ICBEST 2014
June 09-12, 2014, Aachen, Germany

ICBEST 2014
Building for a Changing World

The capital load of the building enclosure system relative to other systems and its impact on the total cost of ownership of condominium buildings in British Columbia

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Abstract

Drawing upon a database of 1651 buildings, this paper shares insight into the distribution of capital costs across the range of systems at different stages in the life cycle of multi-unit residential buildings (MURBS) and its significance for responsible stewardship of enclosure assets, such as roofs and facades. The data was compiled in response to changes in the local condominium statute that mandated building owners to commission maintenance plans and replacement reserve studies with the intent of empowering these common interest communities to be proactive in the management of their tangible capital assets.

The modelling of the physical and financial data encompassed a multi-disciplinary exercise where each consultant on the team was required to make “reasonable” forecasts on the appropriate intervals for major maintenance activities and life cycle renewal of significant capital assets and to develop “defensible” projections of the future maintenance and replacement costs based on market valuations.

This paper demonstrates that the costs associated with the long-range preservation and renewal of components of the building enclosure system collectively have the highest financial impact on the aggregated capital costs (capital load) of all building systems over a 30-year planning horizon. This skewness is significant in its materiality and continues at most life stages and for different classes of MURBS.

In advancing principles toward the development of an asset management strategy, which can be tailored specifically to the asset register of each building, the capital load is further decomposed into a capital consumption index that ranks each asset based on its relative impact on the capital load. The statistics and methodology in this paper contribute towards a compelling business case for prioritized maintenance of the highly integrated systems of buildings in order to preserve the financial stability of the owners’ investment.

1 Introduction

Since the late-1990s the authors have been part of an interdisciplinary team of consultants involved in the preparation of maintenance plans and replacement reserve studies for 1651 buildings, primarily in the Pacific Northwest, including British Columbia, Washington State and Oregon State. These studies are considered decision-support tools that empower building owners, managers and operators to make informed decisions on the appropriation of funds for future capital renewal obligations when the assets approach the end of their useful lives and to establish interim maintenance programs to help the assets reach - and, in some cases - extend their service lives. In accordance with local statutory requirements, the study period for these life and valuation studies must cover a 30-year planning horizon.

Studies that were conducted in the 1990s were initially captured in separate MSExcel spreadsheets. During the early 2000s, a series of decentralized MSAccess databases served as the data management platform. Some attempts were made to aggregate the data from multiple buildings but the MSAccess software had limited capacity to run the necessary calculations across hundreds of thousands of data records. In the mid-2000s the earlier studies from the preceding decade, which were comprised of hundreds of individual building databases, were migrated into a centralized SQL database. The consolidation of the data in SQL was undertaken over a four-year period and the significant overhead cost associated with this data housekeeping exercise was justified for the following reasons: a) to provide a critical mass of aggregated data to support a longitudinal statistical research project on the quantification of the impact of maintenance on the retirement dispersion patterns of building enclosure assets; b) to develop a quality control mechanism for the preparation of future replacement reserve studies and maintenance plans by making meaningful service comparisons across classes of buildings sharing similar attributes, such as construction type and age; and c) to refine the financial “rules of thumb” to facilitate a mixed-scanning methodology where preliminary assessments were undertaken, in certain circumstances, before embarking upon detailed studies.

2 Classification & Normalization of the Data

The statistical population of 1651 buildings included life and valuation data from different sectors, including residential, commercial, civic, industrial and institutional properties, and across different geographical locations in the Pacific Northwest. Recognizing that the data had been assembled by a variety of engineering teams over the span of a decade, including varied states of completeness and inconsistencies in the quality of the data in some of the sectors and systems, the authors carried out statistical analyses to identify and extract a subset of data that could be considered sufficiently “clean” for the purposes of meaningful research and for the development of the internal quality control tool. The resultant dataset comprised a population of 598 buildings exclusively from the MURB sector from which this paper derives its findings.

2.1 Building Systems

The decomposition of buildings into a nested hierarchy of data, ranging from systems to sub-systems to assets to components, is necessary for placing meaningful structure on the complex interaction of the assets. This provides owners, managers and operators with the insight to develop long-range maintenance programs and replacement reserve funds that are aligned towards the sustainment of their different functional needs, such as heating, cooling, lighting and environmental separation. Cross-referencing of the asset register to line items in the owners’ annual operating budgets further facilitates the relationship between the strategic plan (long-range needs), the tactical plan (mid-range needs) and the operational plan (short-term needs).

Drawing upon the ASTM-1557, Uniformat II classification of assets based upon their function, the SQL database organized each building into nine primary systems: structure, enclosure, electrical, mechanical, fire protection, elevators, interior finishes, recreation amenities and site work. Since the structure is mostly protected by the enclosure system (with a few exceptions) the former does not have a material impact on the major maintenance and renewal forecasts for most MURBS, subject to proper stewardship of the latter. Some of the systems are not present in certain buildings and the range of systems was pared back accordingly in those instances. For example, elevators are not included with most townhouse developments and some condominiums do not have recreation amenities. Specialized occupancies, such as resort condominiums and housing cooperatives, include suite interior furnishings as a mutually exclusive asset category. Notwithstanding the differences at individual buildings and specialized governance structures, the base building systems and support infrastructure was consistent across the 598 buildings for research and benchmarking purposes.

