Development of Durability Verification and Service Life Tools for New Zealand

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Abstract

Materials and construction methods continue to evolve and the empirical knowledge derived from traditional building practice is often insufficient for predicting durability problems with emerging materials and construction techniques. Consequently the capability for robust durability assessment of new products and techniques is an essential platform for supporting an innovative, dynamic building industry.

The New Zealand Building Code (NZBC) is primarily performance-based with prescriptive solutions available for only a limited number of materials. For other materials, the Durability clause within the Code offers only the advice that suitable durability performance may be demonstrated through either laboratory testing, a documented history of use, or by analogy with the behaviour of similar building components.

Therefore, BRANZ has developed a Durability Verification framework for assessing building materials, components and systems under the NZBC. The framework systemises existing durability knowledge and verification methods, identifying critical knowledge gaps to guide future research, and provides useful durability information in a convenient manner to a wide range of potential users. This Durability Verification framework has subsequently been extended to include a Residual Service Life Assessment Tool for New Zealand, a broadly-applicable tool guiding the day-to-day decisions of building industry practitioners concerning residual service life of buildings and building elements.

Ultimately, the fully developed tool will generate an explicit mapping of the behaviour of the materials commonly used in New Zealand's buildings. The mapping will define potential durability and compatibility issues that are known to arise, and provide alerts to gaps in knowledge concerning durability performance and required maintenance. This will enable the designer/builder to be aware of cases where provision of specific guidance is necessary and also allow the New Zealand building and construction sector to acquire the appropriate knowledge, tools and confidence to produce durable buildings that meet or exceed their owner's expectations of performance.

Keywords: Materials Performance, Durability, Service Life, Building Resilience

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1. Introduction

Research into materials performance and a strong demand for robust durability research and information have consistently rated as areas of high industry need across the world. The New Zealand Industry Needs Survey, carried out annually by BRANZ, consistently places Materials Performance at the top of the list of priority topics, for both short and long term research. Materials performance and durability is also currently a key strategy topic within New Zealand's Research Strategy for the Building and Construction Sector.

Functional and durable construction is essential both for the health and well-being of owners and occupiers and the credibility of the industry. Consequently, the consideration of materials performance is critical over the entire building life-cycle, from initial construction to in-service maintenance, and finally renovation, alteration or retrofitting. Furthermore, while operation normally accounts for the largest proportion of environmental costs over the life-cycle of a building, the intrinsic service life of the structure lies at the core of the concept of sustainable construction. Until durability performance can be predicted accurately, the feasibility of assessing the sustainability merits of alternative construction styles at the design stage remains doubtful.

1.1 New Zealand Building Code (NZBC) Durability

Ensuring that buildings have an appropriate durability has always been an important aspect of building regulations. This is emphasised by the current NZBC, which includes the functional requirement that: "*Building materials, components and construction methods shall be sufficiently durable to ensure that the building, without reconstruction or major renovation, satisfies the other functional requirements of this code throughout the life of the building*".

The NZBC is a performance-based rather than prescriptive code, intended to permit innovative solutions and minimise the constraints placed on building design or choice of materials and techniques, providing the mandated minimum performance levels are achieved. The Code's B2 Durability clause is the single exception to this philosophy, setting default lifetimes for building elements depending on their criticality of function and ease of replacement (Table 1). These durability provisions apply to any part of the building which is fulfilling another Code requirement (e.g. structural stability or fire performance) but do not extend to aesthetic considerations. It should be noted that the mandated service life allows for routine maintenance, but not reconstruction or major renovation and building elements shall not be required to satisfy a durability performance which exceeds the specified intended life of the building.

