiliar NDE alternative offered no improvement. In this context, EANSW devised and implemented an R & D project, with the specific intention of:

- Evaluating and comparing as many NDE devices/systems as possible, using the benchmark of current industry best practice as a reference.
- Establishing a database of physical properties (bending strength and section modulus) from full scale testing of poles removed from service at the apparent end of their design life.
- Providing the NDE system developers with the unique opportunity of calibrating / developing their systems with the database for eucalypt hardwood poles.

The plan was evolved progressively over a five year period by a purpose appointed sub-committee reporting to the Power Poles Committee of the Electricity Association of NSW, with expert assistance from the University of Technology, Sydney. The eighth and final revision was produced just before NDE data collection commended in April, 1998 [6] and details of the project plan, are described elsewhere [7].

The principal objectives of the project focused on assessing alternative devices / systems by comparing the reliability of their performance with that of the current "industry best practice" *Section Modulus* method, undertaken by industry inspectors. Specifically, the objectives sought to quantify the accuracy / reliability of each NDE system with respect to correctly classifying a pole, in terms of one or both of the following:

- remaining bending strength
- extent and location of loss of wood in a critical plane/zone.

A third objective was also recognised. The absence of data to correlate NDE equipment outputs with real pole strength / condition information has hitherto hampered its acceptance and use. Thus the third objective of the project was to provide an opportunity for any of the NDE systems to correlate their systems with a database derived from testing a significant population of eucalypt hardwood poles typical of those in service in NSW.

In order to provide an accurate and objective "yard stick" for assessing the efficacy of any NDE system for meeting either of the first two objectives, it is necessary to undertake full scale destructive testing and detailed post-mortem analysis of each pole in the sections where the NDE readings were undertaken.

The salient feature of most of the various NDE systems assessed to date, is that that they focus on determination of the section geometry at the ground line – which is generally deemed to be the critical section. In other words, the principal correlation parameter for the NDE "measurement" is the geometric properties of the pole at a particular location - usually the section modulus "Z".

A few systems actually focus on prediction of the bending capacity, but none actually measure it directly – since to do this, one would have to break the pole!

The NDE technologies currently under investigation can be broadly categorised into two groups –

1. those which determine the physical geometry / section properties of the pole at ground line
2. those which, in addition to (1), also are able to indicate one or more of: wood density, stiffness, hardness of fibre strength

Thus the principal “yard-stick” and calibration parameter for assessing the efficacy of most of the NDE systems used in this project, is an accurate determination of the section modulus at critical sections, where the NDE readings are being taken. For the few systems where prediction of pole strength is the principal parameter, actual bending strength and / or stiffness at the ground line (determined from full scale destructive testing) has been used as the assessment "yard stick".

A total of 20 devices collected data on the project test population over a 5 month period. Eight of these are being, of have in the past been used on poles or piles. The rest are prototypes in development.

This evaluation project has been recently completed [8], and the results confirm that imaging technologies represent a significant improvement over current methods for determination of the section modulus. Several of the NDE technologies produce an “image” of the physical dimensions of the section, and also provide information about the relative density of the wood, which could be an accurate indicator of the presence and extent of decay. These technologies have the potential to predict the strength of the pole using correlations with density and or stiffness – although considerable development work is necessary to establish reliable strength predictive methods. This work will continue in the near future.

3. Design Innovation - Education and Application

Numerous examples of innovative design have been constructed in Australia and New Zealand over the past 15 years, ranging from simple dwellings to large assembly buildings, such as the “dome” at the Sydney Olympic site. Two areas of design which are currently developing and giving expression to timber engineered structures, are Education - integrating the design process between Architects and Engineers and Application - using highly reliable engineered products such as LVL large spanning industrial buildings, where steel is traditionally used.

