# Estimating the useful life of buildings

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# Estimating the Useful Life of Buildings

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## ABSTRACT

Obsolescence is a phenomenon that is widely discussed in the literature, although rarely in relation to buildings. In this paper parallels are drawn between obsolescence, depreciation and discounting in order to develop a new method for predicting the impact of building obsolescence based on measurable context factors. These factors have physical, economic, functional, technological, social, legal and political characteristics. Useful life is defined as discounted physical life, where the rate of discount is determined from predicted future obsolescence. As part of the method, a new tool for determining the physical life of buildings is presented. Using an adaptive reuse paradigm to compare predicted useful life with actual useful life, a large number of case studies is analysed retrospectively. The findings demonstrate that the proposed method is robust and that the concept of discounting physical life using obsolescence as a discount rate is valid.

## KEYWORDS

obsolescence, physical life, useful life, discounting, adaptive reuse

## INTRODUCTION

Buildings are major assets and form a significant part of facility management operations. Although buildings are long lasting they require continual maintenance and restoration. Eventually, buildings can become inappropriate for their original purpose due to obsolescence, or can become redundant due to change in demand for their service (Johnson, 1996). It is at these times that change is likely: demolition to make way for new construction or some form of refurbishment or reuse (Langston and Lauge-Kristensen, 2002).

Making better decisions about built assets will significantly improve our sustainability performance and deliver economic, social and environmental benefits to property owners and investors. In particular, the reuse of valuable resources will offset the need to destroy existing buildings and will contribute positively to climate change adaption initiatives that are increasingly urgent. An understanding of how long buildings last contributes to this discussion.

The aim of this paper is to develop a new method for predicting a building's useful life based on an assessment of its physical life and its annual rate of obsolescence. This forecast can be determined initially during design and periodically re-evaluated or monitored as actual events unfold. A unique physical life calculator is employed to arrive at a baseline value. This value is then discounted by a derived obsolescence rate per annum to predict useful life and calculate the ratio of useful to physical life. The approach adopts a large number of adaptive reuse case studies to evaluate retrospectively whether the proposed framework has real world validity. The paper indeed demonstrates that the method is robust. The ability to effectively model useful life enables more sustainable decisions to be made, in the context of both new construction and existing building interventions.

## BACKGROUND

The ISO-15686 series on service life planning for buildings and constructed assets is a useful resource on building durability. However it is more applicable to building components and systems than entire buildings. The estimated service life of any component is calculated as its theoretical life multiplied by a series of factors that are each scored in the range 0.8 to 1.2 (1 = no impact). The factors comprise (a) quality of components, (b) design level, (c) work execution level, (d) indoor environment, (e) outdoor environment, (f) usage conditions, and (g) maintenance level. Whilst a building is a sum of the parts, such parts can be replaced and hence renewed, leaving the basic structure to determine overall life expectancy. Other literature on service life discusses the effect of external and internal actions on building durability (e.g. Douglas, 2006), and principally identifies location, usage and design as the main parameters. This is underpinned by a large amount of technical research.

Obsolescence is the inability to satisfy increasing requirements or expectations (Iselin and Lemer, 1993; Lemer, 1996; Pinder and Wilkinson, 2000). This is an area under considerable stress due to changing social demand (Kintrea, 2007), and brings with it environmental consequences. Yet obsolescence does not mean defective performance. Douglas (2006) makes the further distinction between redundancy and obsolescence. The former means 'surplus to requirements', although this may be a consequence of obsolescence. Nutt et al. (1976:6) take the view that *"... any factor that tends, over time, to reduce the ability or effectiveness of a building to meet the demands of its occupants, relative to other buildings in its class, will contribute towards the obsolescence of that building"*. A few researchers have included political changes to zoning, ascribed heritage classification and other imposed regulatory change also as a form of obsolescence (e.g. Campbell, 1996; Gardner, 1993; Luther, 1988; Kincaid, 2000).

Economic considerations are often dominant in decisions concerning obsolescence in buildings (Baum, 1991). These relate fundamentally to ensuring that the income stream remains greater than the cost stream, and indeed greater than other alternative opportunities of similar risk level. Failure to generate a regular operating surplus renders a building economically obsolete. Such obsolescence can offer advantage, however, as it instigates new investment in more productive and technically advanced infrastructure, which has higher income and hence higher operating surplus potential. The capital investment in delivering the new infrastructure is written off over many years and provides some residual value at the end of its economic life if it is on-sold.

Barras and Clark (1996) argue that relative price factors, and in particular the price of capital investment compared to labour in maintenance and repair activities, determine the speed with which capital goods become obsolete. A rise in real wages or other running costs, a reduction in the production price of capital works or a fall in the rate of interest will all tend to increase the rate of replacement investment, and hence lower the average age of capital stock.