The reason for retaining this prescriptive aspect in an otherwise performance-based code is essentially one of consumer protection: it was considered inappropriate to allow the service life of buildings to be effectively set by market forces, particularly given that a significant proportion of owners would have little expertise in evaluating the relative benefit of construction styles and materials. Note that despite this prescription, the choice of materials for producing building elements of the required durability is left unregulated

Table 1: A summary of the performance requirements for building elements specified by the NZBC B2 Durability clause

Nature of Building Element	Durability Requirement	Typical Examples
(i) Does the building element provide structural stability to the building? (ii) or (iii) Is the building element difficult to access or replace? (iv) or (v) Would failure of the building element go undetected in both normal use and maintenance of the building?	50 years	• Load-bearing walls • Electrical wiring buried in or under concrete slabs • Building underlays behind masonry veneer walls
(vi) Is the building element moderately difficult to access or replace? (vii) or (viii) Would failure of the building element go undetected during normal use of the building but be easily detected during normal maintenance?	(ix) 15 years	(x) Non-structural building envelope cladding (xi) Visible flashings that do not require the removal of the cladding to be replaced
(xii) Is the building element easy to access AND replace AND would failure of the building element be easily detected is 5 years during normal use of the building?	5 years	• External gutters and downpipes • Renewable protective coatings

1.2 Perceived Barriers to NZBC Compliance

Specifying durability in terms of building element service life has a number of drawbacks. These include the issues of perception involved in judging difficulty of replacement and the potential mismatch between Code requirements and the expectation of owners who, for example, are often surprised to discover the roof of their house only needs to last 15 years. Some of the most telling criticism of this approach notes that it may only be truly practical where the building element in question is essentially inaccessible, so that service life is independent of maintenance, and the rate of deterioration under the in-service environment is known. Otherwise, building designers, certifiers and owners assume a significant burden in determining and documenting material and component service life in various environments, based on an assumed level of maintenance. Often the information necessary to do this rigorously is not readily available.

This contention is supported by a previous BRANZ survey of the construction industry on the issue of durability and the B2 clause in particular. Survey respondents across all sectors of the industry cited that a lack of reliable information was a primary barrier to the achievement of durability design (Figure 1).

The absence of reliable information is not unsurprising, given that the same respondents identified ‘trade literature’, ‘industry information’ and ‘past experience’ as the most important sources of information concerning the durability of building materials. It is also notable that the industry places a good deal of reliance on fitness-for-purpose systems appraisals similar to the European Agrément system, but has not yet adopted formal declarations of reference service life, such as those outlined within the ISO 15686 Service Life Planning suite of Standards.

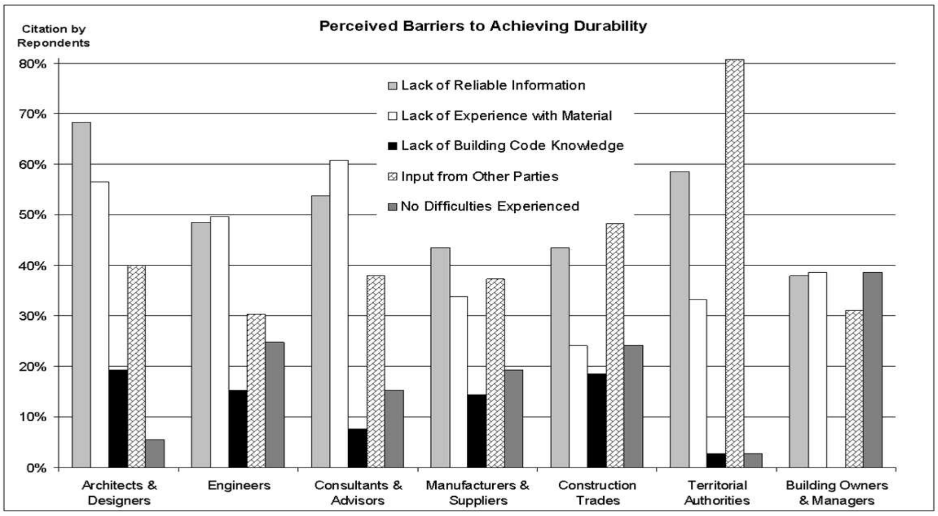

Figure 1: Perceived barriers to achieving the NZBC durability requirements, as identified by surveying the New Zealand construction industry.

Part of this difficulty arises because, despite the unquestioned importance of the subject, there is no broadly applicable methodology available to verify that building materials, components and construction methods will meet the performance requirements of the NZBC B2 Durability clause. Manufacturers and, especially, the statutory bodies responsible for certifying buildings as compliant with the Code, frequently wish to rapidly assess the expected service life of a new material, or even a conventional one in a new environment. The absence of a list of specific test methods that will generate a 5, 15 or 50 year durability rating consequently requires addressing.

