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Abstract

Purpose – Rising energy costs and increasing environmental concerns are catalysts for introducing sustainable design features in buildings. Incorporating sustainable design features in commercial buildings cannot be overstated because it could confer benefits to the investor (owners) and occupants. This study aims to develop a model that could aid in the prediction of operation and maintenance (O&M) costs from the knowledge of building design variables. There is little evidence that design variables influence the O&M costs of buildings. Therefore, this study investigates the relationship between design variables and O&M costs in commercial buildings with the intent of developing a cost model for estimating O&M costs at the early design phase.

Design/Methodology/Approach – The study was approached quantitatively using a survey strategy. Data for the study were obtained from 30 randomly selected commercial buildings in the CBD in Colombo, Sri Lanka. Pareto's 80/20 rule, correlation, and regression analysis were performed on the data to prove the statistical relationships between the buildings' O&M costs and their design variables.

Findings – The study found that 12 significant O&M costs elements contribute to about 82% of total O&M costs. Repairs and decoration had a strong correlation with building shape. Furthermore, the regression analysis found that O&M costs values were primarily dependent on the building size (the gross floor area and height of the buildings). The gross floor area and height handled over 73% of the variance in the O&M costs of commercial buildings in Sri Lanka.

Originality/Value – These findings are a useful insight into the principles for design economies that could contribute to more sustainable commercial buildings.

Keywords: Commercial buildings; Design variables; Regression analysis; operation and maintenance (O&M) costs; Sustainability.

Introduction

The need to evaluate building energy consumption is heightened in recent times by rising energy costs and environmental considerations. For example, the need to improve building energy performance is driving retrofit projects (Lee, Shepley & Choi, 2019; Gorse, Thomas, Glew & Shenton, 2016), while sustainability and energy efficiency awareness is now demanded to contribute to global environmental goals (Lazarevic, 2019; Gil-Baez, 2019).

Energy consumption in buildings is significant when compared to other economic sectors. For example, buildings construction and operations as end-use sectors consume about 36% of global final energy and produce 39% of energy and process-related CO2 emissions in 2018 (IEA and the UNEP, 2019). This includes the energy use by residential and non-residential building sectors and construction industries that manufacture building construction materials: steel, cement, and glass. Whereas the energy use by other industries such as agriculture, fishing, manufacturing, and services contribute 32%, while transport contributes 28%, and other sectors such as non-specified and non-energy use contribute 4% (IEA, 2019).

In keeping with the United Nations Sustainable Development Goals (SDGs), a key focus of sustainable buildings is goals 11 and 12 of the 17 SDGs, which are: building sustainable communities and achieving sustainable consumption and production respectively (UN, 2019). The built environment must re-evaluate for higher performance by balancing (1) economic, environmental and social constraints (2) building structural systems and (3) long-term functionalities of buildings (AbouHamad & Abu-Hamd, 2019). Innovative sustainability features optimise buildings' economic performance by saving energy costs and drive overall efficiency. Most buildings require little or no added costs to incorporate a reasonable level of sustainable design features (Morris & Langdon, 2007). Particularly when one takes a life cycle cost approach, savings in energy consumption of up to 33% are achievable which significantly outweighs any premium paid at design and construction phases (Dwaikat & Ali, 2016).

However, there is evidence to suggest myopia in investment decisions, wherein decisions are based on the estimates of the initial construction cost, with little or no consideration for O&M costs over the lives of buildings (Al-Hajj & Horner, 1998; Weerasinghe & Ramachandra, 2018). For example, the O&M costs of buildings have a significant impact on the building occupiers' budget and it is widely recognised that up to 80% of the operation, maintenance and replacement costs of a building are influenced by the first 20% of the initial costs of the design process (BSI, 2008). Even though, a standardized classification system covering both maintenance and operating costs has been offered by RICS (2012), nevertheless, the structure and volume of the available data do not determine the optimum pay off between capital and through-life costs (Al-Hajj & Horner, 1998). Hence, decisions, data feedback, and continual monitoring and optimisation of O&M costs should continue through the service life of the buildings (Joseph, 2010).