Haapio (2008) states that reliable data for forecasting obsolescence are rarely available. Usually estimates are based on designer or client experience and judgement. Where products are replaced and discarded before their service life has finished, the remaining service life is wasted. As Aikivuori (1996) attests in her study of private sector housing refurbishment, obsolescence-based refurbishment clearly occurs earlier than deterioration-based refurbishment. Therefore future obsolescence deserves more attention during design, including the benefits of buildings that display long life, loose fit and low energy characteristics.

## CONCEPTUAL FRAMEWORK

Obsolescence may be defined as a loss of utility of an asset due to the development of improved or superior products or services, although not utility loss due to natural deterioration or decay. Nevertheless, accelerated deterioration from a lack of proper maintenance and servicing and expected renewal could be regarded as equivalent to physical obsolescence. In addition to accelerated deterioration, obsolescence can be driven by economic, functional, technological, social, legal and even political factors (e.g. Seeley, 1983; Douglas, 2006; Mansfield, 2000).

Buildings, like other assets, can become obsolete over time. Buildings both deteriorate and become obsolete as they age. A building’s physical life, which may be interpreted as its structural adequacy or safety, is effectively reduced by obsolescence, resulting in a useful life somewhat less than its expected physical life.

The concept of obsolescence is not dissimilar to depreciation, but in the latter case value is used rather than utility (performance) to describe the effect. Depreciation is defined as a non-cash expense that reduces the value of an asset as a result of wear and tear, age or obsolescence, and involves setting aside money to replace it when its useful (effective) life is reached. Depreciation is normally calculated using either a diminishing value or straight-line method; the former approach reflects a negative exponential or decay curve.

Parallels can also be drawn to the technique of discounting, which reduces the value of an asset today to take account of the real opportunity cost of money in the future. Discounting also reflects a negative exponential curve over time. Depreciation and discounting both share a common objective of measuring 'decay' in initial values.

The rate of decline caused by obsolescence, just like opportunity cost, is not necessarily a regular (fixed) amount each year, but could be assumed as such in order to make the calculations more manageable in practice. It needs to consider the various types of obsolescence, either by using the more dominant cause and ignoring the others, or adopting the combined effect of all causes. It is likely, as is found with discounting, that the components of the rate work in opposite directions, and therefore a stabilising (central tendency) effect is produced.

The following equations (1-3) describe the basis of the proposed conceptual framework for estimating the useful life of buildings. A scale of 5 is adopted here, where 5 is defined as both maximum asset performance (new) and end of life cycle (before redevelopment).

$$V_p = 5 - \frac{L_p^2}{5} \tag{1}$$

*where:*

$V_p$ = *asset performance (based on building decay)*

$L_p$ = *physical life (expressed on a 0-5 scale)*

$$V_u = 5 - \frac{L_u^2}{5} \tag{2}$$

*where:*

$V_u$ = *asset performance (based on building obsolescence)*

$L_u$ = *useful life (expressed on a 0-5 scale)*

$$L_u = \frac{5}{(1 + O_a)^{L_p}} \tag{3}$$

*where:*

$L_u$ = *useful life (expressed on a 0-5 scale)*

$L_p$ = *physical life (expressed on a 0-5 scale)*

$O_a$ = *annual obsolescence rate (expressed as a decimal)*

A fixed scale is necessary so that comparisons between different buildings having different lives can be made and classified. However, any scale could have been used. These equations can be presented in a graphical format as shown in Figure 1.