2.2 Building Classes

The buildings were organized into three classes based upon common physical attributes and corresponding financial cost models: high-rise buildings, low-rise buildings, and townhouse complexes. In limited cases, some mixed-use developments were included in the dataset.

The high-rise buildings (HR) are all concrete construction, ranging from 5 to 60 floors in heights. This class has some unique attributes, including the largest number of assets, specialized safety assets (such as emergency generators), and assets to move fuels and fluids longer distances (such as booster pumps).

Low-rise buildings (LR), consisting of up to four storeys, are principally of wood frame construction and typically 3-5 floors. This is the most diverse of the three building classes where variability arises due to the use of both types of construction: combustible (wood frame) and non-combustible (concrete). The configurations include single buildings or multiple buildings on a shared-ownership site. A wide variety of floor plate geometries provides additional permutations.

Townhouse complexes (TH) are almost exclusively wood frame construction, typically 1-3 storeys, and sometimes include a shared parking garage sub-substructure. Some of the unique attributes are the exclusion of a central mechanical plant, larger areas of site work, and significant buried infrastructure relative to the other two building classes.

2.3 Building Life Stages

Each of the three classes of buildings was, in turn, organized into four life cycle stages, as follows: 0-16 years (the “childhood” stage); 17-29 years (the “adolescence” stage); 30-49 years (the “adulthood” stage); and 50+ years (the “old age” stage).

Life Stage #1 (0-16 years) - The primary focus during the initial years is on the prescribed maintenance to preserve the warranties on the new assets. Under normal operating circumstances, the owners are confronted with few assets that require replacement and these are typically small projects of relatively low capital cost.

Life Stage #2 (17-29 years) – This life stage is represented by a dramatic shift in the number of capital projects facing the owners. In additional to the forces of physical deterioration, technological obsolescence drives the replacement of some mechanical and electrical components. Many assets are designed with a 20-25 year useful service life and are therefore considered to be mid-life assets. This is one of the primary reasons why replacement reserve studies include a 30-year planning horizon.

Life Stage #3 (30 - 49 years) – At this stage the owners encounter the most expensive of the asset renewal projects, such as the replacement of the windows and wall cladding assemblies. In addition, some of the shorter life assets (that were first replaced in life stages 1 and 2) will now require their second or third rounds of renewal. Functional obsolescence, style obsolescence and legal obsolescence need to be managed carefully at this stage.

Life Stage #4 (50+ years) – This life stage represents, in some respects, the completion of a cycle and a return to life stage 1. The necessary and sufficient maintenance during each life stage, coupled with timely renewal of assets, will ensure that the owners receive many decades of good value from their real estate investment. Most buildings will continue to operate for many decades beyond life stage 4.

The authors established that there is no direct correlation between the age and the condition of a building. Some older building can be in very good condition as a result of the owners having replaced assets at appropriate times within their life cycles. Similarly, some young buildings may be in poor condition due to inadequate maintenance or premature failure of some assets.

2.4 Reinvestment Categories

In order to address the inevitable deterioration of assets and to mitigate against the unfunded liability associated with future capital renewal obligations, reinvestment is necessary at all stages in the lifecycle of buildings. The costs associated with the different funding requirements were organized into three reinvestment categories: “catch-up” costs; “keep-up” costs; and “get-ahead” costs.

Catch-up costs refers to the accumulation of deferred maintenance associated with the assets, which is based primarily upon empirical site observations. For example, a localized blister on a roof membrane that can be effectively repaired without necessitating assembly renewal.

Keep-up costs include the routine maintenance and major maintenance activities to preserve the assets. This reinvestment category also contemplates the planned cyclical renewal activities as each asset approaches the point of functional failure at the end of its useful life. For example, replacement of an aged roof assembly that is approaching functional failure and is beyond economic repair. It is assumed that the owners, behaving rationally, will pursue preventive replacement strategies so as to avoid the collateral damage and other risks associated with failure replacement. Where the risks are deemed acceptable, the owner may sometimes make a conscious decision to run to failure.

Get-ahead costs contemplate the possible adaptation and upgrade of certain assets to counter the forces of retirement associated with the different forms of obsolescence, such as technological obsolescence, economic obsolescence, functional obsolescence, aesthetic obsolescence, and legal obsolescence. For example, replacement of single glazed windows with double or triple glazing for improved energy performance may be considered a form of economic obsolescence.

The following table provides a summary of building counts and average values for each of the three MURB building classes – high-rise (HR), low-rise (LR) and townhouse (TH).

Table 1. Summary of physical and financial attributes of the research data set of 598 buildings.

