The sustainability implications of building adaptive reuse

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The Sustainability Implications of Building Adaptive Reuse

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Abstract— **Building adaptive reuse is an important global topic. In the context of sustainable development and the effects of climate change caused by previous disregard for our environment, adaptive reuse has significant implications. This paper aims to examine how the construction industry can reposition itself to increase focus on the revitalization of existing buildings as an alternative to demolition and replacement. The paper reports on current research undertaken in Australia as part of a nationally-funded program in collaboration with industry, proposes a new model for early identification of adaptive reuse potential, tests this model with case study data, and looks at the social advantage from making better use of what we already have. The paper proposes that adaptive reuse needs to be planned at the outset, and if this is done wisely and routinely, it will provide a means of realizing sustainability objectives without reducing investment levels or economic viability for the industry. In fact, adaptive reuse is the future of the construction industry.**

Keywords- Building adaptive reuse; Sustainability; Obsolescence; Refurbishment potential; Construction industry

I. INTRODUCTION

Climate change is a contemporary and global area of scientific enquiry and research. The challenges that changing environments have on society are significant (e.g. Stern, 2006; Bouwer and Aerts, 2006). Many have concluded that climate change is the most important challenge facing humankind, and indeed other life on Earth. Sir David King, Britain's Chief Scientist, described the Stern Report (Stern, 2006) as the most detailed economic analysis yet conducted.

Climate change will influence our world in a number of ways, including detrimental economic, environment and social impact. Some of the expected challenges of climate change identified by Stern (2006) include:

1. shrinking the global economy (reducing GDP) by 20%,
2. international effort required to reach the required scale of reductions,
3. no action could result in floods, melting glaciers, threatened wildlife, droughts and up to 200 million people becoming refugees,
4. similar scale impacts to the world wars and great depression of the 20th century,
5. irreversible climate changes,
6. global warming and sea level rise for at least another one hundred years,
7. need to decarbonize the power sector by 60-70%, end deforestation and make deep cuts in transport emissions,
8. 40% of wildlife species could become extinct,
9. 1 in 6 of the world population could face water shortages,
10. US$9 trillion in mitigation costs with just 10-15 years to act, and
11. more significant impacts in Africa and the developing world.

The built environment has a prominent role to play in this debate, particularly as it demands 40% of global resources and generates a proportionate amount of waste. Climate change adaptation is about human responses to this challenge, and how the impacts of a changing climate can be minimized as much as practicable (Burton et al., 2005). A major contribution that the built environment can make to climate change adaptation is in the area of making better use of the infrastructure that we already have. While new design and construction should be optimized for environmental performance, it would take around one hundred years to substantially renew the stock of existing buildings even if high environmental compliance was mandatory on every new project, both immediately and globally.

Existing buildings that are obsolete or rapidly approaching disuse and potential demolition are a 'mine' of raw materials for new projects; a concept described by Chusid (1993) as 'urban ore'. Even more effective, rather than extracting these raw materials during demolition or deconstruction and assigning them to new applications, is to leave the basic structure and fabric of the building intact, and change its use. This approach is called 'adaptive reuse'. Breathing 'new life' into existing buildings carries with it environmental and social benefits and helps to retain our national heritage. To date, a focus on economic factors alone has contributed to

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destruction of buildings well short of their physical lives.

This study investigates the role that the construction industry can play in climate change adaptation. There needs to be shift from new-build to reuse or refurbishment and this needs to happen rapidly. But the literature on building reuse is limited and appropriate methods of identification and analysis of opportunities are poorly understood. This study advocates a rethink of our approach to sustainable development. Rather than simply build less, we should be more strategic on where to build and how to make the most of existing resources.

Specifically this paper aims to:

1. outline an integrated model for the assessment of adaptive reuse potential in buildings,
2. validate this model through retrospective evaluation of a large number of completed projects, and
3. speculate on the implications for climate change adaptation of an increased focus on the preservation of existing buildings with adaptive reuse potential as an alternative to premature destruction or dilapidation.

To achieve these aims this paper will discuss the conceptual model that has developed from progress on an Australian Research Council *Linkage Project* entitled "Strategic Assessment of Building Adaptive Reuse Opportunities". Then, using a retrospective approach, a large number of completed adaptive reuse projects will be evaluated by the model to determine if forecasted and actual performances are a close match. A detailed case study of one of these projects is discussed to illustrate the process. Finally the paper will consider the contribution that an adaptive reuse agenda can make to enhance sustainable development in the light of increasing pressure to minimize the effects of climate change while continuing to deliver prosperity and enhanced living standards.