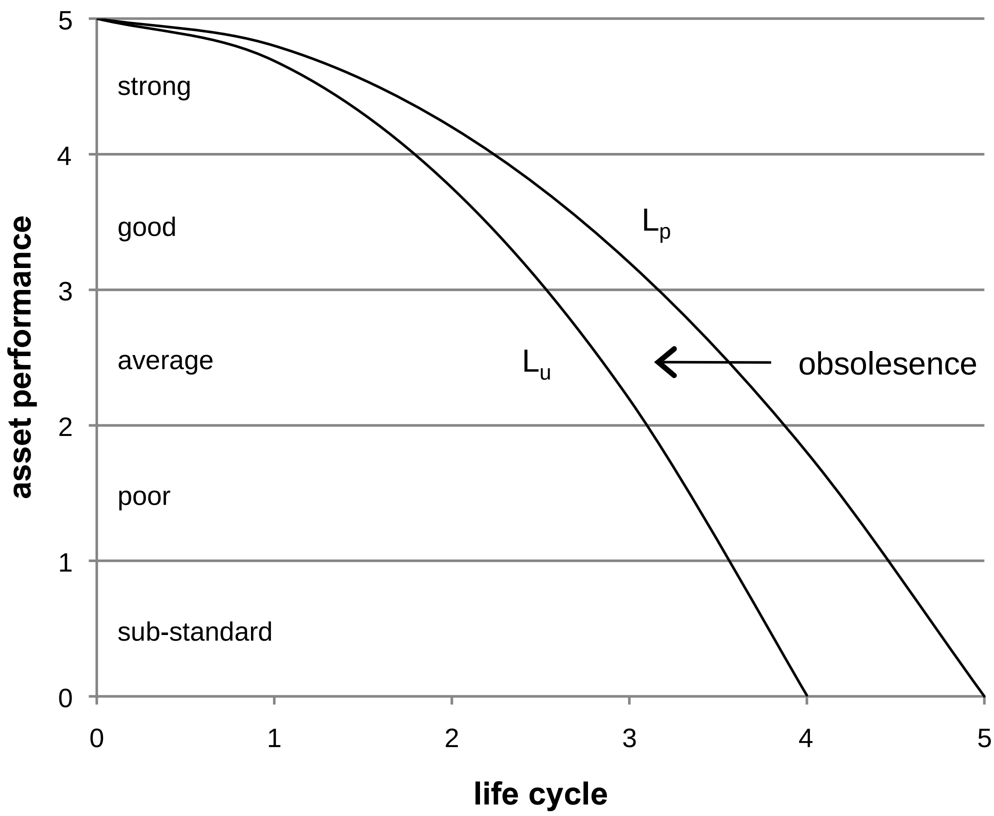


**Figure 1 – Conceptual framework**

So useful life is defined as discounted physical life. The ratio of useful life to physical life provides insight into the impact that obsolescence has on a building over its effective life, regardless of the accuracy of the estimate of physical life, and the lower the ratio the greater is the potential asset performance loss. The asset performance curves can be reset or partially reset through capital investment or other intervention, excluding normal maintenance and repair. For simplicity, only one asset cycle is shown here, but it is acknowledged that over the total life cycle of a project many asset cycles might occur.

According to Equation 3, to estimate useful life ($L_u$) it is necessary to determine both physical life ($L_p$) and the annual obsolescence rate ($O_a$). Equation 3 is in fact a traditional discounting formula. To obtain the useful life in years, simply determine the ratio of $L_u$:$L_p$ and multiply it with the physical life in years.

## PHYSICAL LIFE CALCULATOR

To assist in the forecast of physical life in years, an Excel calculation template has been developed. A series of questions gives insight into the longevity of a building according to three primary criteria: environmental context (location), occupational profile (usage) and structural integrity (design). Each category is equally weighted, and comprises ten questions requiring simple yes/no answers. Where information is unknown, a blank answer (no response) is ignored in the calculation. Three questions under each primary criterion are double weighted due to their relative importance. Figure 2 presents the physical life calculator using the Melbourne General Post Office (GPO) as an example[1].

**Physical life worksheet**

suggested forecast (years) = **200**

Project Name:
Melbourne GPO comprising concrete structure and massive stone-faced masonry walls, steel roof framing with glass vaulted ceiling, large open plan atrium and perimeter offices

| | | | y/n ? |
|---|---|---|---|
| environmental context | Is the building located within 1 kilometre of the coast? | | n |
| | Is the building site characterised by stable soil conditions? | # | y |
| | Does the building site have low rainfall (<500mm annual average)? | | y |
| | Is the building constructed on a 'greenfield' site? | | n |
| | Is the building exposed to potential flood or wash-away conditions? | | n |
| | Is the building exposed to severe storm activity? | | n |
| | Is the building exposed to earthquake damage? | | n |
| | Is the building located in a bushfire zone? | | n |
| | Is the building located in an area of civil unrest? | # | n |
| | Are animals or insects present that can damage the building fabric? | # | y |
| occupational profile | Is the building used mainly during normal working hours? | | n |
| | Are industrial type activities undertaken within the building? | # | n |
| | Is the building open to the general public? | | y |
| | Does the building comprise tenant occupancy? | | n |
| | Is a building manager or caretaker usually present? | # | y |
| | Is the building intended as a long-term asset? | # | y |
| | Does the building support hazardous material storage or handling? | | n |
| | Is the building occupation density greater than 1 person per 10 $m^2$? | | n |
| | Is the building protected by security surveillance? | | n |
| | Is the building fully insured? | | y |
| structural integrity | Is the building design typified by elements of massive construction? | | y |
| | Is the main structure of the building significantly over designed? | | y |
| | Is the building structure complex or unconventional? | | y |
| | Are building components intended to be highly durable? | # | y |
| | Are there other structures immediately adjacent to the building? | | y |
| | Is the building founded on solid rock? | # | y |
| | Was the workmanship standard for the project high? | | y |
| | Is the roof design susceptible to leaking in bad weather conditions? | # | y |
| | Is the building protected against accidental fire events? | | n |
| | Is the building designed as a public monument or landmark? | | y |