Physical Attributes	**All**	**HR**	**LR**	**TH**
Building count	598	217	247	134
Asset count, average	71	90	76	47
Building age, average (years)	21	16	24	19
Gross Floor Area, GFA, averages				
- In square metres	12,800	21,000	9,800	10,000
- In square feet	138,000	229,000	105,000	109,000
Cost of Reproduction New (CRN), average, $ Millions	25.04	44.82	14.83	15.09
Suite count, average	88	154	70	59

The dataset was deemed to contain a representative sample from each building class and for all life stages from 1-50 years.

3 Developing “Realistic” Forecasts and “Defensible” Estimates

The veracity of a replacement reserve study is derived from the rigour of the methodology in its physical analysis (*How long will things last?)* and the corresponding financial analysis *(How much will things cost?).* The financial analysis is, in turn, made up of an expression of two interrelated facets: expenses (*How much money will the owners need?*) and funding (*How much money will the owners have?).* Within the condominium sector, the credibility of a reserve study is contingent on in its ability to provide the owners with realistic forecasts of future events and defensible estimates of the concomitant costs.

3.1 Forecasting Methodology

Over the course of a decade, a series of algorithms embedded into the SQL database, were incrementally refined through testing and validation cycles. The forecasts of the useful services lives for the wide variety of assets across different systems were derived from a hybrid of deterioration models from the engineering discipline and statistical models from the actuarial sciences. These two broad classes of deterioration models provided a range of tools and techniques to quantify the probability of failure (PoF) of each asset during any particular year of the planning horizon and the consequences of failure (CoF). A criticality score (PoF x CoF) was derived from an understanding of the processes and mechanisms by which assets deteriorate, pass through different stages of failure (potential-failure to functional-failure) and the resultant failure modes and effects on the performance of the building and risk exposure to the owners.

From the engineering sciences, the SQL database called upon degradation (performance) curves to return the relationship between time (x-axis) and condition (y-axis). From the statistical sciences, the algorithms utilized survivor curves to express the relationship between time (x-axis) and probability distributions (y-axis). The majority of the probability distributions exhibited varying degrees of positive or negative skewness from the modal year at which replacement was deemed most likely and this continues to pose a challenge when seeking “realistic” forecasts. The observed life tables that are being generated within the longitudinal study periodically return data for further iterations in the model and this is expected to continue for many years. The service life forecasts are therefore constantly being refined as new experiential knowledge comes to light. Additional study is underway on mapping the points of potential failure (P) and functional failure (F) onto the degradation curves and/or the skewed survivor curves and then cross-referencing this to calendar years within the planning horizon.

The forecasts of future event intervals required the engineering teams to make a series of physical assumptions, including the state of the concealed conditions and the necessary and sufficient maintenance to be performed over the planning horizon.

3.2 Estimating Methodology

The team tested a variety of alternative funding formulas to derive a reinvestment rate for major maintenance and asset renewal costs at different stages in the lifecycle of MURBS. In a paper published in 2013 [1] the authors evaluated the relative merits of three alternative formula for quantifying the unfunded liability (catch-up) at the base year of the study for each building and the ongoing funding requirements (keep-up) over the planning horizon.

The simplest of the three formulas sums the value of the capital projects that are forecast to occur over the planning horizon (30 years), typically in future values (FV), and then divides the results by the planning horizon. In other words, the load is divided into the load period. For example, if all projects in future values add up to $30 Million and it is divided into a 30 year planning horizon, the owners need to set aside $1 Million per year. The second formula establishes outline funding requirements for a building by calculating each renewal activity divided by its frequency. For example, a wood trim repainting project every 10 years (Frequency) at $100,000 (Current Value) must be funded in the replacement reserve at $10,000 per year.

The third formula evaluates each renewal activity divided by the frequency of the renewal activity or the length of the planning horizon, whichever is less. This was deemed sufficiently elegant to return a defensible estimation for condominium building as it reports in future values and it respects fluctuations in the funding requirements through the life of the building as capital renewal projects that are initially beyond-the-horizon come into the planning horizon. The formula, expressed as a combination of a summation notation and logic statement, is summarized as follows:

$$\sum \text{IF}\{EY > PH + BY, 0, (\text{Costy} / [\text{IF}(F > PH, PH, F)]) \text{ x } ([\text{IF}(F > PH, PH, F)]) - (EY - BY))\} \quad (1)$$

Where,

Costy	Future Value of Renewal Event
EY	Event Year, year of Renewal Occurrence
BY	Base Year
PH	Planning Horizon, 30
F	Frequency of the Renewal Activity

The funding projections required the engineering teams to make a series of financial assumptions in the face of the vagaries of the marketplace, such as escalation rates to be applied to the future projects and compounded annually, the interest rate to be earned on the accumulating reserve balance, the taxation rate to be applied to the interest income in some jurisdictions, and the sliding scale of unit rates for renewal projects of different scopes.

4 Bottom-up Assessments within Individual Buildings

The data from each of the 581 buildings, which had been assembled individually in a bottom-up methodology, was subsequently aggregated to provide a top-down analysis across the statistical population. Once the forecasts of future events had been made, and the estimates of costs had been calculated, the resultant analysis provided insight into the emergent funding distributions. Two concepts have been advanced in order to articulate some of the analysis -- the first concept is the “Capital Load” (CL) and the second is the “Capital Consumption Index” (CCI).