II. OBSOLESCENCE

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. 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).

Refurbishment can of itself take many forms, ranging from simple redecoration to major retrofit or reconstruction. Sometimes the buildings are in good condition but the services and technology within them are outdated, in which case a retrofit process may be undertaken. If a particular function is no longer relevant or desired, buildings may be converted to a new purpose altogether. This is adaptive reuse.

Older buildings may have a character that can significantly contribute to the culture of a society and conserve aspects of its history. The preservation of these buildings is important and maintains their intrinsic heritage and cultural values. Facility managers are frequently faced with decisions about whether to rent or buy, whether to extend or sell, and whether to refurbish or construct. Usually these are financial decisions, but there are other issues that should bear on the final choice, including environmental and social impacts.

Johnson (1996: p.209) indicates that, as society has advanced, its use of buildings has become more temporal. He states that "advances in technology and commerce, including the growth of industrial and office automation, and user demands for more comfortable environments for work and leisure have led to large numbers of buildings becoming obsolete or redundant and these changes have provided an abundance of buildings suitable for rehabilitation and reuse".

Buildings, like other assets, can become obsolete over time. Buildings both deteriorate and become obsolete as they age. A building's service life, which may be interpreted as its structural adequacy (i.e. structural safety), is effectively reduced by obsolescence, resulting in a useful life somewhat less than its expected physical life. The useful (effective) life of a building or other asset in the past has been particularly difficult to forecast because of premature obsolescence (Seeley, 1983). Obsolescence may be described as constituting one or more of the following attributes:

1. physical
2. economic
3. functional
4. technological
5. social
6. legal
7. political

Surrogate estimation techniques were developed to quantify each of the obsolescence categories listed above. The rationale behind these methods is described in Langston et al. (2008). The conclusions are summarized below.

Physical obsolescence can be measured by an examination of maintenance policy and performance. Useful life is effectively reduced if building elements are not properly maintained. A scale is developed such that buildings with a high maintenance budget receive a 0% reduction, while buildings with a low maintenance budget receive a 20% reduction. Interim scores are also possible, with normal maintenance intensity receiving a 10% reduction.

Economic obsolescence can be measured by the location of a building to a major city, central business district or other primary market or business hub. Useful life is effectively reduced if a building is located in a low density demographic. A scale is developed such that buildings sited in an area of high population density receive a 0% reduction, while buildings sited in an area of low population density receive a 20% reduction. Interim scores are also possible, with average population density receiving a 10% reduction.

Functional obsolescence can be measured by determining the extent of flexibility embedded in a building's design. Useful life is effectively reduced if building layouts are inflexible to change. A scale is developed such that buildings with a low churn cost receive a 0% reduction, while buildings with a high churn cost receive a 20% reduction. Interim scores are also possible, with typical churn costs receiving a 10% reduction.

Technological obsolescence can be measured by the building's use of operational energy. Useful life is effectively reduced if a building is reliant on high levels of energy in order to provide occupant comfort. A scale is developed such that buildings with low energy demand receive a 0% reduction, while buildings with intense energy demand receive a 20% reduction. Interim scores are also possible, with conventional operating energy performance receiving a 10% reduction.

Social obsolescence can be measured by the relationship between building function and the marketplace. Useful life is effectively reduced if building feasibility is based on external income or if the service for which the building is intended is in decline. A scale is developed such that buildings with fully owned and occupied space or with an increasing market presence receive a 0% reduction, while buildings with fully rented space or with a decreasing market presence receive a 20% reduction. Interim scores are also possible, with balanced rent and ownership or steady market presence receiving a 10% reduction.

Legal obsolescence can be measured by the quality of the original design. Useful life is effectively reduced if buildings are designed and constructed to a low standard. A scale is developed such that buildings of high quality receive a 0% reduction, while buildings of low quality receive a 20% reduction. Interim scores are also possible, with average quality receiving a 10% reduction.