**Note:**
Questions indicated (#) are double weighted

**Figure 2 – Physical life calculator**

[1] information provided courtesy of Williams Boag Architects (Melbourne) and via site inspection

Some questions are worded so to deliver a positive score, while some are negative and others neutral (positive or negative). The type of question is distributed evenly throughout the template. The calculation algorithm assumes a base of 100 years and then adds or deducts points (years) according to the responses to questions. It is similar in concept to the *Living to 100 Life Expectancy Calculator*[2] that predicts human life span based on extensive medical and empirical data. Some conservatism is applied to the estimate and the forecast is rounded down to one of the following outcomes: 25, 50, 75, 100, 150, 200, 250 or 300 years. The template is unsuitable for temporary structures or for iconic monuments that both require specialist judgment.

The construction of the calculator has been informed from a broad survey of literature (unspecified), recent ISO-15686 standards and personal experience. It is founded on an adaptive management principle (Gregory et al., 2006; Linkov et al., 2006) that purports to develop a model and then evaluate its robustness through subsequent field-testing and observation. While the results of this testing appear promising, definitive validation arguably can only occur by comparison of estimates with reality, where the latter is measured as the duration of the building before its collapses. But as this is rarely witnessed, certainly through natural causes, field-testing and observation are the best validation methods available to us.

## ANNUAL OBSOLESCENCE

The annual rate of obsolescence is just as unlikely to be a constant value per annum as is the case with a conventional discount rate. It will fluctuate due to a raft of unforeseen events and is therefore impossible to predict accurately. But there is a convenience in the assumption that the annual rate is a constant, as has been our history with the discounting technique for over 150 years. The compound decline in values that flow from this approach mirror the natural rates of decay in buildings as has been understood in the asset management literature for some time (e.g. Leong, 2004).

Obsolescence has been variously described and categorised. In this paper, obsolescence is defined as a combination of physical, economic, functional, technological, social, legal and political factors. The annual rate of obsolescence is moderated by these factors in much the same way that discount rates are moderated by interest rates, inflation, taxation, proportion of equity to borrowing, specific price escalation, affordability and the like (Langston, 2005). But contrary to discounting, obsolescence factors are not directly measurable in the marketplace.

[2] see *http://www.livingto100.com*

To overcome this problem, a series of surrogate estimating techniques has been used based on tangible facts. These are summarised in Table 1. Each factor is assessed on a scale of 0 to 20, where 0 indicates no negative influence and 20 indicates significant negative influence, using interim scores of 5, 10 and 15 as appropriate. In the case of the political factor, positive support through planning incentives can lead to a score between -20 (favourable) and +20 (unfavourable), where a zero score is described as apathy.

**Table 1 – Surrogate estimating of obsolescence attributes**

| | method of measurement |
|---|---|
| physical | examination of maintenance policy and performance, specifically the annual budget allocation for routine maintenance and repair |
| economic | geographic location of a building relative to a major city, central business district or other primary market or business hub |
| functional | extent of flexibility embedded in a building's design, as evidenced by annual churn costs |
| technological | building's reliance on high levels of energy in order to provide occupant comfort |
| social | relationship between building function and its marketplace, such as reliance on external income, or trends in demand or relevance of service |
| legal | quality or standard of the original design, as evidenced by its initial cost per $m^2$ |
| political | level of public and local community interest surrounding a project |

To explain further, a generous annual maintenance budget would indicate that the building is being well looked after, and hence the physical obsolescence factor would be set at zero. If little attention to maintenance was evidenced or expected, then the physical obsolescence factor would be set at 20. Using the same approach, a building sited in the central business district of a major urban centre, an open plan or flexible floor plan, a green building, an owner-occupied building with strong market connections, a high quality building, and a site with an absence of heritage or planning controls/ restrictions in place would each score well (obsolescence factor = 0). It should be noted that environmental obsolescence is subsumed into technological, social, legal and political factors and therefore is not measured separately.

The annual obsolescence rate is taken as the sum of the scores of each factor divided by the physical life and expressed as a decimal. For example, if the sum of the scores is 100 and the physical life is estimated at 100 years, then the annual obsolescence rate (i.e. discount rate) is 1% or 0.01 per annum. The same score for a 50-year life would lead to an annual obsolescence rate of 2% or 0.02 per annum.