For a restricted range of building materials and techniques, the NZBC incorporates the concept of ‘Acceptable Solutions’; prescriptive construction methodologies that, followed to the letter, will ensure Code compliance. Acceptable Solutions primarily exist for time-honoured construction methods (e.g. timber-framed or concrete construction, earth buildings) that draw on a background of many years’ actual service history and development under New Zealand conditions. Even where an Acceptable Solution ordinarily covers durability compliance, the situation becomes complex when new materials with uncertain capability and interactions are introduced.

In cases where an explicit durability evaluation is required, the NZBC documents an approved verification methodology, known as B2/VM1. Unfortunately B2/VM1 offers only the generic guidance that proof of performance should be demonstrated by in-service history, laboratory testing, or analogy with similar products/situations. However, for most building materials this is an over-simplification of the processes required and collating and evaluating this information in a reliable and appropriate fashion can often be complex. Examples of the need for expert judgement include: considering whether the degradation methods in accelerated tests (heat, moisture cycling, freeze-thaw, UV exposure etc) are appropriately matched to real-world causes of deterioration; assigning quantitative service life predictions on the basis of qualitative rankings of observed durability; and assessing likely variation in performance due the different macro- and micro-climates, materials interactions, intensity of use and maintenance that come with a specific instance of use on a particular building.

The provision of additional information was determined to be a logical next step to addressing these difficulties and removing the barriers to durability design. Although the ISO 15686 Standards provide valuable guidance and a uniform approach to the assessment of durability, they do not provide details on the durability of specific materials, or even prescriptive methodologies for the determination of durability. Consequently, to solve the practical and immediate challenges faced by the New Zealand construction industry, there is a demand for more specific guidance documents that will take into account the properties of construction materials, their potential uses, and their performance in the environments within which they are likely to be used. The BRANZ Durability & Residual Service Life Assessment tools are a response to this need.

2. BRANZ Durability & Residual Service Life Assessments

2.1 Durability Assessment Tool

The Durability Assessment Tool is an initiative to improve the breadth, completeness and cogency of durability information available to the local industry. In essence, it involves the compilation of a database of authoritative and independent durability and compatibility information that covers the building components and materials commonly used in residential construction in New Zealand. The database includes summaries of existing Acceptable Solutions for NZBC B2 for building elements and materials that may comply with publications referenced in NZBC Approved Documents. The delivered tool is intended to be helpful to people with a wide range of knowledge and experience and not to replace the existing Approved Documents as the means of code compliance. Envisaged users include designers, statutory bodies, manufacturers and wholesalers, in addition to building science researchers.

The Durability Assessment Tool is explicitly expected to provide the following benefits:

- A catalogue of existing durability information, including précis of, and references to, current Acceptable Solutions.
- A resource for the development of compliance methods for novel building materials and a means of exposing these ideas to the wider industry for critique.
- An explicit mapping of gaps in durability knowledge for current building materials and environments of use, serving to focus the direction of future research.
- A potential method to demonstrate the compliance of a building with the B2 Durability clause of the NZBC.

The individual entries are organised in the database according to the CBI (Coordinated Building Information classification, typically a four digit code that provides a unique logical slot for identifying each component used in building and construction. The classification system, which is based on the European CAWS (Common Arrangement of Work Sections) system, co-ordinates the five main information sources: drawings; specifications; quantities; technical and research information; trade information and publications.

The Durability Assessment or Verification Database entries are organised under a uniform set of logical topic headings covering the code compliance, verification and underlying science aspects of building materials durability (Table 2). The purpose being to provide a division between the normative and informative material, i.e. code compliance advice, and provides a simplified structure that can be easily modified in case of changes to mandated durable life.

Table 2: Simplified overview of the Durability Assessment Database

Description	General description of the building component or material and its history of use.
B2 Requirement	The current New Zealand Building Code (NZBC) durability requirements for the chosen component.
Acceptable Solution	A summary of B2/AS1 – identifies any current Acceptable Solution contained within an Approved Document to the NZBC, by virtue of which complying building materials and components can be shown to satisfy NZBC performance criteria. These are typically restricted to traditional materials and conventional construction practice and are prescriptive in nature.
Durability	Typically consider what aggressive agents act on selected component and degradation mechanisms by which it may fail.
Compatibility	Potential incompatibilities with other building materials, or environments and applications where it is unsuitable
Unknowns	Summarises any outstanding durability questions and research needs related to the selected component.
References	Provides references to external content, e.g. related BRANZ publications, recognised test standards and scientific literature.