4.1 The Capital Load (CL)

The capital load is the combined value of all capital expenses (both major maintenance activities and renewal projects) for all the assets in a single building (the asset register) that has been forecast over the planning horizon (say 30 years) and expressed in future value. Similarly, the operating load (OL) is the combined value of all operating activities carried out over the same period and, by extension, the energy load (EL) is the fuels and electricity consumed and dissipated by the assets over the same planning horizon. When the capital load is combined with the operating load and the energy load, the owners can estimate their total cost of ownership. When considering the system cost distributions, it can be helpful in establishing priorities and developing risk-based maintenance strategies.

The figure below provides an example of the capital load, distributed by system, in current value, as of the base year of a replacement reserve study, and the escalated future values across the 30-year planning horizon.

Table 2. Distribution of the 30-year capital load, by system, within a single building.

System	**Current Value (CV)** As of Base Year	**Future Value (FV)** @ 2% escalation	**Ratios**
Enclosure	2,547,000	3,710,000	58%
Electrical	118,000	159,000	3%
Mechanical	892,000	1,062,000	17%
Fire protection	77,000	110,000	2%
Elevators	300,000	416,000	6%
Finishes	366,000	524,000	8%
Amenities	80,000	107,000	2%
Site work	199,000	279,000	4%
Total (The Capital Load)	$4,579,000	$6,367,000	100%

In the preceding example, the enclosure system represents 58% of the capital funding requirements for the building over the prescribed planning horizon. The next most prominent system includes the mechanical assets collectively representing 17% of the capital load.

While the capital load is helpful in identifying system-level priorities and for establishing a broad 30-year amortization of the funding requirements, it does not reveal the distribution pattern of these costs over time. In other words, it does not reveal the proximity of the individual events along the planning horizon and relative to the base year of the study. To illustrate the significance of proximity for effective project planning purposes, Figure 1 contains a stacked bar chart that demonstrates the uneven distribution of expenses (*How much money will the Owners need?*) at different times over a 10 year tactical planning horizon. The owners are then tasked with aligning their funding trajectory (*How much money will the Owners have?)* to meet the cash flow requirements for the projects as they arise from time to time.

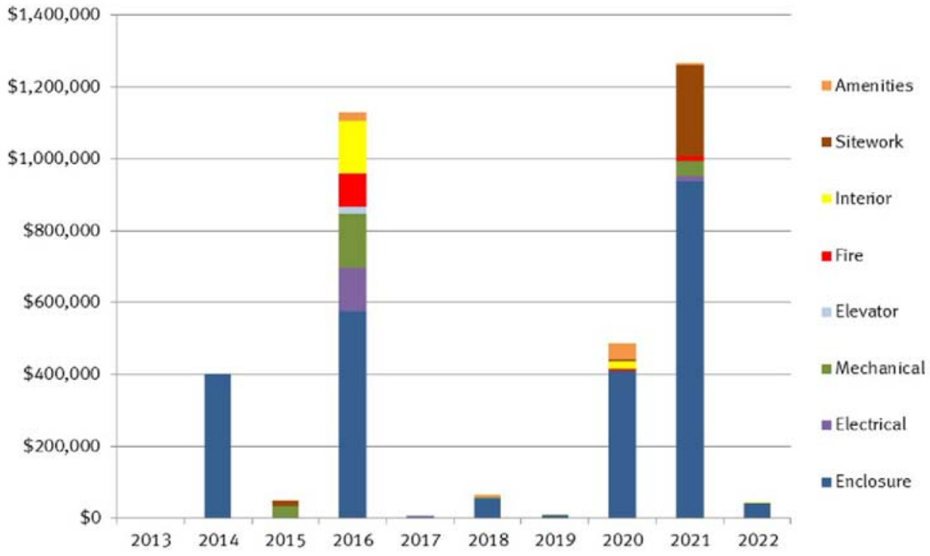

Figure 1. Sample of a 10-year tactical plan from a replacement reserve study.

The enclosure system (shown in "dark blue") has a tendency, due to its heavy portion of the capital load, to overshadow the other systems by a significant margin. Where the capital load provides a total funding requirement to establish an annual funding contribution (“linear”) this needs to factor for the uneven (“lumpy”) distribution of projects. The challenge for the owners, managers and operators is to ensure that the cumulative annual contribution is sufficient to scale the lumpy years or additional capital calls (special assessments) will be required in certain years. These lumps are typically associated with certain expensive projects that can be identified by further analysis of the capital load in the form of a capital consumption index.

4.2 The Capital Consumption Index (CCI)

A sorting of the capital load by each asset within a building returns a ranked list of the asset register with the respective capital consumption rates of each asset. This list is referred to as the Capital Consumption Index (CCI), the purpose of which is manifold, including: to establish separate sinking funds within the collective replacement reserve fund; to identify capital cash flow requirements; and to match an appropriate maintenance strategy to each asset based on risk-based maintenance principles. Table 3 provides a conceptual example of the ranking of the most expensive assets of a sample building.