3.1 Education - The “Duality Project”

Over the last six years the Departments of Architecture and Engineering, the University of Queensland, have developed an Inter Disciplinary Fourth Year design course to foster integrated working methods and innovative building design. This course has a focus on environmental issues and includes an emphasis on the use of timber materials. The course is supported by industry partners, which include the Plywood Association of Australia and the Timber Research and Development Advisory Council of Queensland. One outcome from the course is the development of a **Duality Databas**e. It is named the Duality Database after the work of Sandaker and Eggen in their book the “Structural Basis of Architecture.” They suggested that the structural basis of architecture lies in the resolution of the two dualistic sets of parameters, the technical and the aesthetic.

The database therefore seeks to explore the tectonic armatures used in exemplary buildings, through images, simulation of structural behaviour and video. In particular, it critically assesses the sets of concepts used in the engineering and architecture. By articulating these concepts it has been found that the database assists with cross-disciple communication, extends creativity amongst architects and inventiveness in engineers. More over it exemplified a method of working in practice, which seeks to unite the two professions and extends their design skills.

The database as it is presently structured as an archive of case studies with an emphasis on the synthesis between architecture and engineering. It contains case studies of a range of buildings and student projects developed during the combined architecture and engineering interdisciplinary course. These have a particular material focus and include further case studies of the canons of timber design. These are exemplary buildings and structures where timber is used in a creative and innovative manner in resolving the duality problem. These are analyses using the critical framework established in the Database.

The development of the Timber Module of the Database in this way will provide information to a wider audience and have greater relevance in the design professions. More important it will foster innovative timber design and design practice. As the system has evolved, it was found that the buildings reflected a range of issues that needed investigation to fully understand the concepts involved. The students therefore became less content with just documentation and more interested in examining these related issues. Thus the database, whilst retaining its original structure, has evolved as a flexible system for providing issues and information that are generated out of the building case study. For example, in one case study a simple elegant timber structure raises a number of issues concerned with sustainability and recycling of buildings. The technical detailing that facilitates the kind of demountability needed for recycling developed and the relevance of timber for Environmentally Sustainable Design is higlighted. The inclusion of this kind of information and direction provided an area of potential further investigation and greater depth to the information about the building [10].

3.2 Application - Large Industrial Buildings built from LVL

The design of the building housing a new LVL manufacturing facility for Carter Holt Harvey at Marsden Point in the north of New Zealand’s North Island, represents a significant milestone for large scale industrial buildings. Covering in excess of 2 hectare, the unique feature of this large building is that the structural frame is fabricated primarily from laminated veneer lumber, LVL. The Main Building for the first stage of the development is rectangular in plan, 96 metres wide by 209 metres long and will house the assembly, pressing, finishing and despatch functions of LVL manufacture.

A further stage of the development will add another building for veneer peeling and drying at the southern end of the Main Building. This addition, already designed as an LVL structure, will cover another 0.6 hectare.

figure 1 - aerial view of the Marsden Park Building

At the northern end of the Main Building a 21 metre span gantry is required to traverse almost the full width of the building. The roof is a 3-degree pitch gable shape. At the southern end the roof rises from an eaves height of 7.7 m on both the eastern and western sides to a central ridge. In order to provide additional height over the press, the ridge line for 11 of the 19 bays at the northern end is offset to the east of centre to create a step in the roof on the eastern side. For this part of the building the eastern wall eaves height is 9.9 m.

Rafters extend across the 96 m width and are supported at four points over three 32 m spans. The outer columns are rigidly connected to the rafters to form portal frames; internal supports merely prop the rafters. Rafter or bay spacing along the 209 m length is a uniform 11 m.

Rafters are 1200 mm or 1265 mm deep fabricated LVL I-sections. Outer column sections are similar but are tapered to 800 mm depth at their base. I-sections were chosen for material efficiency, speed and ease of fabrication, simplicity of splice detail and for shipping efficiency.

Rafters are each spliced at 6 locations with the longest segment being 16.2 m long, including the projecting splice elements. Splices are arranged to correspond to points where the moment actions under the various load combinations are low and are less than the moment capacity of either the webs or flanges of the I-section acting alone.

Internal supports for the rafters are mostly prop columns made up of four pieces of 300 x 45 LVL fabricated into box sections. Elsewhere, where column free areas are required, rectangular “lintel” frames, orientated in the longitudinal direction and spanning over two bays support rafters. Large 1200 mm deep LVL box section beams rigidly connected to 900 mm deep box columns were used in order to keep the deflection profile of the supported rafter as close as possible to that of the adjacent rafters.