## VALIDATION

Whilst the above approach can be demonstrated on any new building project, it can only be validated retrospectively. Case studies of completed adaptive reuse projects were selected as the method for this validation since they generally document the history of each project including discussion of the reasons behind their obsolescence. It was decided to identify as many completed adaptive reuse projects as practicable and to undertake a retrospective evaluation of them to discover the proximity of the forecasts of useful life to reality. No restrictions were introduced other than temporary structures and ancient monuments were to be avoided (as the physical life calculator is not applicable for these project types). The robustness of the method would be measured by the correlation between predicted useful life and actual useful life, where the latter would be objectively determined as the date of adaptive reuse less the date of the original construction (or last major refurbishment).

An Internet search was conducted to identify suitable projects and to uncover the necessary information to enable the ‘model’ to be populated with data. Where a project did not have sufficient information available (i.e. 80% of the calculator questions and all 7 obsolescence factors known) or either the date of construction or the date of adaptive reuse was unavailable, it was discarded.

After an extensive online search in 2008, a total of 64 projects were identified and compiled into a database for further analysis. Many more were found but key information was not readily available. A few projects were local to the author and investigated by site visit. The total number of adaptive reuse projects globally is unknown. The selected projects covered a range of building typologies and locations and spanned from an actual useful life between 8 years (built in 2000) and 265 years (built in 1740). The average year of original construction was 1898 and the average year when the project was adaptively reused was 2001, giving a mean difference of 103 years.

A summary of the database showing the results is provided in Table 2. The projects have been sorted into increasing order based on the percent difference between predicted and actual useful life (as shown in Column J). The Melbourne GPO project, used to demonstrate the physical life calculator previously, is included in this table as Project #57.