Furthermore, various levels of O&M cost data and information need to cater to actual practices and requirements of buildings, ensure accuracy, ease of use, and provide estimates from different levels of available data and information (Al-Hajj & Horner, 1998). Even though clients need to inform in advance of their future financial commitments and costs implications as the design, construction, and use phases evolve. Still, the existence of many different cost data collection systems and diverse types of equipment, devices, and systems limit the establishment of a simplified model for predicting O&M costs at the early stage (Krstić & Marenjak, 2017). Since the information on building design variables are readily available at the design stage of the buildings, the variables such as plan shape, size of buildings, storey height, the total height of the building, floor area, grouping of buildings, wall to floor ratio, and degree of circulation space can be used to predict the O&M costs, as it is already proved that these variables influence the construction costs of buildings (Ashworth & Perera, 2015; Belniak & Zima, 2013). However, there is little evidence on the design variables that influence the O&M costs of buildings.

Therefore, the current study investigation aims to develop a model that could help in the prediction of O&M costs from the knowledge of building design variables. Accordingly, this study investigates the relationship between design variables and O&M costs in commercial buildings with the intent of developing a cost model for estimating O&M costs at the early design phase. O&M costs prediction models developed using the available information on building design variables would be helpful at the design stage, along with the various models that predict the construction costs of the buildings.

Literature Review

O&M Costs and Life Cycle Costing of Commercial Buildings

O&M costs include the costs associated with running the building itself (operation costs) and the costs of keeping the building in good repair and working condition (maintenance costs) (RICS, 1986). Similarly, Lai and Yik (2008) defined the operation costs as the costs required for running and managing buildings, and maintenance costs as the costs of retaining a building or its parts in a suitable state) that enables constructed assets to serve their intended purposes. The BSI (2008) defined the cost elements that makeup O&M. Accordingly, the operation costs comprise rent, insurance, cyclical regulatory costs, utilities including energy costs, and taxes, while maintenance costs include costs for maintenance management, adaptation or refurbishment of the assets in use, repair and replacement of minor components, replacement of major systems and components, cleaning, grounds maintenance, and redecoration.

A brief review of the literature shows that Life Cycle Costs (LCC) of commercial buildings are dominated by expenses incurred during their use phase and these include operational and maintenance expenses of about 69% of LCC (Wang, Wei & Sun, 2014). Further, O&M costs account for about 55% of the total building costs over 40 years lifespan. Lam, Chan and Chan (2010) suggest that maintenance cost is about 50% of all annual construction activities in Britain. In France, O&M costs of healthcare facilities average 23-34% of total costs (Lai & Yik, 2011). In commercial buildings in the USA, BOMA and Kingsley Associates (2017) provided a breakdown of operating expenses. Accordingly, 82% of the operating costs of a typical commercial building go to utilities (25%), repairs and maintenance (23%), cleaning (17%), and administrative work (17%). Yu and Chow (2001) show that in typical commercial buildings, air conditioning accounts for 43% of energy consumption, office equipment (17%), lifts and escalators (6%), and lighting (34%). Based on the above findings, it can be concluded that the O&M costs of buildings account for a significant percentage of LCC, while the costs of energy contribute a greater proportion to it.

Considering distinct types of buildings, commercial buildings deserve focus in the current study because of evidence that suggests that commercial buildings consume higher O&M costs than residential, institutional, and other industrial buildings (Goh & Sun, 2015). In Wang et al. (2014) study, residential buildings came second with O&M costs accounting for 69% of total life cycle costs. Further, Kshirsagar, El-Gafy, and Abdelhamid (2010) showed that the O&M costs of institutional buildings fall within the range of 52 to 61%. For industrial buildings, O&M costs vary from 40 to 54% (Gurung & Mahendran, 2002). Accordingly, empirical findings of earlier studies suggest that O&M costs of commercial buildings are significant, thus need attention from the beginning. Hence a mathematical model developed to quantify the O&M costs of commercial buildings finds its justification.

Existing models for estimating O&M costs of buildings

Building O&M costs estimating models are broadly classified into three types such as parametric models with regression analysis, element-based floor area models, and probabilistic models (Kishk & Al-Hajj, 1999). However, the same authors showed the shortcomings of the area and probabilistic models over regression analysis. Although the cost is influenced by many factors, only the impact of floor area is considered in the element-based floor area models. Similarly, probabilistic models using the most common technique of Monte Carlo simulation that simulate activities over time requires a life history of the system to be studied. On the other hand, in the parametric method to cost estimating, the cost drivers are related to cost by cost estimating relationships through regression analysis (Li, Peter, & Love, 2005), where regression analysis enables a mathematical equation to describe the available data in the best manner and higher practical usefulness is accepted (Pelzeter, 2007). For example, Al-Hajj and Horner (1998) proposed a model that has eleven elements of cost, which can predict the total O&M costs of buildings to the accuracy of about 1.13%. Also, Langdon (2006) believed that parametric models with regression analysis play a vital role in predicting O&M costs. Most recently, Zeki´c-Sušac, Keževi´c and Scitovski (2019) showed that multiple linear regression has the potential to predict the total cost of energy consumption in public buildings. Therefore, multiple regression analysis is the most popular, useful, and applicable technique in O&M costs estimations as well as has applications in other areas.