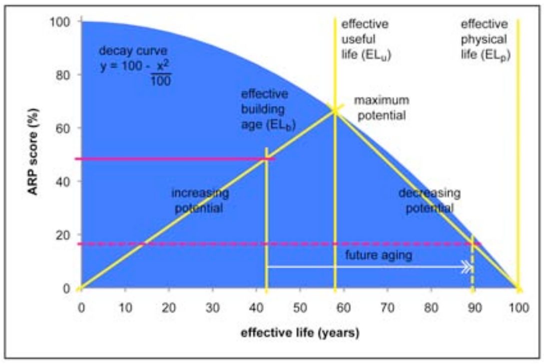
Political obsolescence, a less publicized concept, can be measured by the level of public or local community interest surrounding a project. Useful life is effectively reduced if there is a high level of (restrictive) political interference expected. A scale is developed such that buildings with a low level of interest receive a 0% reduction, while buildings with a high level of interest receive a 20% reduction. Interim scores are also possible, with normal public and local community interest receiving a 10% reduction. Where a project can receive a significant benefit from political interference, rather than a constraint, it is feasible to extend the assessment scores into the positive range (i.e. -20% to +20%). In this case, should the potential interference be seen as an advantage, it may extend a building's useful life and help offset other obsolescence considerations, which are all negative or neutral. Examples of a positive influence include government funding opportunities or enhanced tax concessions that can be accessed when pursuing an adaptive reuse strategy (Gardner, 1993).

In addition to the above, environmental obsolescence is obviously relevant to today's society and arguably deserving of individual assessment. But in this study environmental issues are subsumed within technological obsolescence given the choice of an energy intensity surrogate. As the marketplace continues to become more sustainability-conscious, social, legal and political obsolescence will increasingly reflect the environmental agenda.

III. INTEGRATED MODEL

The conceptual framework of an approach to identify and rank adaptive reuse potential (ARP) for existing buildings is described fully in Langston et al. (2008). It has generic application to all countries and all building typologies. It requires an estimate of the expected physical life and the current age of the building, both reported in years. It also requires an assessment of physical, economic, functional, technological, social, legal and political obsolescence. Obsolescence is advanced as a suitable method to reduce expected physical life in order to calculate objectively the useful life of a building. An algorithm is developed that takes this information and produces an index of reuse potential expressed as a percentage. Existing buildings in an organization's portfolio, or existing buildings across a city or territory, can therefore be ranked according to the potential they offer for adaptive reuse. Where the current building age is close to and less than the useful life, the model identifies that planning should commence.

The ARP model is summarized in Figure 1. Its application was first demonstrated for a real case study in Hong Kong in Langston and Shen (2007).



$$\text{ARP (increasing)} = \frac{100 - \frac{EL_u^2}{100}}{EL_u} \cdot EL_b \qquad \text{ARP (decreasing)} = \frac{100 - \frac{EL_u^2}{100}}{100 - EL_u} \cdot (100 - EL_b)$$

Figure 1. ADAPTIVE REUSE POTENTIAL MODEL (LANGSTON ET AL., 2008)

The estimation of expected physical life is the starting point for the calculation of useful life. Useful life is then determined through application of Equation 1. The form of the equation confirms the notion that useful life is indeed discounted physical life, and uses the long-established method of discounted cash flow as its basis, where the "discount rate" is taken as the sum of the obsolescence factors per annum (i.e. factors are divided by L_p).

$$\text{Useful life } (L_u) = \frac{L_p}{\left(1 + \sum_{i=1}^{7} O_i\right)^{L_p}} \qquad (1)$$

where:

L_p =*physical life (years)*
O_1 =*physical obsolescence (% as decimal pa)*
O_2 =*economic obsolescence (% as decimal pa)*
O_3 =*functional obsolescence (% as decimal pa)*
O_4 =*technological obsolescence (% as decimal pa)*
O_5 =*social obsolescence (% as decimal pa)*
O_6 =*legal obsolescence (% as decimal pa)*
O_7 =*political obsolescence (% as decimal pa)*

Values for EL_u (effective useful life), EL_b (effective building age) and EL_p (effective physical life) are determined by multiplying L_u, L_b and L_p by 100 and dividing by L_p respectively, which enables a maximum scale for *x* and *y* axes of 100. L_b is defined as the current age of the building (in years).

The above approach makes four important assumptions. First, that a maximum scale of 20% is used to judge the impact of each obsolescence category over the building's physical life. Second, that this rate of reduction is uniform each year. Third, that each obsolescence category is equally weighted. Finally, that the rates of obsolescence can be summed across categories, as opposed to selecting the most significant category and ignoring the rest. Future refinement of the model may need to revisit some of these assumptions.

To assist in the forecast of physical life, a calculation template has been developed. A series of questions gives insight into the longevity of a building according to three primary criteria: namely environmental context, occupational profile and structural integrity. Each category is equally weighted, and comprises ten questions requiring simple yes/no answers. Where information is unknown, a blank answer (no response) is then ignored in the calculation. Three questions under each primary criterion are double weighted due to their relative importance.

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 Calculator* that predicts human life expectancy (see http://www.livingto100.com). 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.