Table 3. CCI ranking of the three most expensive asset renewal projects.

Asset ID in the asset register	Asset CCI Rank	Parent System	Capital Cost in Future Value (FV)	Ratio relative to the Capital Load of $6,367,000
Asset #5	1	Enclosure	$2,400,000	37%
Asset #17	2	Mechanical	$1,100,000	17%
Asset #4	3	Enclosure	$ 850,000	13%
…	…	…	…	…
Asset #52	71	Finishes	$ 4,000	< 1%

There are several factors that impact the capital consumption rate for each asset, including volume and scale of the asset, accessibility, maintainability, durability, and integration with other assets. The aggregated amount of money spent on maintaining the asset over its useful service life relative to the eventual cost of replacement is expressed in a maintenance-to-replacement ratio.

5 Top-Down Assessment across Multiple Buildings

The data from the statistical population of 598 buildings was aggregated in order to develop the benchmarking analysis, the financial rules of thumb and the quality control mechanism.

5.1 Asset Counts

While there is currently no industry standard in BC for an appropriate level of granularity for capital reporting on assets in MURBS, it is generally accepted that level-3 of the ASTM Uniformat II classification is appropriate, particularly given the efficacy of aligning the asset register to the granularity of the line items in the owners' operating budget. Table 4 provides a summary of the average number of assets within each of the eight primary systems at high-rise (HR), low-rise (LR) and townhouse (TH) complexes.

Table 4. Average number of assets per system for each building class.

System	Sampling of assets from the asset registry	HR assets	LR assets	TH assets	Avg.
Enclosure	Roofs, decks, balconies, glazing, cladding, etc.	22	21	16	20
Electrical	Transformers, switchgear, lighting, security, etc.	8	6	4	6
Mechanical	Plumbing, drainage, heating, ventilation, etc.	23	17	7	15
Fire Safety	Control, detection, suppression, egress, etc.	8	7	3	6
Elevators	Controls, pumps, tanks, cylinder, cab, etc.	2	2	0	2
Finishes	Flooring, wall coverings, furniture, millwork, etc.	10	8	2	7
Amenities	Fitness equipment, sauna, hot tub, etc.	9	6	4	6
Sitework	Fencing, paving, landscaping, irrigation, etc.	8	9	11	9
	Averages	90	76	47	71

High-rise buildings have the largest number of assets (90 average), followed by low-rise buildings (76 average) and then townhouse complexes (47 average). These counts correspond to the unique physical attributes and functional needs of these three types of MURB developments. The enclosure system and the mechanical system represent the largest counts of assets in the total asset registry across all three building types.

While the asset counts provide a statistical summary that can be useful for consultants to ascertain the level of effort of each discipline in the preparation of replacement reserve studies, it is important to extend this analysis, principally for the benefit of the owners, by attaching certain weights and ranks derived from other metrics, such as major maintenance requirements, useful services lives, replacement costs and consequences of failure after the point of functional failure. These additional facets provide for a meaningful prioritization scheme that is matched to the lifecycle behaviour of each asset and the development of a corresponding risk-based maintenance model to translate the capital load into actionable information to guide to the owners, managers and operators in making stewardship decisions.

5.2 Asset Service Lives

While all the assets are susceptible to physical deterioration, some of the systems contain assets that are subject also to varied forces of obsolescence. Technological obsolescence, associated with diminished manufacturing of replacement parts is a powerful renewal driver in the electrical system, principally assets such as elevator controls and fire alarm controls. Economic obsolescence, principally associated with energy efficiency measures, is impactful on the enclosure system (primary), followed by the electrical and mechanical systems (secondary). Recognizing the impact of physical deterioration, coupled with other replacement drivers, Table 5 provides a summary of the number of assets within each system that are considered to be fall within three broad "durability" classes.

Table 5. Percentage of assets per system that fall into the three durability classes.

System	**Long Life Assets** 30+ years	**Medium Life Assets** 17-29 years	**Short Life Assets** 1-16 years
Enclosure	35%	52%	13%
Electrical	35%	46%	18%
Mechanical	24%	42%	34%
Fire Safety	31%	53%	16%
Elevators	10%	76%	14%
Finishes	23%	45%	32%
Amenities	6%	57%	37%
Sitework	55%	28%	17%
	24%	**50%**	**23%**

The boundaries for the three durability classes were derived from physical patterns in the observed life tables of the longitudinal study, the dispersions on the probability distribution curves, and the financial patterns arising from the expenditure forecasts over the planning horizon. Within this classification scheme, approximately half of all assets within MURBS are deemed to be medium-life assets (17-29 years). In this regard, a 30 year planning horizon for a replacement reserve study is considered reasonable and prudent. Figure 2 provides a visual representation the durability distributions by system.