2.2 Residual Service Life Tool

Practitioners, especially Building Officials, Builders and their trainers, require reliable information on in-service materials, and methods by which their remaining lives can be determined. Similarly, building research organisations require a consistent framework to assess materials in-service.

The ISO Standard 15686 defines Service Life as the *period of time after installation during which a building or its parts meets or exceeds the performance requirements* and Residual Service Life has been defined as the *service life remaining at certain period of consideration*. Hence, a residual service life (RSL) prediction for a building is an estimation of the remaining period of time during which the building or its parts will meet or exceed the performance requirements at any given point in time. Examination of the literature suggests that models for estimating Residual Service Life fall into two broad approaches:

- Models based on assessing the degradation of building elements (e.g. EPIQR & Medic);

- Models based on assessing loss of functional capability (particularly the ISO 15686 suite of standards

The ISO 15686 factor method is widely-accepted and has considerable momentum in Europe. This provides a deterministic approach to service life prediction, based on declaration of a reference life for a particular building component under a carefully prescribed set of conditions, plus a series of factors, such as simple multiplicative modifiers, that permit estimation of service lives for the same component under other conditions. The factors account for variations in indoor and outdoor climate, workmanship, maintenance, design execution and in-service loading. However, accurate quantification of the factors requires considerable expertise and experience and, despite the simple approach, considerable thought and work is necessary to derive conclusions from this approach. It is not necessarily well-suited to application by end-users.

The EPIQR tool was developed from collaboration between various European-based research organisations including BRE, CSTB and assesses the state of degradation of the building. The MEDIC tool is used with EPIQR and uses probabilistic calculations to calculate the remaining lifespan of building elements. The EPIQR/MEDIC type models answer typical questions on how to improve specific buildings, necessitating knowledge of past and future building states. These are typically expressed as probabilities of building elements transitioning from one condition to another in a given environment. Often complex models are adopted to provide a sound mathematical basis for the manipulation of transition matrices describing these probabilities. This approach implies reasonably extensive and sophisticated databases and periodic re- inspection; most of the existing tools have been in Europe and North America and would require adaption to local conditions and associated verification.

A Centre Scientifique et Technique du Batiment (CSTB) initiative called EVA, the *Reference Service Life Evaluation Platform*, aims to provide a central database of the service life of building materials and components. EVA is an online implementation of the factor method from ISO 15686 Part 8 *Reference Service Life and Service-Life Estimation*. The database, with an interim English version is intended to serve as a bridge between users, who need the estimated service life data, and the durability specialists providing the reference service life declarations.

The BRANZ Residual Service Life tool is an initiative to develop a broadly-applicable tool guiding the day-to-day decisions of building industry practitioners concerning residual service life of buildings and building elements. Buildings deteriorate with age and old designs may not match well with modern functional requirements. Consequently, cost-effective practices need to be developed for considering maintenance and refurbishment strategies. Understanding the Residual Service Life of existing building elements & components is an essential facet of evaluating said strategies.

The Residual Service Life assessment tool development or FutureFit (Figure 2) involves a simple deterministic estimate involving visual correlation of the condition of a component, or its defects, with an atlas of case study photographs. Although there are only a limited number of cases where degradation correlates with differentiated visual signs of distress in a predictable time sequence, the tool intends to provide useful and specific information to the end-user for a number of key building components. The approach be taken could also facilitate the identification of common defects or material degradation mechanisms by less experienced practitioners.