Figure 2 presents the physical life calculator. The rationale behind the questions and the choice of weighting is the subject of a separate paper currently under development. Field-testing of its suitability across a range of building types is an integral part of this study.

IV. RESEARCH METHODOLOGY

The integrated model, articulated here for the first time, involves the estimation of physical life (using the physical life calculator), the assessment of each of the seven obsolescence rates (using surrogate estimation techniques), the discounting of physical life to derive useful life (using Equation 1) and the determination of adaptive reuse potential (using the ARP model).

To validate this approach on new projects is impossible. It has therefore been decided to identify as many completed adaptive reuse projects as practicable and to undertake a retrospective evaluation to discover the proximity of the forecasts to reality. No restrictions were introduced other than temporary structures and ancient monuments were avoided (as the physical life calculator is not applicable for these projects).

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 it was discarded. Some projects were known to the author and investigated by site visit. Critical information comprised the date of construction and the date of adaptive reuse.

After an extensive online search, 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. 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 I. The projects have been sorted into increasing order based on the percent difference between predicted and actual useful life (Column J). Figure 3 shows graphically the spread of results for useful life (both expected and actual) from the sample.

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

V. RESULTS

A. Physical Life Forecast

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 154.30 years.

Table I. RETROSPECTIVE STUDY SUMMARY

A	B	C	D	E	F	G	H	I	J	K	L
1	Richmond	1852	n/a	2003	150	0.30	96	151	-36.42	0.00	no potential
2	Cambridge	1920	n/a	2004	100	0.60	55	84	-34.52	24.80	moderate and decreasing
3	New York	1850	n/a	2004	150	0.27	101	154	-34.42	0.00	no potential
4	Seattle	1890	n/a	2001	150	0.47	75	111	-32.43	38.30	moderate and decreasing
5	San Antonio	1940	n/a	2007	100	0.75	48	67	-28.36	48.60	moderate and decreasing
6	Seattle	1926	n/a	2001	100	0.60	55	75	-26.67	38.70	moderate and decreasing
7	Cleveland	1890	n/a	2002	150	0.37	87	112	-22.32	40.00	moderate and decreasing
8	Dorchester	1810	n/a	1986	200	0.18	141	176	-19.89	20.50	moderate and decreasing
9	Beacon	1927	n/a	2003	100	0.50	61	76	-19.74	38.60	moderate and decreasing
10	Adelaide	1869	1876	1989	150	0.33	91	113	-19.47	39.60	moderate and decreasing
11	Hong Kong	1932	n/a	2007	100	0.50	61	75	-18.67	41.60	moderate and decreasing
12	Madrid	1914	n/a	2004	100	0.25	74	90	-17.78	17.40	low and decreasing
13	Los Angeles	1926	n/a	2007	100	0.40	67	81	-17.28	31.70	moderate and decreasing
14	Beechworth	1867	n/a	1997	200	0.30	110	130	-15.38	54.20	high and decreasing
15	Richmond	1909	n/a	2004	150	0.40	82	95	-13.68	56.80	high and decreasing
16	Minneapolis	1878	1928	2004	100	0.40	67	76	-11.84	40.10	moderate and decreasing
17	Georgetown	1765	n/a	1960	200	0.08	172	195	-11.79	4.70	low and decreasing
18	Bexhill-on-Sea	1935	n/a	2008	150	0.57	65	73	-10.96	73.30	high and decreasing
19	Melbourne	1882	n/a	2001	150	0.23	106	119	-10.92	35.20	moderate and decreasing
20	Richmond	1918	n/a	2001	100	0.30	74	83	-10.84	29.60	moderate and decreasing
21	Beijing	1740	n/a	2005	250	0.02	238	265	-10.19	0.00	no potential
22	New York	1920	n/a	2006	100	0.25	78	86	-9.30	24.90	moderate and decreasing
