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The Application of Life Cycle Costing for Building Retrofit

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ABSTRACT
This paper examines the feasibility of applying the life cycle costing (LCC) technique to the building retrofitting for earthquake protection and the best mechanism for doing this. Particularly to decide on whether earthquake prone buildings should be retrofitted (strengthened) or demolished. In New Zealand, buildings must comply with earthquake codes. These codes were adopted in the 1970’s and have been used as a basis for determining the strength for buildings to withstand an earthquake. Buildings built prior to the earthquake codes do not conform to these codes making them more vulnerable to damage and destruction during an earthquake. Decisions about the future use of these buildings are currently being made. An important part of this decision is the comparative cost of different retrofitting solutions versus demolition. Life cycle costing is a valuable technique for assisting with making this decision. In this paper, the usefulness of life cycle costing for assisting with the demolition/retrofit decision is demonstrated. The key factors of using LCC for building retrofit is explained and assessed. The results of this paper will aid building decisions in the local environment and the international community by adding cost appreciation to decisions about vulnerable earthquake prone buildings.

KEYWORDS
Life Cycle Costing, Retrofit.

1 INTRODUCTION
This paper discusses and examines the application of life cycle costing in retrofitting earthquake vulnerable buildings in New Zealand. Life cycle costing can aid decisions when clients, property owners and others need to develop strategies for dealing with such vulnerable buildings. A building
owner may need to weigh up various options such as not retrofit, retrofit with different solutions or demolish and rebuild. Increasingly, and especially in New Zealand, not retrofitting is no longer an option. Therefore, costs of various systems against demolish and rebuild strategies becomes an important factor. This paper also assesses the key factors while applying life cycle costing for building retrofit.

2 BACKGROUND

New Zealand is at risk from earthquakes. This means that buildings need to be designed and built to withstand earthquakes. In order to minimize earthquake losses, the government has introduced earthquake legislation. The overarching legislation is the Building Act (2004). This act sets out provisions for earthquake prone buildings and policy guidance for buildings not meeting the required standard.

Recent legislation in New Zealand (Department of Building and Housing 2004) regarding earthquake prone buildings may be summarized as follows:

(a) New buildings and extensions to new buildings must be designed to current code - which embodies best available practice.

(b) Existing buildings including unreinforced concrete or unreinforced masonry (i.e. brick buildings) are required, through the Building Act (2004), to be strengthened as near as practicable to current code standards.

The responsibility of assessing earthquake prone buildings in a region is that of the territorial authorities. The Building Act (2004) requires these authorities to assess buildings and make recommendations on what needs to be done to the building to make it safe, including having powers to require demolition of a building. A suggested approach to this assessment (Earthquake Prone Building Provisions, 2004) is for territorial authorities to develop a profile of likely earthquake prone buildings in their region, first through an initial desk study, then through an initial evaluation of performance. The territorial authority will then require an owner to seek a detailed assessment on those buildings that the initial assessment indicates may be earthquake prone. If earthquake prone, buildings will require remedial work, owners will have to make decisions between various options. In order to make these decisions, the territorial authority needs to consider the costs of the building changes with property owners. The overall purpose of these requirements is to identify non-residential buildings which are seriously at risk (Hopkins 2005). The extent of the problem will only be known once each building is examined. A building could be classified as sufficiently unsafe in an earthquake to require attention. Buildings not meeting a certain threshold would be required to be strengthened, not to full code compliance, but to a level that is as near as is reasonably practicable under the circumstances, possibly to at least two thirds of current code. Once identified to be in need of reducing or removing earthquake risk, decisions will have to be made for the building
on the strengthening technique to be adopted, given the relative cost of the different options.

There are many methods and techniques available to assist in making economical decisions in the construction industry. However, different methods have their own advantages and disadvantages, as well as various application ways. A suitable analytical method is therefore essential for a wise retrofit solution.

3 LIFE CYCLE COSTING

In the building industry, it has long been recognized that to evaluate the costs of buildings on the basis of the initial capital costs alone is not satisfactory. Life cycle costing is accepted to be a process to determine the total cost of a building over the term of its life. The costing takes account of initial costs, running costs, repairs and maintenance, periodic replacement and the costs incurred or benefited from its disposal (Arditi and Nawakorawit 1999). It has been traditionally used when making decisions regarding the selection of a particular design or component, either during the initial design of a building or at the time of refurbishment. Life cycle costing can be applied to retrofitting when deciding on the types of retrofit systems or on new designs for earthquake strong buildings.

