EVALUATION OF BUDGETING METHODS FOR MAINTENANCE OF HERITAGE BUILDINGS

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ABSTRACT

Heritage buildings have evolved into development catalysts that, when properly maintained, can improve their surrounding area's liveability while sustaining productivity in an ever-changing global context. Unfortunately, the high uncertainty involved in preserving heritage buildings frequently leads to over-budget projects. This article evaluates the factors that contribute to projects being over budget and the methods used to develop project budgets. History-based budgeting methods, value-oriented budgeting methods, analytical budgeting methods, and budgeting by condition description are frequently used, while new artificial intelligence models are also emerging. In addition, the review considers the Monte Carlo method and compares it with artificial intelligence models. Considering the high uncertainty involved when maintaining heritage buildings, it is concluded that the Monte Carlo method could be a very effective tool. For this reason, it is recommended that its use be tested on heritage building projects.

OPSOMMING

Erfenisgeboue het ontwikkel in ontwikkelingskatalisators wat wanneer behoorlik onderhou word hul die omliggende gebiede se leefbaarheid kan verbeter terwyl produktiwiteit in 'n voortdurend veranderende globale konteks volgehou word. Ongelukkig lei die hoë onsekerheid verbonde aan die bewaring van erfenisgeboue dikwels tot projekte wat hul begroting oorskrei. Hierdie artikel evalueer die faktore wat daartoe bydra dat projekte oorspandeer en die metodes wat gebruik word om projekbegrotings te ontwikkel. Geskiedenisgebaseerde begrotings-metodes, waardegeoriënteerde begrotingsmetodes, analitiese begrotingsmetodes en begroting volgens toestandbeskrywing word gereeld gebruik, terwyl nuwe kunsmatige intelligensie modelle ook na vore kom. Daarbenewens word die Monte Carlo methode oorweeg en met kunsmatige intelligensie-modelle vergelyk. Met inagneming van die hoë onsekerheid wat betrokke is by die instandhouding van erfenisgeboue, word tot die gevolgtrekking gekom dat die Monte Carlo metode 'n baie effektiewe hulpmiddel kan wees. Om hierdie rede word aanbeveel dat die gebruik daarvan op erfenisbouprojekte getoets word.

1. INTRODUCTION

Buildings are designed and constructed to fulfil a variety of functions, and they must continue to function as intended throughout their lifecycle. However, buildings are exposed to environmental factors that cause them to degrade, prompting the need for maintenance to ensure that they continue to function and perform as intended. Neglect, insufficient maintenance management, and a lack of awareness of heritage buildings may also contribute to the degradation of heritage buildings [1]. As a result, every building, whether heritage or non-heritage, requires maintenance and protection to avoid degradation [2] and to extend its life and functioning [3].

Heritage buildings are a valuable inheritance, with sentimental values attached to a distinct history, culture, and tradition that need preservation [4]. Lack of maintenance of heritage buildings can affect their functions, operation, and performance [5]. Appropriate maintenance is required to ensure their longevity. However, the maintenance of heritage buildings or conservation projects frequently fails to achieve the delivery objectives of quality, time, and cost (budget) [4].

This research examines the literature on heritage building maintenance and evaluates cost prediction models.

2. LITERATURE SURVEY

2.1. Heritage buildings

In South Africa, heritage buildings are all structures over sixty years old that are protected under the National Heritage Resources Act, 25 of 1999 (NHRAct), including their fixtures and fittings. Thus, any alterations, demolitions, or modifications to such structures must be approved and permitted by the Heritage Conservation Commission or the Provincial Heritage Resources Authority. The relevant section of the National Heritage Resources Act reads:

> *"section 34 (1) No person may alter or demolish any structure or part of a structure, which is older than 60 years without a permit issued by the relevant provincial heritage resources authority."*

Heritage buildings are structures that inspire us to learn more about the people and cultures who created them [6]-[8]. Heritage buildings' aesthetic qualities and their historical, social, spiritual, and symbolic value contribute to their significance [9]. Therefore, they require ongoing care and protection to preserve their historical, architectural, artistic, archaeological, spiritual, political, and economic importance [9], [10]. Several researchers support the central theme of the value of conservation and preservation rather than destruction [11].