Longitudinal forces on the building are transferred via two sets of bracing, each comprised of roof bracing and vertical plane bracing in the outer longitudinal walls and along the internal column lines. Braces are fabricated LVL sections connected with dowel jointed steel fin plates and bolted brackets. This high capacity connection system was developed in conjunction with the University of Technology, Sydney (UTS) specifically for buildings such as this.

3.3 Design approach

The basic principle for economical design of buildings of this type is repetition and integration of the design, fabrication and erection processes. The acceptance by the mechanical engineers responsible for the plant layout of a rectangular plan and a uniform grid for the column layout provided an excellent basis for the implementation of repetitive / standardised details. This repetition not only reduces the set-up time for manufacture of each component, but also reduces costs through faster assembly and reduction of error.

Another factor that can be critical to cost, particularly for portal frame buildings, is building height. Obviously clearance heights inside must meet the reasonably anticipated functional requirements. For this building the clearance height in the localized area of the press is significantly greater than for any other requirement and this was provided for by offsetting the ridge for part of the building. Another consideration affecting height was the intersection of the Main Building with the future Stage 1B addition. The higher clearance requirements for the Stage 1B building meant that its side wall height would be sufficient to contain the gable end of the Main Building provided the ridge height was kept to the minimum.

3.4 Decision to use an LVL structure

The decision to go with an LVL may seem ‘automatic’ given the company is Carter Holt Harvey and the building is to house an LVL manufacturing plant. It is interesting to note however, that there are many LVL plants around the world and with the exception of the CHH South Australian plant, very few of these are housed in structures built from this obviously well credentialled material. We can all postulate on the reasons why other companies involved in the manufacture of LVL have lacked the conviction in their own material and allowed steel to be used [9].

The following factors, which will be relevant to any decision to use an LVL system for a large span building, have been demonstrated in the success of this project:

- The structural reliability of LVL has been amply demonstrated with many large span buildings constructed in Australasia during the last 14 years.
- The availability of a fully prefabricated system.
- Cost competitiveness with alternative materials especially given the ready availability of wide bay spacings and reduced numbers of internal columns.
- Speed of construction.

Connection systems for large spanning buildings such as this are also being developed, focusing on the use of nail plate reinforced dowel or bolt connections [11]. The first stage of this collaborative R&D (between Timberbuilt P/L and UTS) has been completed and the results confirm that significant performance increases will be possible using this system [12].

For a design team experienced in timber engineering, the design of this building using LVL is little different than the design of a steel building would be to engineers similarly experienced in steel design. However for design with LVL the solutions are not as established and their creation is both challenging and satisfying and the Timberbuilt team who created this building have set a new milestone for Timber Engineering in Australia and New Zealand.

4. Durability Design

In the early 1990's the need to advance durability design was identified as a high priority for the timber industry and the concept of considering that durability design could be undertaken in a similar manner to structural design, was proposed. The challenge was taken up to develop a rational approach to durability design [13] using a reliability-based procedure to determine residual strength and stiffness of members subjected to decay, termites and physical degradation.

4.1 Background to Project

Early in 1994, the National Market Development Committee (NMDC) identified durability design as one of the major impediments to future timber use and utilization in Australia. A draft research and development proposal was subsequently developed by the Technical Advisory Group (TAG) for NMDC's consideration. It was based largely on earlier recommendations [13] with the thrust being to base durability design on reliability (probabilistic) principles as distinct from the existing prescriptive or deterministic methods which are rapidly becoming obsolete with respect to building regulations and user expectations and needs.

In 1994, three separate durability research proposals were developed and submitted to the Forest and Wood Products Research Development Corporation (FWPRDC) for funding. These submissions, which were unsuccessful, provided the impetus to develop an integrated reliability-based durability design research proposal for submission to the FWPRDC.