Essentially the life cycle costing method involves several steps. Raw data is collected. The raw data for life cycle costs will typically consist of a set of data representing the predicted costs of events spanning over the life cycle of the building or component in question. Whilst this raw data can be of some use to a building owner for determining affordability within budget constraints, it may be too complex to enable comparison between alternatives under consideration to be easily made (Ashworth 2004). The data is therefore further processed to bring it to a single figure representing the total life cycle cost (Flanagan et al. 1989). This cannot be achieved by simple addition as the current value of future expenditure diminishes according to the period of future intervention. The life cycle costing methodology therefore requires all costs to be brought to a common time period by means of discounting. The total costs are typically expressed either as a “present value” or an “annual equivalent cost”. Thus, when comparing different systems, such as retrofit systems, a single figure for each system can be calculated which represents the systems life cycle cost.

3.1 Life cycle costing in the New Zealand Construction Industry

Hoar and Norman suggest that a lack of understanding of the life cycle costing technique can limit the extent of its use (Hoar and Norman 1990). In New Zealand life cycle costing is well understood as a technique for assisting with refurbishment decisions (Wilkinson et al. 1995). In the research by Wilkinson et al. (1995), nearly all consultants and clients
interviewed had a clear understanding of the concept of life cycle costing. This extended to knowledge of which components to include in a life cycle costing analysis.

Ashworth suggests that there is still a significant need to convince clients that life cycle costing is worthwhile (Ashworth 2004). This has been a longstanding problem. Flanagan et al. also commented on the potential limitation of life cycle costing due to client knowledge suggesting that since life cycle costing has a seemingly scientific basis some clients may not like it as they feel it removes managerial decision making (Flanagan et al. 1989). Wilkinson et al. (1995) found that, despite understanding the technique, life cycle costing is, according to consultants, infrequently requested by clients. Some of the reasons for this have been examined in previous research. For instance, the research by Picken on life cycle costing suggested that "... the respondents from the USA felt that the reluctance of clients to pay for life cycle cost studies was an important factor in holding back life cycle costing." (Picken 1989). Drake considers why life cycle costing is not often used. He suggests that clients do not want to commit increased capital expenditure to gain uncertain future benefits. In other words when faced with the need to make a decision to commit further capital expenditure now, to obtain future savings in operating costs, they will do so only if the benefits can be clearly demonstrated (Drake 1976). Clients need to know why a procedure is being used and the benefits. For retrofitting earthquake prone buildings there is a clear need to understand what the options are financially.

Flanagan and Norman (1989) argue that one of the key benefits of life cycle costing is that it assists with effective decision making. They suggest that this is done in four ways; by identifying the total cost commitment undertaken in the acquisition of any asset, rather than merely concentrating on the initial capital costs; by facilitating an effective choice between alternative methods of achieving a stated objective; by detailing the current operating costs of assets such as machinery, individual building elements (heating systems, roof coverings), or complete building systems and finally by identifying those areas in which operating costs might be reduced, either by a change in operating practice, or by changing the relevant system (Flanagan et al. 1989). Other researchers have also commented that one of the prime uses of life cycle costing is as a decision making tool used to evaluate the financial differences between a finite number of mutually exclusive schemes (Ashworth 2004; Dale 1993; Ruegg and Marshall 1990). By being able to accurately compare alternative solutions, decisions on whether to demolish and rebuild or retrofit earthquake prone buildings can be made. Within New Zealand, use of life cycle costing has been documented for environmental and product selection (Mithraratne and Vale 2004). The most common use in the New Zealand building industry is for making comparisons of alternative solutions to services requirements, particularly those services with high energy use components such as heating and air conditioning but has not been extended to retrofitting.
In the New Zealand construction industry, two main benefits of life cycle costing technique were repeatedly mentioned in the survey conducted by Wilkinson et al., (1995). The first was that life cycle costing enables alternatives to be considered in a manner that takes account of all costs over the life cycle of the building or particular component under consideration, and not just initial capital costs, as suggested by Flanagan and Norman’s work (Flanagan et al. 1989). The second benefit was understood to be the ability to make economic comparisons of alternatives such as between higher initial costs and lower operating costs or lower initial costs and higher operating costs (Ashworth 2004; Dale 1993). There was general agreement that the life cycle costing technique aided the decision making process. In terms of retrofit solutions, various maintenance costs of different systems can be reflected in the overall life costs. Thus if one system requires maintenance and another does not this can be reflected in the life cycle costs of the building and could potentially impact on the choice.