Aside from such arguments, supporters of heritage building preservation argue that there are secondary advantages, such as increased tourism, employment, energy savings, waste reduction, and the direct benefit of upgrading the building stock [12]. As a result, demolishing heritage structures is not an option in many cases, since it poses a severe threat to the land's value and lifespan.

2.2. Factors affecting budget overrun in heritage buildings

Maintenance management aims to reduce the need for building defect repair by improving planning and execution, using appropriate materials and equipment at the right time, and lowering overall lifecycle costs [13]. Building age, function, building or unit size, building height, the kind of building structure, finishes used, services, building materials, and others are all included as building characteristics. These features typically differ from building to building, and require a distinct distribution and allocation of maintenance costs to be preserved [14]-[17]. The height and shape of a building may also influence its maintenance expenses [18].

Cost overrun is the difference between actual and expected expenses [19]-[22]. It is one of the most critical aspects that can prevent the development and, in some cases, the success of a project. It affects the project and the contractor's profit, potentially resulting in project failure [20]. Cost overruns are common in construction projects, whether new or maintenance, and they vary from project to project depending on the extent and complexity of the work.

Inflation contributes to cost overruns and delays in heritage renovations [23]. Other aspects include increased environmental restrictions, poor site management, poor cost control, a lack of resource planning, claims and disputes with clients, poor relationships with subcontractors, the cost of accidents (damage, injury, and death), unclear and inadequate drawing design details, and misunderstanding municipal requirements. In addition, human factors, tools and equipment, replacement parts and materials, funding allocation, and available information can also lead to cost overruns [24].

Changes in the scope of work are a significant contributor to cost overruns. Deviations are common in construction projects, but are significantly more prevalent in heritage buildings [25]. In addition, the lack of as-built drawings and other information is typical of heritage buildings, and can contribute to the prevalence of cost overruns on heritage buildings [25].

Poor craftsmanship and training are common in maintenance projects [26], [27], and frequently result in human mistakes [28] that might have short- and long-term impacts on maintenance costs [29]. In addition, extra remedies might be necessary to address such flaws. Poor training can also increase the building upkeep costs.

Building services offer tenants or inhabitants a healthy and safe environment [30]. These include water supply, power, communication systems, and ventilation [31]. However, the availability of construction materials, elements, components, facilities, and services and the low quality of spare parts can influence maintenance costs [28], [32]. In addition, incompatibility and poor-quality materials used during construction [33] can significantly impact the asset's maintenance, operating expense, and life service [34]. Corrosion of plumbing and drainage systems may also increase maintenance requirements [35].

The tenants or residents have an impact on the maintenance cost of a building [28]. The use of the property, vandalism by tenants, failure or delay in reporting failures, and accessibility to the property [29] can influence maintenance costs. Up to 25 per cent of total maintenance needs can be a result of tenant influence [36]. Yip [37] suggests that the maintenance manager strategise with tenants to reduce the gap between maintenance management and legitimate expectations or demand.

Political issues can also impact the cost of maintenance, especially when national or local government policies change [29]. 'Right to purchase' legislation, new health and safety rules [38], and inadequate management are contributing factors.

Owners frequently underestimate the total costs [28] of preserving a building in its original state [39]. Thus, it is vital to budget sufficiently for building maintenance.

2.3. Budgeting techniques used for the maintenance of buildings

This section describes the budgeting technique models that are commonly used to estimate maintenance costs or project costs.

'Maintenance cost' includes all costs associated with maintenance, restoration, and improvement [24]. The expected maintenance cost can be determined using different techniques. It is challenging to estimate the expected cost of conservation work [4], since it is difficult to foresee the nature of such work in respect of its ultimate content, scope, and requirements. In many cases, the precise work can only be determined once the structure has been opened and dismantled [4]. The accuracy of budgeting for maintenance work also depends on the available information, such as the nature of the building, the maintenance strategies, conditions under which the maintenance is to be implemented, labour costs, prices of materials and spare parts, and funds available to support the maintenance work.