## Table 2 – Retrospective study summary

| A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Richmond | 1852 | n/a | 2003 | 150 | 0.30 | 96 | 151 | -36.42 |
| 2 | Cambridge | 1920 | n/a | 2004 | 100 | 0.60 | 55 | 84 | -34.52 |
| 3 | New York | 1850 | n/a | 2004 | 150 | 0.27 | 101 | 154 | -34.42 |
| 4 | Seattle | 1890 | n/a | 2001 | 150 | 0.47 | 75 | 111 | -32.43 |
| 5 | San Antonio | 1940 | n/a | 2007 | 100 | 0.75 | 48 | 67 | -28.36 |
| 6 | Seattle | 1926 | n/a | 2001 | 100 | 0.60 | 55 | 75 | -26.67 |
| 7 | Cleveland | 1890 | n/a | 2002 | 150 | 0.37 | 87 | 112 | -22.32 |
| 8 | Dorchester | 1810 | n/a | 1986 | 200 | 0.18 | 141 | 176 | -19.89 |
| 9 | Beacon | 1927 | n/a | 2003 | 100 | 0.50 | 61 | 76 | -19.74 |
| 10 | Adelaide | 1869 | 1876 | 1989 | 150 | 0.33 | 91 | 113 | -19.47 |
| 11 | Hong Kong | 1932 | n/a | 2007 | 100 | 0.50 | 61 | 75 | -18.67 |
| 12 | Madrid | 1914 | n/a | 2004 | 100 | 0.25 | 74 | 90 | -17.78 |
| 13 | Los Angeles | 1926 | n/a | 2007 | 100 | 0.40 | 67 | 81 | -17.28 |
| 14 | Beechworth | 1867 | n/a | 1997 | 200 | 0.30 | 110 | 130 | -15.38 |
| 15 | Richmond | 1909 | n/a | 2004 | 150 | 0.40 | 82 | 95 | -13.68 |
| 16 | Minneapolis | 1878 | 1928 | 2004 | 100 | 0.40 | 67 | 76 | -11.84 |
| 17 | Georgetown | 1765 | n/a | 1960 | 200 | 0.08 | 172 | 195 | -11.79 |
| 18 | Bexhill-on-Sea | 1935 | n/a | 2008 | 150 | 0.57 | 65 | 73 | -10.96 |
| 19 | Melbourne | 1882 | n/a | 2001 | 150 | 0.23 | 106 | 119 | -10.92 |
| 20 | Richmond | 1918 | n/a | 2001 | 100 | 0.30 | 74 | 83 | -10.84 |
| 21 | Beijing | 1740 | n/a | 2005 | 250 | 0.02 | 238 | 265 | -10.19 |
| 22 | New York | 1920 | n/a | 2006 | 100 | 0.25 | 78 | 86 | -9.30 |
| 23 | Richmond | 1913 | n/a | 2003 | 150 | 0.40 | 82 | 90 | -8.89 |
| 24 | Washington | 1892 | n/a | 2002 | 150 | 0.27 | 101 | 110 | -8.18 |
| 25 | Salt Lake City | 1904 | n/a | 2003 | 150 | 0.33 | 91 | 99 | -8.08 |
| 26 | Hong Kong | 1906 | n/a | 2003 | 150 | 0.33 | 91 | 97 | -6.19 |
| 27 | Georgetown | 1796 | n/a | 1962 | 200 | 0.13 | 156 | 166 | -6.02 |
| 28 | Richmond | 1905 | n/a | 2007 | 150 | 0.30 | 96 | 102 | -5.88 |
| 29 | Melbourne | 1939 | n/a | 2000 | 100 | 0.55 | 58 | 61 | -4.92 |
| 30 | Bath | 1790 | n/a | 2004 | 250 | 0.08 | 205 | 214 | -4.21 |
| 31 | Launceston | 1868 | n/a | 2001 | 200 | 0.23 | 128 | 133 | -3.76 |
| 32 | Richmond | 1902 | n/a | 2006 | 150 | 0.27 | 101 | 104 | -2.88 |
| 33 | Geelong | 1911 | n/a | 1996 | 150 | 0.40 | 85 | 85 | 0.00 |
| 34 | San Diego | 1924 | n/a | 2008 | 200 | 0.23 | 84 | 84 | 0.00 |
| 35 | Norwich | 1855 | n/a | 2006 | 250 | 0.20 | 152 | 151 | 0.66 |
| 36 | Halifax | 1907 | n/a | 2007 | 150 | 0.27 | 101 | 100 | 1.00 |
| 37 | Philadelphia | 1877 | n/a | 2001 | 200 | 0.23 | 128 | 124 | 3.23 |
| 38 | Los Angeles | 1906 | n/a | 2003 | 150 | 0.27 | 101 | 97 | 4.12 |
| 39 | Cambridge | 1887 | n/a | 2008 | 200 | 0.23 | 128 | 121 | 5.79 |
| 40 | Auckland | 1914 | n/a | 1998 | 150 | 0.33 | 91 | 84 | 8.33 |
| 41 | Sydney | 1892 | n/a | 2002 | 200 | 0.25 | 121 | 110 | 10.00 |
| 42 | Carisle | 1891 | n/a | 2001 | 200 | 0.25 | 121 | 110 | 10.00 |
| 43 | Brunswick | 1928 | n/a | 2007 | 150 | 0.37 | 87 | 79 | 10.13 |
| 44 | Perth | 1880 | n/a | 2001 | 200 | 0.20 | 134 | 121 | 10.74 |
| 45 | Los Angeles | 1925 | n/a | 2007 | 150 | 0.33 | 91 | 82 | 10.98 |
| 46 | North Adams | 1890 | n/a | 1999 | 200 | 0.25 | 121 | 109 | 11.01 |
| 47 | New York | 1918 | n/a | 2008 | 150 | 0.27 | 101 | 90 | 12.22 |
| 48 | Seattle | 1927 | n/a | 2008 | 150 | 0.33 | 91 | 81 | 12.35 |
| 49 | Pittsburgh | 1879 | n/a | 1976 | 150 | 0.20 | 111 | 97 | 14.43 |
| 50 | New Haven | 1932 | n/a | 2003 | 150 | 0.40 | 82 | 71 | 15.49 |
| 51 | Richmond | 1897 | 1920 | 2003 | 150 | 0.30 | 96 | 83 | 15.66 |
| 52 | Sydney | 1894 | n/a | 1985 | 150 | 0.23 | 106 | 91 | 16.48 |
| 53 | Richmond | 1920 | n/a | 2006 | 150 | 0.27 | 101 | 86 | 17.44 |
| 54 | Chicago | 1913 | n/a | 2002 | 200 | 0.30 | 110 | 89 | 23.60 |
| 55 | London | 1947 | n/a | 2000 | 100 | 0.40 | 67 | 53 | 26.42 |
| 56 | New York | 1890 | 1957 | 2007 | 100 | 0.40 | 67 | 50 | 34.00 |
| 57 | Melbourne | 1859 | 1919 | 2004 | 200 | 0.28 | 116 | 85 | 36.47 |
| 58 | Barcelona | 1962 | n/a | 2003 | 75 | 0.40 | 56 | 41 | 36.59 |
| 59 | San Francisco | 1917 | n/a | 2002 | 150 | 0.17 | 117 | 85 | 37.65 |
| 60 | Canberra | 1976 | n/a | 2003 | 100 | 0.95 | 39 | 27 | 44.44 |
| 61 | Chicago | 1922 | 1932 | 2007 | 200 | 0.30 | 110 | 75 | 46.67 |
| 62 | Canberra | 1927 | n/a | 1998 | 200 | 0.33 | 105 | 71 | 47.89 |
| 63 | Canberra | 1927 | n/a | 2003 | 200 | 0.28 | 116 | 76 | 52.63 |
| 64 | Gold Coast | 2000 | n/a | 2008 | 50 | 1.10 | 29 | 8 | 262.50 |
| | Mean: | 1898 | | 2001 | 154.3 | 0.34 | 98.09 | 99.67 | 5.42 |