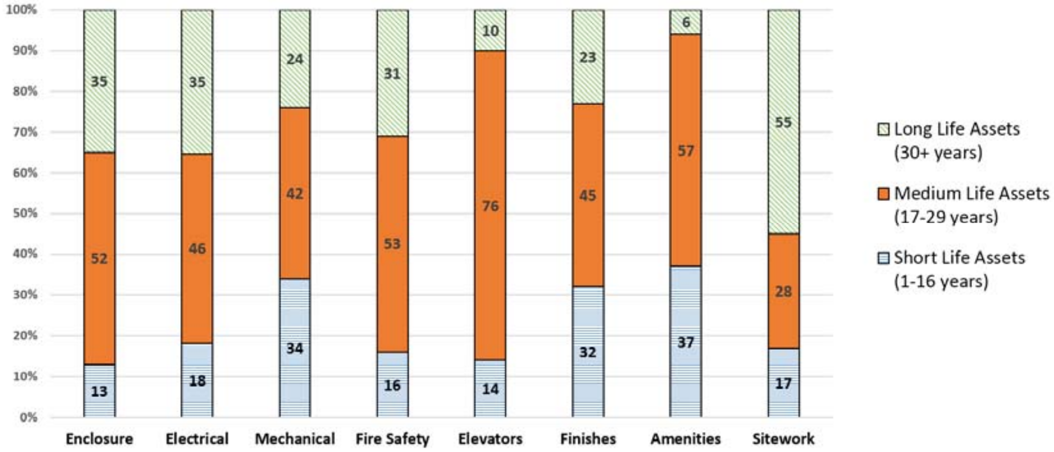

Figure 2. Ratios of long-life, short-life and medium-life assets within each system.

With the exception of elevators and site work, there are subtle differences between the durability distributions within each of the systems. It should be noted, however, that small differences can have significant financial ramifications, particularly since some of the long-life assets are relatively expensive to replace. While long life assets are generally robust in nature, they may have a low asset utilization rate (such as a standby generator that does not accumulate many run hours per year) and a low maintenance-to-replacement ratio (such as unit substations which requires relatively minimal maintenance). Some short-life assets require extensive maintenance on regular intervals (such as balcony membranes), whereas, some long-life assets require infrequent maintenance interventions on longer cycles thereby lowering the ratio of routine maintenance costs to capital renewal costs.

While there is a correlation between long-life assets and larger projects costs, it must be recognized that smaller value projects, on shorter cyclical intervals, will have material value as a group, particularly when accumulated over a 30 year horizon. In this light, we turn our attention to project values and correlate this with the durability classes.

5.3 Project Values

Owners are principally concerned with the impact of projects on the bottom line and whether to fund certain projects as either a capital expense (capex) or operating expense (opex). Recognizing that a capital cost threshold is a common means of distinguishing expense categories, the data set was filtered to identify projects above certain threshold values and the resultant project counts were mapped against each system across the three building classes. Table 6 returns the results from a $500,000 threshold, which was deemed to have sufficient materiality to flush out the relatively large projects that would be deemed legitimate capex in all circumstances.

Table 6. Count of capital projects over $500,000 in value across the 598 buildings.

System	**HR**	**LR**	**TH**
Enclosure	467	443	391
Electrical	3	2	0
Mechanical	97	79	21
Fire Safety	5	3	0
Elevators	49	22	0
Finishes	24	19	4
Amenities	1	4	0
Sitework	2	4	26

Based on the data in the subset of 598 buildings, the vast majority of large capital projects were within the enclosure system, followed by the mechanical system. The capital projects classification included both major maintenance activities (for asset preservation while in service) and asset renewal at end of useful service life. To reveal the proximity of these projects to the base year, Table 7 provides a sampling of the some of the key projects that have their first occurrence at different life stages.

Table 7. Sampling of typical asset renewal projects at different life stages of buildings.

System	Stage 1: **0-16 years**	Stage 2: **17-29 years**	Stage 3: **30-49 years**	Stage 4: **50+ years**
Enclosure system	Balcony membranes; exterior paints, stains and coatings; some sealants (urethanes); sealed IGUs.	Most low slope roofs, some pitched roofs; some exterior sealants (silicones); sliding glass doors.	Cladding and glazing; some pitched roofs.	Cladding and glazing
Other systems	Recirculating pumps; overhead gate motors; sump pumps; hallway carpets; domestic water heaters.	Boilers; exhaust fans; make-up air units; plumbing distribution piping; fire alarm panels, elevator controls; interior re-decorating.	Transformers, switch gear; some hard paving.	Sanitary and storm water collection; some hard paving.

The enclosure system includes a mix of long-life assets (such as cladding), medium life assets (such as roofs) and short life assets (such as paint coatings and balcony membranes). Some assets straddle different age classes depending on product applications, such as urethane sealants (short-life) and silicone sealants (medium-life).

Since all projects include escalation to future value, it is important to recognize the long-life assets including the compounding effects over longer time spans than the short-life assets. Figure 3 provides a conceptual representation of the resultant capital cost distribution at the different life cycle stages based upon the aggregated data from the 598 buildings. This distribution contemplates the compounding effect of escalation and the repeat intervals of short-life assets over the 30-year planning horizon.