The budgeting methods for the maintenance of buildings identified in the literature include key figure-orientated or history-based budgeting methods, value-orientated budgeting methods, analytical calculation of maintenance, and budgeting by condition description.

2.3.1. Key figure-orientated or history-based budgeting methods

This approach uses key figures related to historical spending – for example, the maintenance cost per square metre based on gross floor area (GFA). This approach is often used since it does not need professional knowledge or significant computation [40]. However, it is criticised [41] because it assumes an average maintenance expenditure over multiple years, and does not foresee high-uncertainty circumstances.

2.3.2. *Value-orientated budgeting methods*

The yearly standard rate multiplied by the specific building value is used to generate the maintenance budget using general flat or fixed rates [40], [41]. The value-oriented strategy is simple to use, and allows for quick and uncomplicated financial computations. However, this technique is criticised [40] because it is based on constant average values, and does not account for cyclic deviations or annual increases in construction costs.

2.3.3. *Analytical methods*

Analytical approaches, as opposed to key figure- or value-oriented methods, provide a more thorough picture of the maintenance resources that are needed. This approach allows maintenance specialists to do more exact and building-specific estimations of the necessary maintenance methods [40], [42]. Once all of the essential building data, such as geometry, technology level, location, and so on, have been obtained, calculating yearly maintenance costs takes just a little longer than using the above methods [40].

2.3.4. *Budgeting by description of the condition*

Condition-oriented budgeting is among the most accurate calculation techniques [40]. It is based on systematic and periodic building inspections and the subsequent description of the status of specific building components. This method has the benefit of detecting and determining maintenance requirements early on. Budgets can be created based on priorities, allowing for the immediate repair of current damage and avoiding costly secondary harm [41]. However, different inspectors might provide different ratings for the same building, based on their competence and personal opinions [40]. This necessitates the use of standardised valuation standards that are used consistently throughout building inspections.

2.4. Cost prediction models

Cost prediction is essential for any corporation, since it is a precursor to budgeting and resource allocation. However, obtaining input data when the extent of work is unknown can result in inaccurate estimates [43]. Therefore, several cost prediction models have been developed to improve predictions. This section compares and contrasts several costing models and their use. Table 1 illustrates some of the models that have been used, and their application scope, in research published from 1995 to 2020.

Table 1: Cost models used by previous researchers

No.	Author	Year	Cost method	Scope
1	Tijanić *et al*. [44]	2020	Artificial neural network (ANN)	Estimating road construction
2	Kwon *et al*. [45]	2019	Case-based reasoning (CBR)	Cost prediction for ageing residential buildings
3	Kwon *et al*. [46]	2019	CBR	Compensation cost estimation model for construction noise claims
4	Mubin [47]	2019	Monte Carlo simulation	Modelling of schedule, cost, and risks of Dasu hydropower project
5	Kwon *et al*. [48]	2019	CBR and genetic algorithm	Service life estimation for MEP components
6	Kim *et al*. [49]	2019	Loss distribution approach (LDA)	Building maintenance costs of apartment housing in Korea
7	Hashemi *et al*. [50]	2017	ANN and genetic algorithm (GA)	Cost estimating model for power plant projects
8	Joubert and Pretorius [51]	2017	Monte Carlo simulation	Creating a ranked checklist of risks in a portfolio of railway construction