23	Richmond	1913	n/a	2003	150	0.40	82	90	-8.89	62.00	high and decreasing
24	Washington	1892	n/a	2002	150	0.27	101	110	-8.18	44.60	moderate and decreasing
25	Salt Lake City	1904	n/a	2003	150	0.33	91	99	-8.08	54.60	high and decreasing
26	Hong Kong	1906	n/a	2003	150	0.33	91	97	-6.19	56.80	high and decreasing
27	Georgetown	1796	n/a	1962	200	0.13	156	166	-6.02	30.20	moderate and decreasing
28	Richmond	1905	n/a	2007	150	0.30	96	102	-5.88	52.40	high and decreasing
29	Melbourne	1939	n/a	2000	100	0.55	58	61	-4.92	61.50	high and decreasing
30	Bath	1790	n/a	2004	250	0.08	205	214	-4.21	26.20	moderate and decreasing
31	Launceston	1868	n/a	2001	200	0.23	128	133	-3.76	54.90	high and decreasing
32	Richmond	1902	n/a	2006	150	0.27	101	104	-2.88	51.20	high and decreasing
33	Geelong	1911	n/a	1996	150	0.40	85	85	0.00	24.60	moderate and increasing
34	San Diego	1924	n/a	2008	200	0.23	84	84	0.00	39.00	moderate and increasing
35	Norwich	1855	n/a	2006	250	0.20	152	151	0.66	62.90	high and increasing
36	Halifax	1907	n/a	2007	150	0.27	101	100	1.00	54.70	high and increasing
37	Philadelphia	1877	n/a	2001	200	0.23	128	124	3.23	57.60	high and increasing
38	Los Angeles	1906	n/a	2003	150	0.27	101	97	4.12	53.00	high and increasing
39	Cambridge	1887	n/a	2008	200	0.23	128	121	5.79	56.20	high and increasing
40	Auckland	1914	n/a	1998	150	0.33	91	84	8.33	58.30	high and increasing
41	Sydney	1892	n/a	2002	200	0.25	121	110	10.00	57.20	high and increasing
42	Carisle	1891	n/a	2001	200	0.25	121	110	10.00	57.20	high and increasing
43	Brunswick	1928	n/a	2007	150	0.37	87	79	10.13	60.80	high and increasing
44	Perth	1880	n/a	2001	200	0.20	134	121	10.74	49.60	moderate and increasing
45	Los Angeles	1925	n/a	2007	150	0.33	91	82	10.98	56.90	high and increasing
46	North Adams	1890	n/a	1999	200	0.25	121	109	11.01	56.70	high and increasing
47	New York	1918	n/a	2008	150	0.27	101	90	12.22	49.20	moderate and increasing
48	Seattle	1927	n/a	2008	150	0.33	91	81	12.35	56.20	high and increasing
49	Pittsburgh	1879	n/a	1976	150	0.20	111	97	14.43	39.30	moderate and increasing
50	New Haven	1932	n/a	2003	150	0.40	82	71	15.49	60.10	high and increasing
51	Richmond	1897	1920	2003	150	0.30	96	83	15.66	51.40	high and increasing
52	Sydney	1894	n/a	1985	150	0.23	106	91	16.48	43.30	moderate and increasing
53	Richmond	1920	n/a	2006	150	0.27	101	86	17.44	47.00	moderate and increasing
54	Chicago	1913	n/a	2002	200	0.30	110	89	23.60	56.60	high and increasing
55	London	1947	n/a	2000	100	0.40	67	53	26.42	43.40	moderate and increasing
56	New York	1890	1957	2007	100	0.40	67	50	34.00	41.00	moderate and increasing
57	**Melbourne**	**1859**	**1919**	**2004**	**200**	**0.28**	**116**	**85**	**36.47**	**49.10**	**moderate and increasing**
58	Barcelona	1962	n/a	2003	75	0.40	56	41	36.59	33.20	moderate and increasing
59	San Francisco	1917	n/a	2002	150	0.17	117	85	37.65	28.60	moderate and increasing
60	Canberra	1976	n/a	2003	100	0.95	39	27	44.44	59.00	high and increasing
61	Chicago	1922	1932	2007	200	0.30	110	75	46.67	47.70	moderate and increasing
62	Canberra	1927	n/a	1998	200	0.33	105	71	47.89	49.40	moderate and increasing
63	Canberra	1927	n/a	2003	200	0.28	116	76	52.63	43.90	moderate and increasing
64	Gold Coast	2000	n/a	2008	50	1.10	29	8	262.50	18.40	low and increasing
	Mean:	**1898**		**2001**	**154.30**	**0.34**	**98.09**	**99.67**	**5.42**	**43.04**	

KEY:	*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 F and G)*
	K	*ARP Score (%)*
	L	*ARP Comments*

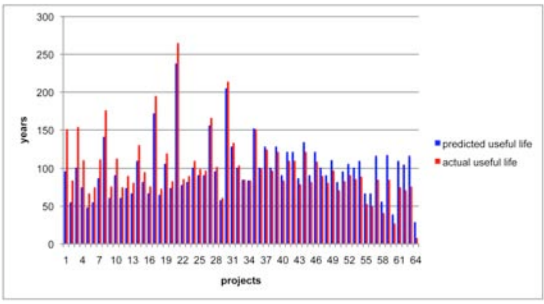


Figure 3. COMPARISON OF EXPECTED AND ACTUAL USEFUL LIFE

B. Annual obsolescence rate

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 smaller in magnitude, to translate physical life into predicted useful life.