Kelly argues that life cycle costing cannot be used until a limited number of alternative schemes have been substantially developed. However at the outset of the design process for a building there are an almost limitless number of possible alternative solutions to the clients brief, the number being effectively limited only by the creative ability of the designer and the time and resources available to explore the alternatives (Kelly 1990). To achieve the conditions to make life cycle costing comparisons it is necessary to have already made most major decisions regarding the form and specification of the building. By the time this position is reached the decisions which have greatest impact on the capital cost have already been made (Kelly and Male 1992). This suggests that at least when applied to the design of total buildings life cycle costing can contribute to the fine tuning process but not to fundamental decision making. In New Zealand, life cycle costing is not commonly used at the feasibility stage, or only a crude life cycle costing is made at this stage. The reason is lack of definition of one product or alternative against another. However, by the time the project reaches the detailed design phase, the technique starts to be commonly used. This is the stage where it is felt that the main benefits of life cycle costing are to be found (Wilkinson et al. 1995). This is the stage where retrofitting life cycle costing analyses would be most beneficial.

In New Zealand, various sources of information on behaviour of houses in earthquakes were reviewed by Beattie (Beattie 2001). These included Earthquake Commission claim records, Edgecumbe earthquake reconnaissance reports, house damage records from the Northridge earthquake, earthquake damage assessors, builders and Territorial Authority personnel interviews, museums and libraries. From this review the systems were chosen for testing as being the most in need of guidance to the New Zealand construction industry. Four systems, including an exterior wall clad with sheet sheathing, a braced pile foundation system, a brick veneer corner and gypsum plasterboard lined interior walls of a 1960s two-storey duplex housing unit, were selected as being areas where there
was a need to formulate repair techniques for increasing levels of earthquake damage. As an extension to this analysis, comparative costs would have given additional weigh to decisions or helped justify decisions.

4 KEY FACTORS OF LCC FOR BUILDING RETROFIT

Since LCC relies on projections into the future, the selection of the economic criteria and speculation of future changes is critical. These include the choice of methodology, discount rate, analysis period, maintenance schedules, frequency of component replacement, administrative, staffing etc (Kirk and Dell'Isola 1995). To apply LCC in the building retrofit project, some key factors need to be specified.

4.1 Required retrofit levels

According to the latest legislation, the earthquake vulnerable buildings need to be retrofit to above 66% of the current code level (or New Building Standard), which is a legislator’s situation. The building owner can decide to retrofit the building to certain percentage of the current code. In the area with high earthquake risk, a higher retrofit level may be preferred. The required retrofit level significantly influences the retrofit costs and the benefits of strengthening.

4.2 Retrofit cost

The retrofit cost is the assessed cost of the structural cost of strengthening buildings to the level required by the Legislation Regime. It will be analysed in accordance with the data received from an accepted tender. The reasons for analysing tenders rather than the ‘actual’ retrofit cost are as follows:

- It would be time consuming to analyse the variation account correctly due to the complexity of final accounts.
- The published cost analysis would be outdated by using final accounts, since the preparation of final accounts is often delayed for a variety of reasons.
- The increased costs and contractual claims are hard to be allocated to the individual elements (Ashworth 2004).

Hopkins (Hopkins 2006) suggests that the retrofit cost is calculated to vary according to the extent of reduction in damage ratio as the consequence of the retrofit work. Since the damage ratio differs from every single seismicity zone, the retrofit cost varies with the seismicity of the building location and the expected retrofit level.
4.3 Non-monetary costs

Non-monetary costs are project-related effects for which there is no objective way of assigning a dollar value, such as social and ethical concerns. Compared with technical matters, these costs are not so readily formalized or calculated (Arditi and Messiha 1999). Nevertheless they should not be ignored.

In building retrofit projects, the social cost is non-monetary costs. Social costs include the costs for controlling noise, vibration, safety and air pollution. Furthermore, social costs also cover the emotional cost provoking the attachment of local community to the historical buildings.