No.	Author	Year	Cost method	Scope
9	Pesko *et al*. [52]	2017	ANN and support vector machines (SVM)	Estimating costs and duration of urban roads
10	Marzouk and Elkadi [53]	2016	Factor analysis and ANN	Estimating water treatment plants
11	Yip *et al*. [54]	2014	General regression neural network and Box–Jenkins time series models	Predicting the maintenance cost of construction equipment
12	Kim [55]	2013	CBR and AHP	Highway projects
13	Wyrozebski and Wyrnzebska [56]	2013	Programme evaluation review technique (PERT), graphical evaluation and review technique (GERT), and Monte Carlo simulation	Project planning
14	Gunduz *et al*. [57]	2011	The parametric cost estimation system	Estimating the cost of light rail transit and metro networks
15	Kim [58]	2011	CBR	The railway bridge project is in the planning phase
16	Edwards *et al*. [59]	2010	General regression neural network (GRNNs)	Cost of construction equipment maintenance
17	Chou [60]	2009	Web-based CBR system	Cost budgeting for a pavement maintenance project
18	Palcic and Lalic [61]	2009	Analytical hierarchy process (AHP)	Selecting and evaluating the process
19	Cheng *et al*. [34]	2009a	Evolutionary fuzzy hybrid neural network model (EFHNN)	Design phase cost estimation of projects in Taiwan
20	Lai *et al*. [62]	2008	AHP and simulation-based	Cost budget determination for public construction projects
21	Bouabaz and Hamami [63]	2008	ANN	Estimating costs of repair of bridges
22	An *et al*. [64]	2007	CBR and AHP	Construction costs
23	Kim *et al*. [65]	2005	ANN and GA	Preliminary estimate of residential buildings
24	Sonmez [66]	2004	Regression analysis and neural networks	Estimation of building projects
25	Trost and Oberlender [67]	2003	Multiple linear regression (MLR) and factor analysis	Preliminary estimate of capital projects
26	Attalla and Hegazy [68]	2003	ANN	Reconstruction projects
27	Williams [69]	2003	Regression models	Bid construction projects
28	Bjornson and Barney [70]	1999	Neural networks	Tax court determination of reasonable compensation
29	Hegazy and Ayed [71]	1998	Parametric cost-estimating	Projects where little information is known about the scope of the project
30	Hsu *et al*. [72]	1995	Neural networks	Rainfall-runoff process

2.4.1. *Case-based reasoning*

Case-based reasoning (CBR) is an artificial intelligence strategy for solving a given problem. It uses the data and knowledge obtained from previous comparable situations. This is the type of analogical reasoning that concentrates on reasoning that is based on prior experience [73]-[76]. This technique has been widely implemented in different domains because it can identify answers, even when the existing problems are not well-structured or the associated data is poor. Case-based reasoning has been used to forecast maintenance expenses for ageing residential structures in Taiwan [48] and to develop a web-based CBR system that could be used to estimate early costs for pavement maintenance projects [60]. CBR can handle a variety of parameters for estimation, including numerical and nominal data such as areas and building kinds, the number of households, year of construction, and repair items [77]. Cases are retrieved in CBR based on their similarity, which is defined by the distance measurement function and the weights of the characteristics [78].

However, the application of CBR to maintenance cost calculations is problematic because the relevant data might not be consistently gathered [45]. This necessitates the creation of a reliable database.

2.4.2. *Analytical hierarchy process*

Dr Thomas Saaty created this approach in 1980 to aid in the resolution of technical and administrative issues [79]. The analytical hierarchy process (AHP) approach is becoming a more relevant tool in many decision-making scenarios. Its goal is to quantify relative priorities for a specific variety of options on a proportional scale, based on the decision-judgement maker. The AHP is appropriate for sectors where intuition, rationality, and irrationality are present about risk and uncertainty [61]. This approach is used to weight the various assessment criteria, and simulation is subsequently used to generate a variety of feasible project budgets using project expenses (budgets) as variables [62].

The AHP can be combined with a multi-criteria assessment model to provide a simulation-based cost model [62]. For example, Palcic and Lalic [61] used the AHP to select and evaluate projects. Using multi-attribute utility theory and AHP, Marzouk and Moselhi [80] developed a model to predict markup and assess bid offers. For construction project bid markup choices, Dozzi *et al*. [81] applied an AHP-based multi-criteria utility theory. The AHP approach, according to Chou [62], is an effective tool for tackling multi-criteria decision making (MCDM) problems such as determining building project expenditures.

2.4.3. *Loss distribution approach*

Banks and insurance firms generally use the loss-distribution approach (LDA) to estimate and measure the related operational risks and estimate loss distributions, based on real data, to evaluate the projected losses caused by accidents [49]. The LDA is essentially a statistical analytic approach that allows the user to determine cost factors such as the average, deviation, and variance. The LDA is a mixture of the loss-frequency and loss-severity distributions. The loss-frequency distribution shows how often a loss will occur over a certain risk measurement period, while the loss-severity distribution shows how much loss will be suffered each time [49]. The loss distribution for each event type and business line can be estimated using the LDA [82], allowing users to predict the entire loss distribution. The capacity to predict the loss distribution of operational risk, based on a risk matrix, is the most important aspect of the LDA [49].