A two day workshop (with researchers, industry, regulators and end users) was held in July 1995 to review and refine the proposal. This workshop was principally funded by the FWPRDC. The NMDC subsequently endorsed the proposal and upon successful submission to the FWPRDC the Research Agreement was signed by all parties around December 1995. Stage 1 of the two-Stage project was completed in September 1999.

4.2 Objectives

The primary objective of this project is to improve the confidence of **timber users** in the durability performance of timber and timber structures by increasing the durability knowledge base and developing a reliability-based design method.

The specific objectives of the whole project are:

1) To review, develop and publish consensus protocols for durability and corrosion assessment.
2) To measure or rate the resistance of timber to these hazards.
3) To quantify the levels of hazard (risk) associated with fungi, termites and corrosion of connectors in timber throughout Australia.
4) To develop, validate and calibrate a reliability (i.e. probabilistic) based durability design method for timber and timber products that encompass the main environmental agents and material resistance.
5) To develop a user friendly computer aided design software package that is based upon the design procedures developed.
6) To have Codes, Standards, Regulatory Bodies and major users adopt the new durability design procedure.

To achieve these objectives, two interrelated stages were originally envisaged to encompass a time frame of 6 to 8 years. Objectives (1) to (4) encompass **Stage 1**, which was primarily involved with durability data collection, establishment of testing and assessment protocols and preliminary model development. **Stage 2** is a continuation of the current project and will bring to conclusion the development of a durability design method [objectives (4) to (5)]. Under Stage 2, tasks will include refinement and validation of the durability design method, design software and design code or manual development and continued implementation and adoption of the design procedures.