*A* *Project ID*
*B* *Location*
*C* *Date or Original Construction*
*D* *Date of Previous Major Renewal*
*E* *Date of Adaptive Reuse (Completion)*
*F* *Predicted Physical Life (years)*
*G* *Annual Obsolescence Rate (%)*
*H* *Predicted Useful Life (years)*
*I* *Actual Useful Life (years)*
*J* *Percent Difference (columns H and I)*

The physical life calculator produced a range of outcomes from 50 years to 250 years. Given all projects were adaptively reused it is not surprising that shorter lives were not found. No project scored 300 years either but several were close. The diversity of outcomes seemed reasonable and in all but a few cases an appropriate forecast was achieved. The mean physical life estimated in this study was 154.3 years.

Obsolescence rates were assessed according to the previously described criteria and summed. The total was then divided by the physical life estimate to give an annual rate of obsolescence. The mean value was 0.34%. The highest annual rate found was 1.10% and the lowest was 0.02%. The coefficient of variation across all projects was 53.09% and therefore demonstrated significant dispersion. These figures are used in much the same way as a conventional discount rate, albeit they are smaller in magnitude, to translate physical life into predicted useful life.

Predicted useful life was then computed using a derivation of Equation 3. These results were compared to actual useful life as determined by the difference between the date of adaptive reuse completion and the date of original construction. Where a major renovation occurred between these two dates, the renovation date was in lieu of the original construction date. Actual useful life has been overestimated as no cognisance was taken of the duration of the adaptive reuse site processes, which in all likelihood would span several years on large projects. Similarly, a few projects lay dormant for many years before a decision was taken to revitalise them, and this time has not been subtracted (as often it was unavailable). It is considered that the overestimation of actual useful life is probably in the order of 5%.

The mean predicted useful life was 98.09 years. The mean actual useful life was 99.67 years. The proximity of these two figures was encouraging. However, the percent difference between estimated and actual was calculated for each case study, and this varied between -36.42% and +262.50%. While the mean difference was just +5.42%, the absolute value of the differences led to a true mean of 22.51%. Overall the ratio of predicted useful life to physical life was 63.57% indicating that approximately one-third of physical life remained when these projects had become obsolete. This was confirmed by a subsequent study that showed the mean ratio was 63% across ten generic building archetypes (Langston, 2011).

To validate the reliability of the model, predicted and actual useful life were compared using linear regression. The line of best fit was computed as $y=0.9527x$. In fact, if actual useful life was reduced by about 5% to account for inherent overestimation, the line of best fit would have been $y=x$ thus indicating a $45^{o}$ line or perfect comparison. The degree of scatter is illustrated by an $R^2$ of 0.72013, which is a high value and suggests a tight relationship. If the line of best fit is assumed to be $y=x$, then $R^2$ falls to just 0.69971, which is a truer indication of reliability. While a correlation between predicted and useful life is on face value illogical, the use of regression employed here demonstrates quantitatively the accuracy of the method, as shown graphically in Figure 3.

The validation approach does not distinguish between the reliability of the physical life calculator (in predicting $L_p$) and the reliability of the annual obsolescence rate process (in predicting $L_u$). However, it does show quite clearly that the combined approach leads to realistic outcomes, and in the spirit of adaptive management this should be taken as significant. Further testing and model refinement will obviously occur over time, both by the author and undoubtedly by others, and until sufficient time has elapsed the findings at this stage may be considered preliminary.