This technique can be used to estimate future necessary maintenance costs by calculating distributed maintenance costs, based on a thorough examination of numerous scenarios [49]. Kim, Lee and Ahn [49] add that the LDA method could be used to assess various aspects with specific inherent hazards. However, it is feasible to predict the cost for a broad range of specific maintenance scenarios using this thorough matrix.

2.4.4. *General regression neural network*

The general regression neural network (GRNN) has been used to forecast the cost of construction equipment maintenance [59]. For example, a multilayer perception (MLP) model was used to estimate the future value of construction plant maintenance costs. It was concluded that MLP neural networks outperform other modelling techniques such as multiple regression. In addition, Hong and Pai [83] examined the effectiveness of several models in forecasting engine reliability measures, including general regression neural networks (GRNNs), support vector machines, and auto regressive moving average (ARMA).

In comparison, Yip *et al*. [54] employed artificial neural networks, general regression neural networks (GRNN), Box-Jenkins models, time series models, and analysis to detect the complex underlying nonlinear interactions among time series data.

2.4.5. Artificial neural network (ANN)

McCulloch and Pitts developed the first mathematical model of an artificial neural network (ANN) in 1943 [84]. An ANN is a mathematical model that attempts to model the structure and functions of biological neural networks [85], [86]. ANNs are adaptive nonlinear information processing systems that integrate several processing units with properties such as self-adapting, self-organising, and real-time learning [87]. ANN research has progressed significantly, and has been extensively used [88].

An ANN is very data-driven, and performs poorly when given a small quantity of data [70], resulting in over-specification, which means that it can perform well with existing data but cannot anticipate new scenarios. ANNs are advantageous since they can generate predictions with less established statistical training [89], expose all possible interrelationships between variables, and can be developed using various training approaches. However, determining causality might be difficult with ANNs. They are also computationally complex and vulnerable to overfitting [90].

ANNs can handle complex problems, including pattern recognition, grouping, classification, and prediction/forecasting [72]. For example, in forecasting problems, it has been shown [43] that neural networks can be trained using historical data, and then forecast new situations based on their generalisation capability.

To anticipate the early expenses of residential structures, Kim *et al*. [65] developed a hybrid model combining an ANN and a genetic algorithm (GA), using data from residential structures built in South Korea from 1992 to 2000 to predict the initial costs of residential buildings using hybrid models of ANNs and GAs. They concluded that a GA could help estimators to overcome the problem of a lack of appropriate rules for estimating ANN parameters.

Cheng *et al*. [34] created a new model method by combining three different soft computing paradigms – GAs, fuzzy logic theory, and neural networks – into a method called the evolutionary fuzzy hybrid neural network model (EFHNN) to estimate project costs during the design phase in Taiwan. As a result, they were able to obtain a 10.36% total estimation accuracy. However, the downside was that it had a very long computation time.

2.4.6. Genetic algorithm

John Holland developed genetic algorithms (GAs) in the 1960s. He later refined them with assistance from his students and colleagues at the University of Michigan in the 1960s and 1970s [91]. Holland intended to evaluate adaptation phenomena as they occured in nature and to explore ways to incorporate natural adaptation processes into computer systems. One of these meta-heuristic methodologies and evolutionary computing models is the GA [43].

For example, Kwon *et al*. [45] used CBR and GAs to anticipate the cost of maintaining ageing residential structures and MEP component maintenance.

2.4.7. Monte Carlo simulation

The Monte Carlo simulation entails using a statistical sampling approach to approximate solutions to quantitative problems [92]. It has been used in many scientific problems [93]. For instance, a real-life system or scenario model is created, with specific variables having distinct possible values represented by a probability distribution function of the values for each variable. Kwak and Ingall [94] observed that the Monte Carlo approach simulates the whole system several times, up to thousands of times, randomly selecting a value for each variable from its probability distribution. The result is a probability distribution of the system's total value, computed over many iterations [94].