C. Useful life estimation

Using Equation 1, predicted useful life was computed. These results were then compared to actual useful life as determined by the difference between the date of adaptive reuse completion and the date of construction. Where a major renovation occurred between these two dates, the renovation date was taken as the original construction date. This approach has overestimated the actual useful life as no cognizance 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 revitalize them, and this time has not been subtracted. It is considered that the overestimation of actual useful life is 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.

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 was 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 $y=x$, 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 was employed here to demonstrate quantitatively the accuracy of the model, as shown graphically in Figure 4.

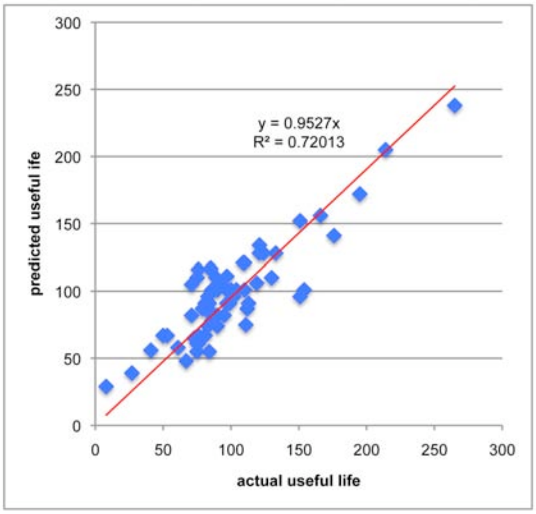


Figure 4. VALIDATION OF USEFUL LIFE FORECAST

D. Adaptive reuse potential

Entering the key data into the ARP model led to the determination of the ARP score. This varied from 0 to 73.30% with a mean of 43.04%. ARP relates to a scale of 50-100 being a high score, 20-49 being a moderate score and 0-19 being a low score (zero actually indicates no potential), each reflecting approximately one-third of the area under the decay curve. Overall, 91% of projects demonstrated a moderate or high ARP score, but this is not surprising given all of them were examples of completed adaptive reuse. Obviously a few of them may have been bad decisions, or the model inadequate to value them, so maybe 9% of projects were not simulated correctly.

The model can also describe adaptive reuse potential as increasing or decreasing. In this study 27% of projects exhibited a score that was high and increasing, 23% high and decreasing, 16% moderate and increasing, 25% moderate and decreasing, 5% low and increasing, 3% low and decreasing, and 1% exhibited no potential.

The previous results confirm that the integrated model is reasonably robust for predicting the useful life of buildings. Further research is underway to test if the derived ARP score is also robust. This involves the detailed examination of a number of existing projects that have yet to undergo revitalization. The methodology to be applied needs to consider economic, environmental and social benefits and compare the ARP ranking across the range of projects with this evaluation. If the ARP ranking matches the evaluation ranking then it can be concluded that the ARP model is quite robust. The results will be reported in a future paper.

VI. DETAILED CASE STUDY – GPO MELBOURNE

A detailed case study is provided to illustrate the methodology used in the previous analysis. The chosen project was the General Post Office (GPO) in Melbourne (Project 57 in Table 1). The building was constructed on the corner of Elizabeth and Bourke Streets in 1859, following some earlier and modest structures dating back to 1837. Between 1859 and 1867 a much grander two-storey building was developed. The building underwent further major renovation, completed in 1919, including the new sorting hall.

However, in 1992 Australia Post announced plans to end the GPO's major postal role in favor of decentralized mail centers. The building was to be sold. In 1993 a shopping centre was proposed but the permit later lapsed. In 1997 a hotel was proposed, but this idea also did not proceed. Then again in early 2001 plans for a retail centre were announced. The project had to overcome a major setback when almost gutted by fire in September 2001. Nevertheless, the work was finally completed and the building was opened to the public in October 2004 (further information can be found at http://www.melbournesgpo.com/#history).

The building included a tasteful restoration of the main sorting hall (see Figure 5) and a modern extension to the northern end of the complex (see Figure 6). Williams Boag Architects, along with design consultants like Arups and the successful contractor St Hilliers, were involved in this important project. It is now one of the more prominent and well-known adaptive reuse case studies in Australia. It subsequently won the RAIA National Award for Commercial Buildings and the Sir Osborn McCutcheon Commercial Architecture Award.