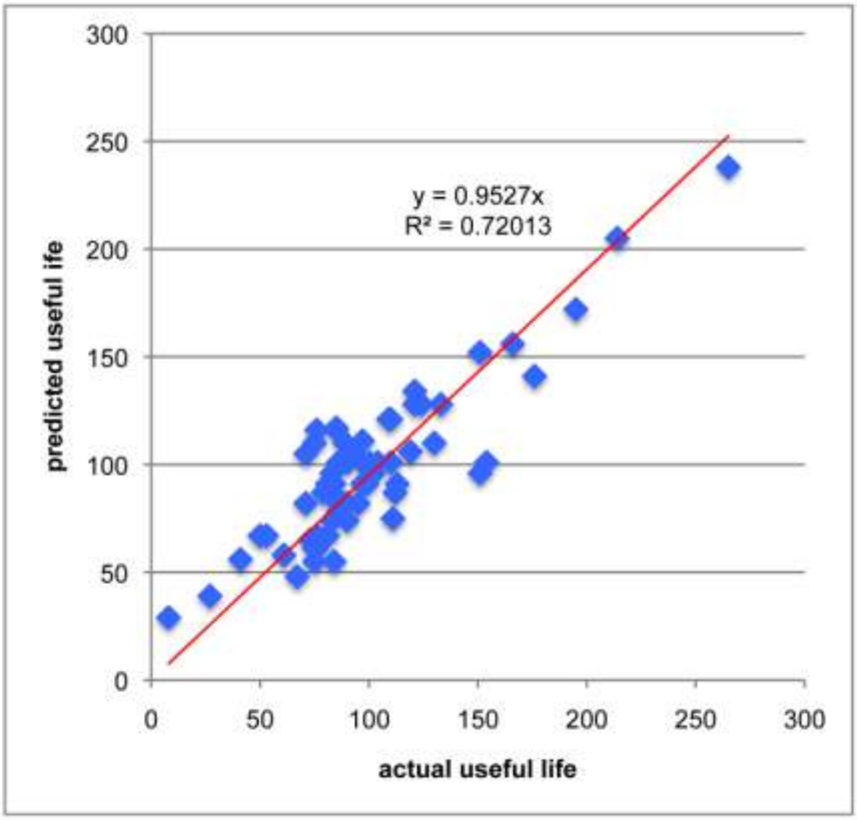


**Figure 3 – Validation of useful life forecast**

## DISCUSSION

This paper describes a method for estimating useful life and tests it quantitatively against history. In the case of the physical life calculator, its design appears arguably contrived and a simplification of reality given the complexity of the problem and the underlying issues. Models are only as good as their performance, and to date empirically this appears reasonable. In time, given more evidence of accuracy, the approach could be tuned and allowed to predict physical life to a finer level. Yet the prediction of physical life can still be made via expert opinion, and the calculator is but a tool to assist and provide some independent advice if required.

In the case of annual obsolescence, the advocated approach makes four important assumptions. First, that a maximum scale of 20% is used to judge the impact of each obsolescence factor over the building's physical life. Second, that this rate of reduction is uniform each year. Third, that each obsolescence factor is equally weighted. Finally, that obsolescence rates can be summed across categories, as opposed to selecting the most significant factor and ignoring the rest. These matters are discussed further below.

Models, by definition, are intended to simulate reality. To do this they make assumptions that simplify the complexity of the final product while maintaining reasonable forecasting accuracy. In this research, surrogates for each obsolescence factor have been sought that are both objective (measurable) and readily available for use in practice. The accuracy of the model is judged by its forecast of the outcome, and provided this is robust, the inner workings of the model are (by definition) validated. More information on these surrogates can be found in Langston (2008). It is also fair to say that other surrogates could be invented and applied within the overall framework.

The range of impact for each factor and its equal weighting are obviously capable of adjustment. This has not happened yet, and so far appears unnecessary. Range and weighting are of course related, so increasing the range for one from 0-40% would be the same as doubling its weight compared to the remaining obsolescence factors.

The notion of a regular annual obsolescence rate compared to a variable rate over time is selected purely for convenience. Similar decisions apply to the use of diminishing depreciation and discounted cash flow calculations. While more complex algorithms are possible, the difficulty in using them outweighs the additional accuracy that might be expected. Furthermore, it is not well understood in the literature how the passage of time impacts on obsolescence, and it may indeed be impossible to predict annual variations at all.

The question of summation of obsolescence factors is interesting. It can be argued that if economic obsolescence is considered the most influential, then the building is obsolete as soon as its economic life is reached. Therefore, only economic obsolescence matters. But in this paper the position is advanced, if we are to measure obsolescence objectively, that it is necessary to break it down and unpack the issues. It is argued here that economic obsolescence cannot be considered in isolation to issues of accelerated deterioration, functional change, technological advancements, social relevance, legal compliance or political interference – they are all related. By measuring each, a sense of the whole is determined. To compartmentalise one aspect is to reduce its richness and oversimplify the drivers. For example, Bottom et al. (1999) concludes in relation to a study of office buildings in London that building design quality characteristics and tenant organisation work practice typologies can be used to explain functional performance as perceived by occupiers. The cross-relationships are compelling. Others may disagree.

## CONCLUSION

Useful life can be predicted. Through the application of surrogates that can suitably reflect the impact of physical, economic, functional, technological, social, legal and political obsolescence, physical life estimates can be "discounted" to determine a building's useful life. Such an approach offers advantage in being able to better predict possible adaptive reuse potential, or indeed just to make informed decisions about the timing of building upgrade or decommission. The ratio of useful life to physical life, argued in this paper at around 63% (or roughly two-thirds), is a useful heuristic that may help to compare the performance of different building typologies or investment options.
This research makes an important contribution to the literature and provides a platform for more advanced modelling of building performance and adaptive reuse intervention. The benefits of this work to sustainability and climate change adaptation are undeniable as the construction industry, at least in the developed world, continues to move from a paradigm focused on new-build to one of refurbishment and reuse.

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