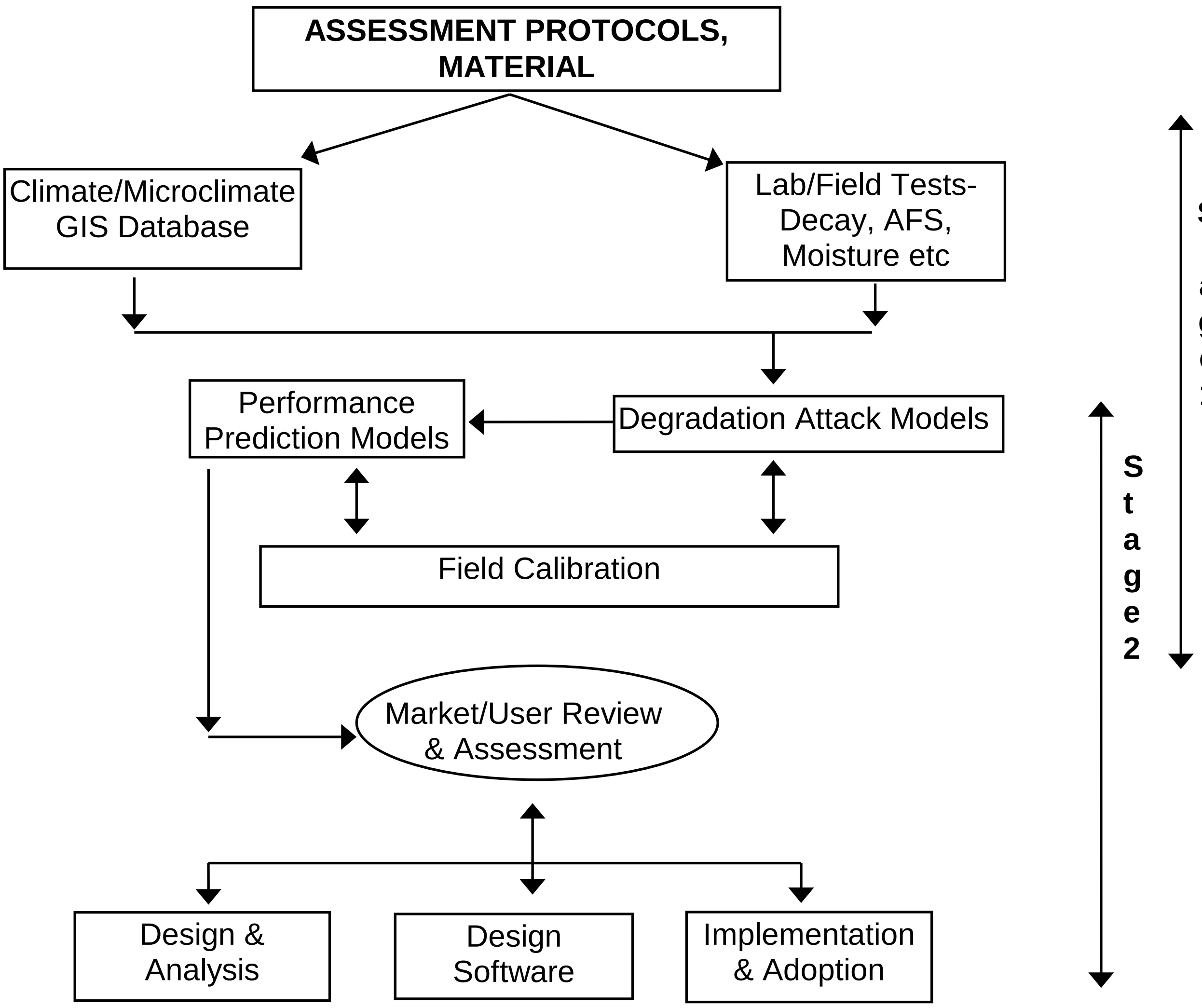

figure 2 Overview of Durability Design Project

4.3 General Achievements and Outcomes - STAGE 1

Predictive Models:
Preliminary predictive models have been developed for the following:-

- moisture movement in soils and in timber in and above-ground
- estimating micro-climatic conditions
- termite attack to buildings
- corrosion rates for various connectors
- decay rates in timber for in and above-ground

Quantification of Hazards:
The following research and associated activities have been completed:-

- Over 5000 households have been surveyed to determine termite potential including the relationships between materials of construction, construction type and age of dwelling
- Above-ground decay hazard and durability is being determined at 11 primary and 16 secondary sites across Australia
- In-ground decay hazard and durability has been determined for 5 primary and 22 secondary sites across Australia
- Joint degradation hazard and Indices are being developed
- A GIS Macro-climate data base has been established
- A Micro-climate data base from over 30 monitored houses from Cairns to Narranderra to Adelaide has been established.

Material Resistance (protocols):
Protocols and assessment procedures have been developed for the following:-

- Termites - Accelerated Field Simulator (AFS) techniques have been developed for in and above-ground resistance of untreated timber. Additional procedures for treated timber are proposed for Stage 2.
- Decay in and above-ground for treated and untreated timber
- Corrosion. Accelerated laboratory and chamber tests for equilibrium moisture content, moisture content, salt, mass loss. These include field verification of laboratory procedures.

Material Resistance:
The following has been achieved:-

- In-ground decay and termite resistance research has been maintained or established including historical sites/tests and new treated and untreated experiments.
- Existing and new above-ground decay experiments have been established including Australian Wood Preservation Committee (AWPC) above-ground decking trials
- Corrosion/Moisture. Field and laboratory research for a range of connectors for both treated and untreated timber and glued products has been conducted.

4.4 Future Developments

Stage 1 of the Project has achieved a very satisfactory level of results with respect to the overall project objectives within budget and almost on time. Results and data generated from Stage 1 are now being adopted, providing benefit to industry via code and regulation changes. The Project has gained International peer recognition and collaborative research with overseas institutions is now being pursued.

The level of research risk to achieve the Projects objectives has reduced significantly over the conduct of Stage 1. Given continued financial support, Stage 2 of the Project can be completed by mid 2002 which will then enable implementation and adoption, and will place the timber industry at the forefront of durability design.

5. Conclusions

The last 20 years has seen an enormous amount of research and development activity, linked with innovative applications to establish Timber Engineering as a vibrant design theme in Australia and New Zealand. Despite limited resources, significant achievements have been accomplished which have not only established a sound foundation for timber design in these two countries, but have also contributed to “state of the art” in the international scene. We look forward to this continuing in the future.

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- Dr Bob Leicester (CSIRO) - Durability Project

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