Figure 5. GPO MELBOURNE INTERIOR (FORMER SORTING HALL)

Figure 6. GPO MELBOURNE EXTERIOR (SHOWING NEW EXTENSION

Actual physical life of the project is unknown, despite its near demise in 2001, and an inspection would suggest there are many good years left. The expected physical life was determined using the data shown previously in Figure 2. Using 1919 as the new base, the calculated life of 200 years means the building should be structurally safe until 2119. Future major renovation could extend this date, and would undoubtedly occur given its heritage value to the City of Melbourne.

Obsolescence was assessed as though the evaluation was undertaken in 1919. At that time, physical obsolescence would have been rated high as maintenance would not have been a priority, and this was evidenced by accelerated deterioration that subsequently occurred. Economic obsolescence was zero as the building was in the center of Melbourne. Functional obsolescence was also low as the remodeled building had substantial open space. The massive external walls of the building provided some thermal mass that would help insulate the interior from the outside conditions, but nevertheless some form of heating was essential and the demand on energy would have been moderate. But from a social perspective this building was owned and occupied by a government authority and did not rely on external income to survive. The building was constructed to a reasonably high standard and so legal obsolescence was low. But as a major community building, it would be logical to assume that future changes would attract considerable community interest, so political obsolescence would be high as this may limit future opportunities for change.

Therefore obsolescence was assessed at 15%, 0%, 5%, 10%, 0%, 5% and 20% respectively across the seven categories (total 55%), leading to an obsolescence rate (over 200 years) of 0.28% per annum. Using Equation 1, useful life was calculated at 116 years. Again applying the base of 1919, the building would be expected to become obsolete in 2035. The reality was considerably less (a difference of 36.47%).

Using these outcomes for physical and useful life, an ARP score of 49.1% is achieved, as shown in Figure 1 previously. This is interpreted as moderate potential and increasing. A few years later and the building would pass 50% and be seen as having high potential. The maximum ARP score possible is 66.6% given a useful life of 116 years (note this is 58% of the expected physical life, or 58 years on the 100-year scale used in Figure 1). But substituting expected useful life with the actual useful life of 85 years, the ARP score would have risen to 81.9%. This is a very strong case for adaptive reuse on the basis of the substantial 'embedded physical life' remaining in the building.

VII. IMPLICATIONS FOR SUSTAINABLE DEVELOPMENT

The ARP score serves as a means of benchmarking (identifying low, moderate or high potential for reuse in individual buildings), timing (understanding increasing or decreasing reuse potential and prioritizing work) and ranking mutually exclusive projects (the higher the score the more potential for reuse). Application of this integrated model makes it possible to quickly scan the stock of existing buildings within an organization's property portfolio or a specific location and to determine which buildings are worthy of further more detailed investigation. If the model is accurate then better use of existing resources in analysis and design effort can be achieved. Validation of the robustness of the ARP score itself is the next stage of the *Linkage Project*. It involves the comparison of the ARP score with a comprehensive feasibility study for a sample of projects yet to undergo reuse. If the ranked order of the realized benefits of each project is identical to the ARP ranking, then the model provides a shortcut for future project selection.

Adaptive reuse is a special form of refurbishment that poses 'interesting' challenges for designers. Changing the class (functional classification) of a building may introduce new regulatory conditions and perhaps require zoning consent. There are clear economic, environmental and social benefits that can make this option attractive to developers. In some cases an increase in floor space ratios can be obtained and concessions received for pursuing government policy directions by regenerating derelict public assets. In recent years redundant city office buildings have been converted into high quality residential apartments, bringing people back to cities and in the process revitalizing them. Society also wins through preservation of cultural and heritage values and better use of existing infrastructure.

A. Economic benefits

Rehabilitated space can be created more quickly than new space, unless extensive structural reconstruction is required. Johnson (1996) suggests that rehabilitation typically takes half to three-quarters of the time necessary to demolish and reconstruct the same floor area. The shorter development period reduces the cost of financing and the effect of inflation on construction costs, so organizations that wish not to relocate have less disruption to operations and cash flow, and reducing temporary accommodation expenses.

Despite the time advantages, the cost of converting a building is generally less than new construction because many of the building elements already exist. Given there are no expensive problems to overcome, like asbestos removal or foundation subsidence, the reuse of structural elements is a significant saving. Older buildings, however, may not comply with present regulations, particularly in the area of fire safety, which may generate some structural changes or additional protective measures. It is essential that any building being considered for major refurbishment have a thorough survey undertaken to confirm its structural and constructional quality, and its compliance with building ordinances.