The Monte Carlo simulation is a parallel procedure, meaning that each iteration's outcomes are independent. As a result, the Monte Carlo simulation has been widely employed in engineering and science research [95]. The table below shows how Monte Carlo has been used in studies dating back to 1975.

Table 2: Use of Monte Carlo method by past researchers

No.	Author	Year	Scope
1	Mubin *et al.* [47]	2019	Modelling schedule, cost, and risks of the Dasu hydropower project
2	Joubert and Pretorius [51]	2017	Creating a ranked checklist of risks in a portfolio of railway construction
3	Bouayed [96]	2016	Risk of project cost overruns
4	Wyrozebski and Wymzebska [56]	2013	Project planning
5	Wang *et al.* [95]	2012	Life cycle cost management
6	Boyle *et al.* [97]	1997	Estimate the security pricing
7	Chu *et al.* [98]	1994	In-layer structure formation in thin liquid films
8	Keen and McGreevy [99]	1990	Structural modelling of glass
9	Boyle [100]	1977	Option valuation problems in the theory of finance
10	Bortz *et al.* [101]	1975	Ising spin systems

The key benefit of the Monte Carlo technique over other deterministic models is that it allows for the inclusion of uncertainty in cost analysis [95]. In addition, freeware or commercially available software can be used to perform the analysis [102].

2.5. Comparison of the costing models

A comparison of the costing models is shown in Table 3 below. Most models (CBR, AHP, LDA, GRNN, ANN, EFHNN, and GA) are based on artificial intelligence; these models typically require large amounts of training data to develop effective estimates.

On the other hand, the Monte Carlo method is a stochastic model that can be used with minimal input data and that allows for random variation. For example, it is possible to use a triangular distribution for input estimates and to develop a random distribution of estimated costs.

Table 3: Comparison of the cost models

No.	Comparison factors	CBR	AHP	LDA	GRNN	ANN	EFHNN	GA	MCM
1	Dependent on artificial intelligence	√	√	√	√	√	√	√	X
2	Uses complex software	√	√	√	√	√	√	√	X
3	Dependent on a large amount of historical data	√	X	√	√	√	√	X	X
4	Requires complex mathematical expertise	√	√	√	√	√	√	√	X
5	Three-points estimate as input	X	X	X	X	X	X	X	√
6	Practical and user friendly	X	X	X	X	X	X	X	√
7	Includes uncertainty in cost prediction	X	√	√	√	√	√	X	√

3. CONCLUSION

Budget overruns in conservation projects are typically caused by increased building material costs and a scarcity of traditional construction materials. They can also be influenced by changes in the scope of work, the nature of the building's attributes, and changes in policy and standards. The absence of experienced artisans can also lead to poor craftsmanship.

History-based budgeting methods, value-oriented budgeting methods, analytical budgeting methods, and budgeting by condition description are the most often used budgeting strategies for building maintenance. Still, their accuracy depends on the assumption that sufficient information is available and that it can be effectively used to prepare a budget.

The literature review evaluated alternative methods with the potential to be used to prepare heritage building project budgets. However, most models use artificial intelligence, which requires large amounts of training data. Furthermore, considering that many heritage building projects are unique, the use of pattern recognition techniques is also questionable.

The use of the Monte Carlo method to prepare heritage building project cost estimations has been limited. However, based on the criteria considered here, a Monte Carlo simulation could be an effective tool for this purpose.

4. RECOMMENDATIONS

Heritage building projects are highly variable in nature, and thus it is recommended that the Monte Carlo method be tested on heritage building projects. The results of the simulation could then be compared with the actual results. It should also be useful to evaluate the risk perception of the project managers when using the Monte Carlo method to prepare a budget. The Monte Carlo method allows for uncertainty in input estimates, and can provide a prediction confidence level. It can also be used to identify critical aspects with high levels of uncertainty. This information could then be used to improve the information gathering and planning of these aspects to reduce the uncertainty associated with a project. It would also be useful to evaluate and compare the benefits of various prediction models with each other and to infer which is best to use for specific types of high-value maintenance projects.

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