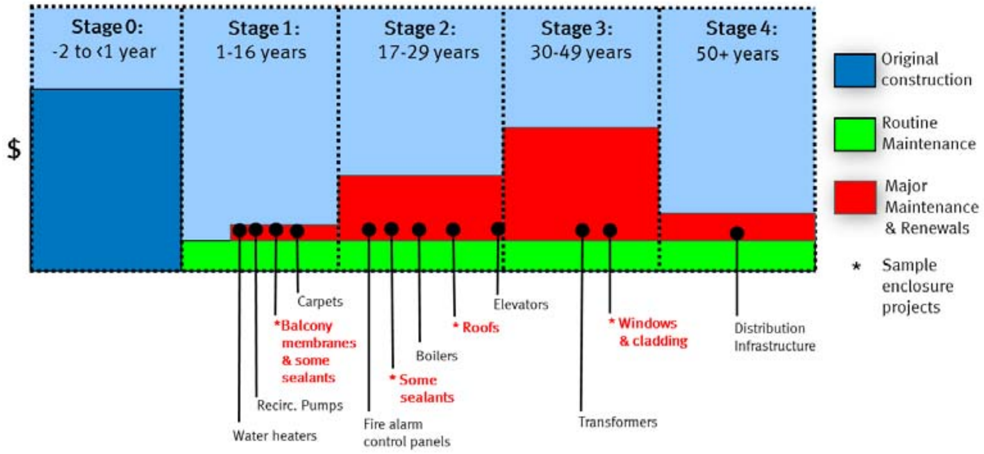

Figure 3. Financial model of the distribution of capital costs over the four life stages with sample projects.

This financial model is useful in conceptualizing the variability in the order of magnitude project expenditures forecast at different stages in a building’s life cycle. The four life-stages together represent one life-cycle of a building. The authors expect that most residential buildings in BC will continue to operate through multiple life-cycles. The necessary and sufficient maintenance during the first life-cycle (years 1-50) will prepare the owners for the 2nd life-cycle (years 51-100).

5.4 Asset CCI

The capital consumption index, which is a translation of the capital load to individual assets, is typically ranked from the most expensive project to the least expensive project. Table 8 provides a sample from a CCI ranked list of assets from the dataset of 598 buildings.

Table 8. Sampling from CCI ranking of some of the most expensive asset renewal projects.

Project Name	**Asset Durability Rank**	**Asset CCI Rank**	**Parent System**	**HR**	**LR**	**TH**
* Re-glazing	Long Life	1	* Enclosure	✓	✓	✓
* Re-cladding	Long Life	2	* Enclosure	✓	✓	✓
Domestic plumbing re-piping/relining	Med. Life	3	Mechanical	✓	✓	
In-ground site infrastructure	Long Life	4	Site work		✓	✓
* Re-roofing, low slope and sloped	Med. Life	5	* Enclosure	✓	✓	✓
* At grade/podium waterproofing	Med. Life	6	* Enclosure	✓		
* Exterior sealant	Med. Life	7	* Enclosure	✓	✓	
Unit substation	Long Life	8	Electrical	✓		
* Parking garage traffic membranes	Short Life	9	* Enclosure	✓	✓	
Exterior roadways	Long Life	10	Site work			✓
Elevator modernization	Med. Life	11	Elevators	✓	✓	
Unit substation	Long Life	12	Electrical	✓		
* Exterior repainting of cladding/trim	Short Life	13	* Enclosure	✓	✓	✓
Fire alarm retrofit	Med. Life	14	Fire safety	✓	✓	

Based on the research data set, the enclosure system has seven of the most expensive projects (*) that a typical MURB in BC will encounter across the four life stages shown in Figure 3. The funding requirements for these types of significant projects complicates the linear (amortized) annual rates that are applied effectively to smaller projects across the planning horizon. Identification of the types of large projects and their proximity to the base year is of tremendous value to the owners in determining an appropriate funding trajectory.

5.5 Cost Distributions by Building Class

While buildings exhibit variability in their physical attributes across the three building classes, the net result of the financial analysis is less varied. The following table illustrates the capital load distributed by system across the three building classes.

Table 9. Distribution of the 30-year capital load across each system (irrespective of age).

System	**HR**	**LR**	**TH**	**Average**	**Range**
Enclosure	60 %	62 %	79 %	65%	19%
Electrical	5 %	4 %	2 %	4%	5%
Mechanical	17 %	15 %	6 %	14%	11%
Fire protection	3 %	3 %	1 %	2%	2%
Elevators	6 %	5 %	n/a	4%	6%
Finishes	6 %	6 %	1 %	5%	5%
Amenities	1 %	1 %	1 %	1%	0%
Site work	2 %	3 %	10 %	4%	9%

The following figure provides a graphical summary of these distributions.