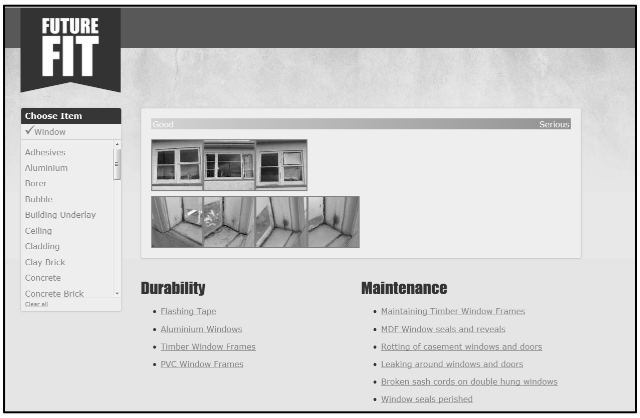

Figure 2: Residual Service Life Tool – FutureFit

Ultimately, the Residual Service Life Tool is expected to provide the following benefits:

- Documentation of methods for assessing residual service life.

- A web-accessible tool for determining residual service life comprising assessment methodologies and photographic illustrations, which may also be downloaded or accessed on handheld devices

- A catalogue of existing residual service life information, including précis of, and references to, current New Zealand Building Code Acceptable Solutions;

- Condition assessments to be carried out on site allowing Auditors to use photographs from the site to compare with condition scales in the office;

- Condition scales for commonly encountered components established and expanded as and when new components were encountered. Differing components constructed of the same material should follow similar patterns for given conditions;

- An explicit mapping of gaps in residual service life knowledge for current building materials and environments of use, serving to focus the direction of future research.

On a broader theme, the intention is to provide the industry with the appropriate knowledge, tools and confidence to reliably identify defects and make sensible decisions on the retention or replacement of building components and materials.

Initials trials of the Durability Verification and Service Life Tools have been carried out within the BRANZ House Condition Survey (HCS), a systematic survey of the structure, type and condition of dwellings within New Zealand. The photographic database (for example Figure 3) was correlated with a five point rating scale and used as the basis for the inspector to provide a condition rating for each component inspected (Table 3).

Table 3: BRANZ House Condition Survey Rating Scale

CONDITION	*Description*			*Rating*
SERIOUS	Health & safety implications, needs immediate attention.			***1***
POOR	Needs attentions shortly - within the next three months			***2***
MODERATE	Will need attention within the next two years			***3***
GOOD	Very few defects - near new condition			***4***
EXCELLENT	No defects - as new condition			***5***
Frequency of defect	***0-10%***	***10-25%***	***25-50%***	***50-100%***

Rating 4

Rating 1

Figure 3: Examples of Weatherboard Condition Rating

The results have assisted in providing an overall picture of the condition of housing in New Zealand, outlining the type and frequency of major defects within residential properties (Figure 4). It is envisaged that further development will enable more robust maintenance regimes to be developed to increase the overall lifetime of the country's housing stock.

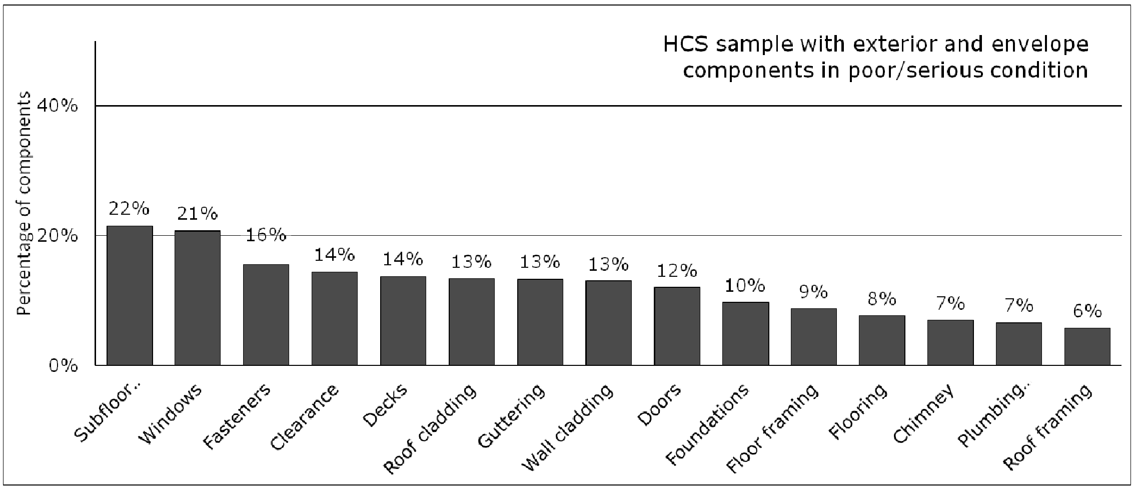

Figure 4: Exterior and building envelope components in poor or serious condition.