4.4 New construction costs

The new construction cost is the assessed cost of new construction of an entire building (Seeley 1996). The value of new construction cost is used directly to calculate the value of the benefits of reduced damage and indirectly to obtain the cost of retrofit.

4.5 Damage Ratio

The values of difference between the damage ratio before and after retrofit form the key benefits of strengthening. Morrison (Morrison 1993) modified the data of US to suit New Zealand building types. In the report, four sets of relationships between earthquake intensity and damage ratio are given, one of each building type.

Moreover, Yong (Yong et al. 2001) argues that the earthquake loss can be written as Loss = Hazard × Vulnerability × Exposure. The total values of the buildings, facilities and business interruption cost are all related to the economic productivity of the region, which is commonly measured by its Gross Domestic Product (GDP). This argument needs to be carefully considered in New Zealand, especially when the retrofit project locates in Auckland and Wellington, since GDP of these two metropolitans is higher than other cities in New Zealand. Therefore the damage cost and damage ratio will be different from the buildings of other cities.

4.6 Discount Rate

Life cycle costing requires prediction of the discount rate over the life study period. Choosing a discount rate is a subject much of the life cycle costing literature discusses as there are different approaches. For instance, Hoar and Norman argue that the discount rate is set so that the present value represents the sum of money if set aside today which would just cover the future forecast expenditure (Hoar and Norman 1990). Whereas Flanagan & Norman suggest the discount rate should be based on the opportunity
cost of capital (Flanagan et al. 1989). However, Ruegg and Marshall suggest a risk adjusted discount rate should be used to allow for varying degrees of risk between projects and the uncertainty of future events (Ruegg and Marshall 1990). Reflecting uncertainty of future events would be required in retrofitting decisions but is difficult to undertake. For instance, choosing one system over another and receiving less damage as a result of the chosen system but having to pay an initial higher cost.

In the analysis of building retrofit projects, the discount rate is set as 5% according to current macro economics in New Zealand. A sensitivity analysis of discount rate varying from 0% to 10% will be carried out to examine the influence on the total life cycle cost.

4.7 Risk assessment

It is probably fair to claim that one reason for the relatively slow introduction of life cycle costing methods to the building industry is that life cycle cost estimates are in some sense inaccurate, or based merely on guess-estimation. Decisions about building-related investments typically involve a great deal of uncertainty about future costs, cost growth, future inflation rates and the anticipated life of the component or facility (Cole and Sterner 2000). Risk management therefore needs to be introduced into life cycle cost analysis. Useful techniques can be applied to the problem of dealing with risk and uncertainty, which allow the decision-makers to incorporate and react to risk and uncertainty in investment appraisal and life cycle costing (Ashworth 1989).

There is evidence (Flanagan et al. 1987) to suggest that sensitivity analysis will become more widely practiced as a direct result of the development of computer software packages, which not only have the basic accountancy element of LCC but also the ability to perform a wide range of sensitivity studies, enabling them to embrace more accurately the dimension of qualitative assessment. In the application for building retrofit projects, some key variables, such as the seismicity, floor areas, the retrofit period and discount rate, are suggested to be examined (Boussabain and Kirkham 2004; Hopkins 2006).

5 CONCLUSIONS AND FUTURE WORK

This paper has illustrated the potential application of life cycle costing in retrofitting earthquake vulnerable buildings. The new legislation in New Zealand calls for earthquake building to be identified and work undertaken to mitigate potential problems. Life cycle costing can aid decisions when clients, property owners and others need to develop strategies for dealing with such buildings. A building owner may need to weigh up various options such as not retrofit, retrofit with different solutions or demolish and rebuild. Increasingly, and especially in New Zealand, not retrofitting is no
longer an option. Therefore, costs of various systems against demolish and rebuild strategies becomes more important.

A major role for Life cycle costing is to provide a comprehensive framework for decision-making rather than evaluating specific choices only (Flanagan et al. 1989). Careful analysis using life cycle costing as a frame work can aid the ultimate decisions for those involved in retrofitting earthquake prone buildings. The key factors of LCC process, which may influence the decision maker in the process, have been examined.

A series of case study on different building types will be carried out to identify the costs and benefits occurring in the retrofit projects. The architecture of life cycle costing financial analysis software for retrofitting earthquake prone buildings is therefore to be set up.

6 REFERENCE