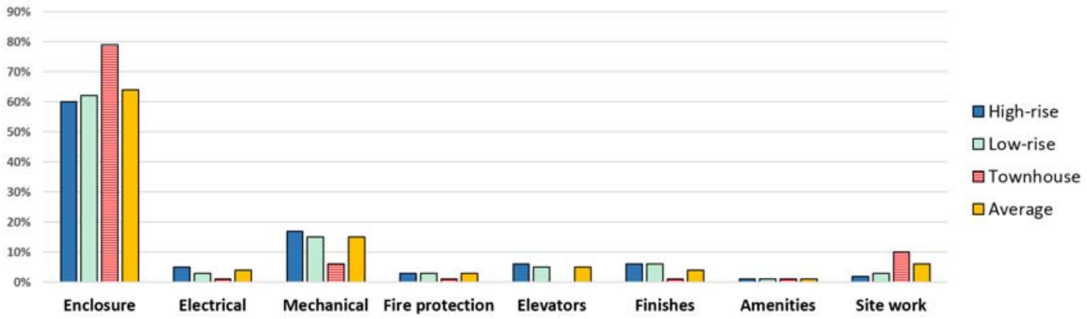

Figure 4. Percentages that each system contributes to the capital load at the three building types.

It is clear and unequivocal that the building enclosure is consistently the most expensive system for all building types and by a significant margin (at an average of 65% of the capital load) followed by the mechanical system (at an average of 14% of the capital load). The enclosure system also has the largest variability across the building classes, with an 18% difference between high-rise buildings at the lower-end (60%) and townhouse at the higher-end (79%). The significant costs of the enclosure system is associated with many factors, including: a) layered and highly integrated assemblies, b) site overhead costs associated with gaining safe access to the assemblies on the exterior facade of the building; c) longer durations for attending to the large field areas for major maintenance activities and renewal projects (as opposed to service on terminal and packaged devices of the mechanical and electrical systems); d) the limited opportunities for swap-out or rebuild of internal components; and e) higher demolition costs of the field areas.

The higher ratio of relative enclosure costs at the townhouse complexes is an expression of the reduced number of electrical and mechanical assets at these developments and greater surface area of roofs and walls relative to each unit. High-rise buildings have larger volumes of repetitive enclosure elements and are therefore able to leverage some economies of scale over the other two building classes.

5.6 Evaluation at Different Life Stages

As buildings age, the distribution of the capital load varies at each life stage. The following table illustrates the capital load ratio for the enclosure system for each of the four building classes across the four life stages.

Table 10. The enclosure system portion of capital load at different life stages

Enclosure portion of the capital load	**0-16 years**	**17-30 years**	**31-50 years**	**50+ years**	**Average**	**Range** 0 - 50yrs
HR	58.85	63.30	59.88	-	60%	4%
LR	58.11	66.82	59.29	(44.92)	62%	6%
TH	83.21	76.12	75.91	-	79%	8%

The enclosure portion of the capital load does not vary much between each life stage, which is a reflection of the straight line amortization over the 30-year planning horizon. A longer planning horizon, however, would result in greater variability. Since the earliest condominiums in British Columbia were constructed in the late 1960s there is currently insufficient data for extended modelling in this jurisdiction. The data on low-rise buildings over 50 years in age arises principally from heritage conversion projects that are present only in this building class and are not yet statistically significant.

6 Risk Management Considerations

Recognizing the relative criticality of the enclosure system, in terms of its significant impact on a sustainable investment for the owners, this paper concludes by pointing towards a metric to guide the refinement of risk-based maintenance strategies in the residential sector, principally for condominiums in British Columbia.

A program of leveraging the maximum service lives from the enclosure assets, with the intent of delaying the renewal projects as long as reasonably possible and to buy additional time to raise funds, requires a significant investment in preservation activities geared towards the dual goal of "reaching" life (in some cases) and "extending" life (in other cases). Under-maintenance will fail to mitigate capital costs but over-maintenance will have diminishing returns. The types of maintenance tasks and their intervals, must be aligned to each of the enclosure assets based upon the impact of each maintenance tasks in managing risk relative to the probability of failure (PoF) and the consequences of failure (CoF) of the enclosure assets. The varying degrees of maintenance on the different assets can be articulated by a maintenance-to-replacement ratio (MRR), which is as metric that provides a useful measure of the return on investment in preserving each asset. Using an illustration, should the owners spend $18,000 maintaining the roof over a 25-year period, and at the end of its life incur a cost of $180,000 to replace that same roof, the MRR would be 10%.

Higher MRRs need to be supported by a compelling argument that the preservation investment is not resulting in over-maintenance but is necessary to lower the PoF (such as shifting of the modal year on a survivor curve) and mitigate against the CoF (such as collateral damage or safety). Similarly, assets with lower MRRs, need to be guarded against possible under-maintenance. In this way the owners, have access to a means by which to periodically test the efficacy of their asset maintenance program and obtain a line-of-sight from their current annual plan (operational) to the mid-range plan (tactical) and the long-range plan (strategic).

References

[1] Albrice, D., Branch, M. (2013). *Quantifying and Benchmarking the Unfunded Liability of 600 Condominium Buildings in BC*. Institute of Asset Management and Institute of Engineering Technology.