3. Discussion and Future Work

3.1 Durability Assessment & Residual Service Life Tool Development

Linkages between the Durability Assessment or Verification Database and the Residual Service Life tool are currently being developed to provide a more robust durability assessment framework for the industry. Initial positive feedback and participation from stakeholders in this research confirm that it is a practical approach to document the progress of some material failures to allow both early identification of defects and to offer insight into material degradation with time. It was also noted that practitioners sometimes need assistance in identifying building materials, particularly when looking at older or discontinued products and the tool offers a route to access experts' knowledge of material failures. However, a number of technical risks have been identified in adopting this approach, which require further work to optimise the database and are currently being investigated.

- Visual appearance may not be diagnostic of the cause of component / element distress;

- Only a limited number of cases exist where degradation correlates with differentiated visual signs of distress in a predictable time sequence;

- The history of a component, such as environmental exposure, workmanship, maintenance, design execution, and in-service loading, cannot be accounted for in estimation of remaining life despite their critical nature;

- Calibration of probability / time for transition of component from one condition state to the next can be uncertain and component dependent;

- The approach may have the potential to focus attention on individual components at the expense of a holistic approach that considers durability of assemblages;

- Misplaced confidence in guidance provided by the tool may discourage more thorough investigation and testing.

3.2 Building Resilience

Although considerable research has been carried out into the resilience of buildings, materials and components by both BRANZ and overseas researchers, there are still substantial gaps in knowledge and information available. Such areas include how these factors are influenced by extreme weather events, how buildings can be made more resilient and how maintenance can extend the service life of materials and the buildings.

Over the last decade New Zealand has experienced a number of extreme weather events, which have been a significant cost to the industry, home-owners, councils, government and the insurance industry. Prior to the Canterbury earthquakes in 2010-2011, 94% of adverse event building insurance claims were for storms, severe floods, snow and landslides. Despite being built in areas of risk, New Zealand's housing stock has limited resilience, which is further compromised by poor maintenance and repair of our existing buildings as shown in BRANZ House Condition Surveys. Research and insurance data indicate that increased costs and building damages have resulted from extreme weather events, this puts the existing stock even further at risk and there is a strong need for our buildings to be made more resilient to such events.

The next stage of the Durability Assessment & Residual Service Life Tool development project will contribute to the development of assessment methodologies to evaluate the resilience of products, materials and buildings that are subjected to extreme weather events. The project will involve a robust investigation into the resilience of buildings and structures, taking into consideration the material and building characteristics, property characteristics, external elements, geographical location and hazards / combination of hazards. The research will build on the knowledge and information gained through the Durability Assessment and Residual Service Life tool development.

4. Conclusions

New Zealand has had a mandatory requirement for durability in its national Building Code since 1992. In theory, this should have stimulated industry awareness of the issues behind achieving appropriate service life of building materials and have fostered an active interest in the development of standards and methodologies that could facilitate good durability design.

In practice, the transition from prescriptive to performance-based solutions has not been without its difficulties and the potential innovative and economic benefits have yet to be fully realised. New Zealand is a small country and there are few independent organisations with the technical resources and breadth of expertise to carry out rigorous assessments of materials durability. This is particularly evident when new, or composite, building systems are introduced to the market.

While based on sound scientific and engineering principles, durability assessment remains as much art as science. This should change as the adoption of uniform assessment philosophies facilitates reliability-based service life prediction techniques. However, from a pragmatic perspective it is still essential that researchers, manufacturers and standards bodies continue to develop and refine predictive test methods for individual materials and their applications. It is hoped that the Durability Assessment Tool will prove a compelling initiative to collect these methods in a convenient and user-friendly form, spread them through the construction industry and stimulate the development of new ideas and techniques Similarly, the adoption of assessing building elements / components guided by the Residual Service Life tool has the potential to assist in determining durability information and predicting service life of these components.

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