B. Environmental benefits

Environmental benefits from rehabilitation arise through the recycling of materials, reuse of structural elements and the reduction in generated landfill waste. These translate into cost advantages to the owner, but have much wider environmental implications. Older buildings sometimes were constructed using a range of quality materials that typically display a useful life well in excess of their more modern counterparts (e.g. use of solid stone walls, slated roofs, marble floors, etc.). The embodied energy saving through reuse of these materials or other forms of recycling can be substantial.

Furthermore, many older buildings employ massive construction in their external envelope, which can reduce energy consumption in heating and cooling through passive design and deliver long-term operational efficiencies. Opening windows, natural ventilation and natural lighting are all desirable qualities where external noise and pollution are not issues. Low-rise structures also eliminate the need for expensive vertical transportation systems.

The reuse of existing public infrastructure, like telecommunications, water, gas, sewerage and drainage, can relieve demands on local authorities to extend infrastructure and to reclaim natural landscapes from sprawling urban development.

C. Social benefits

Older buildings sometimes provide social benefits such as intrinsic heritage values. They can retain attractive streetscapes, add character and provide status and image to an organization through the use of massive and highly crafted materials. Older buildings are often in advantageous locations in city centers and close to transport making reuse (where appropriate) more viable. They add to a sense of community and are often appreciated as comfortable working environments by occupants.

Reduction in vacant or derelict buildings potentially adds vibrancy to communities, reduces crime and other unsocial behavior, and raises living standards through added investment and revitalization.

Tully (1993) argues that refurbishment generates 25% more employment than new building construction per square meter of floor space as a result of the higher ratio of labor-intensive activities. However issues of legislative compliance, fire safety, disabled access and heritage constraints (such as a requirement for facade retention) are possible disadvantages that should be properly explored. The redesign of existing buildings is often more challenging than new-build although the scope of work may be lower.

D. Impact on the global construction industry

A change in focus away from new construction might be received with some disquiet from developers and contractors. It may be assumed that the effect on the economy would be undesirable and work against wealth creation and rising living standards. But a move towards refurbishment (including but not limited to adaptive reuse) will add efficiency to our industry. What should result is higher profit levels and more work opportunities, leading to better investment levels and economic viability for the industry as a whole. In most countries new-build is adding just a few percent to our stock of buildings each year, while the vast majority are progressing slowing yet irrevocably down the decay curve towards eventual destruction. Devoting effort to ensuring that natural decay is not accelerated and that maximum value is extracted from our investments is just commonsense.

But the biggest opportunity for the global construction industry is converting existing buildings into more sustainable assets that can reduce our reliance on fossil fuels and minimize waste generation and pollution (Fournier and Zimnicki, 2004). In this way significant inroads can be made quickly in curbing our carbon use and contributing towards reductions in climate change pressure. Redirecting the industry towards retrofit activities will accelerate climate change adaptation targets compared to new construction initiatives and help avoid or at least delay some of the undesirable climatic consequences of modern human civilization. It will also help ensure that building longevity is enhanced.

Furthermore, where new-build does occur, it should be designed with future adaptive reuse in mind. If planned at the outset, subsequent works can be made more efficient and investment returns further strengthened. The seven categories of obsolescence described in this paper can be seen as important principles for designers (e.g. use of high quality materials, flexibility in spatial layouts, reduced reliance on non-renewable energy). In fact, the ideals of ‘long life, loose fit and low energy’ advocated in architecture schools for centuries is now more important than ever, and coupled with recycling and deconstruction initiatives in buildings that have reached the end of their physical lives, our industry can demonstrate higher sustainability performance. A rating scheme for adaptive reuse potential in new design is our next research topic.

VIII. CONCLUSION

Building adaptive reuse is an important global topic. In the context of sustainable development and the effects of climate change caused by previous disregard for our environment, adaptive reuse has significant implications. This paper has examined how the construction industry can reposition itself to increase focus on the revitalization of existing buildings as an alternative to demolition and replacement. The paper has reported on current research undertaken in Australia as part of a nationally-funded program in collaboration with industry, proposed a new model for early identification of adaptive reuse potential, tested this model with case study data, and looked at the social advantage from making better use of what we already have. The paper proposed that adaptive reuse needs to be planned at the outset, and if this is done wisely and routinely, it will provide a means of realizing sustainability objectives without reducing investment levels or economic viability for the industry. In fact, adaptive reuse is the future of the construction industry.

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