Some other models for estimating the O&M costs of buildings, give considerable attention to cooling energy estimation. For example, Kirkham, Boussabaine, and Grew (1999) applied a regression technique to model the energy cost of sports centres where the floor area and the number of users were used as two independent inputs. Mack and McWilliam (2013) proposed a model that has eight predictors to calculate the percent change in cooling energy consumption to about 20% accuracy level. Their model is applicable during the O&M stage of buildings, where there are adequate historical building operational data available. Another model is developed by Geekiyanage and Ramachandra (2018) to estimate the cooling energy demand of condominium buildings in Sri Lanka using two independent variables: the number of floors and window-to-wall-ratios. Thus, the regression analysis is used instead of other approaches to estimate the O&M costs of buildings in the current study.

A limitation of the foregoing regression models is their applicability at the O&M stage of buildings, based on available historical O&M cost data. Therefore, they seem less accurate and restricted to a specific life cycle. Further, the existence of different cost data collection systems limits the development of a simplified prediction model at the initial stages. Current study use data relating to commercial building design variables available at the pre-construction stage of buildings to serve as predictors of O&M costs. Hence the developed simplified regression model for forecasting O&M costs of commercial buildings in Sri Lanka is principally based on building design variables. Accordingly, the next section reviews the literature relating to the relationship between building design variables and O&M costs.

Building design variables and O&M costs of buildings

Design problems are momentous as the decisions and actions were taken during the initial stages of a building may be difficult to change at the building's O&M stage. Earlier studies have examined the principal design variables that influence construction costs of buildings (Ashworth & Perera, 2015; Belniak & Zima, 2013; Cunningham, 2013; Ibrahim, 2007). These include plan/shape, size, storey height, the total height, grouping buildings, wall to floor ratio, and degree of circulation space. Ibrahim (2007) added envelope area, roofing, open space, and voids to design variables. In Ibrahim’s view, the more complex the shape, the higher will be the overall cost of a structure.

Although studies have focused on design variables that affect the O&M costs, their main concern has been on the energy consumption of buildings (Catalina, Virgone, & Iordache, 2011; Depecker, Menezo, Virgone, & Lepers, 2001; Krem, 2012). For example, Krem (2012) investigated the effect of design variables on energy and structural performances over climate changes in high-rise office buildings. However, only the shape of the building footprint and the placement of the structural cores were considered as the design variables. Krem (2012) concluded that the energy performance of high-rise office buildings is highly influenced by their morphology. Similarly, Perera, Chethana, Illankoon and Perera (2016) found that building characteristics such as building age, height, size, shape, and orientation are key factors contributing to housing maintenance costs. It is interesting to find buildings that have been designed to meet similar needs incurring different expenses due to differences in some of their design variables.

Table 1 presents a summary of some of the impacts of design variables on the O&M costs of buildings, undertaken by some notable studies. The design variables are pooled together for use in the current study investigation to prove their relationships with the O&M cost of commercial buildings. Accordingly, the current study is limited to the building design variables such as building shape, size, height, storey height, circulation space, and grouping of buildings based on their significance highlighted in the extent of literature.

Table 1. The impact of design variables on O&M costs of buildings

Research Methodology

The current research aims to develop a prediction model for O&M costs of commercial buildings bases on building design variables. Thus, this research is concerned with quantifiable observations of O&M costs and design variables and subject themselves to statistical analysis. Further, the researcher is independent of the research subject of the current study. Accordingly, this research reflects the positivist philosophical stance that undertakes an observable social reality, in a value-free way using a highly structured method (Saunders, Lewis & Thornhill, 2009). The quantitative nature of the current study undertakes a deduction approach, where research hypotheses are developed based on existing theory, tested, and confirmed through data collected (Saunders et al., 2009). Accordingly, the research developed and tested null and alternative hypotheses for the effects of building design variables: building shape, size, height, storey height, circulation space, and grouping of buildings on O&M costs. The deductive approach of the research requires substantial amounts of data to address the research hypotheses (Saunders et al., 2009). The survey strategy is usually associated with a deductive approach and allows us to economically collect a large amount of quantitative data from a representative sample. Subsequently, those data can be analysed quantitatively using descriptive and inferential statistics to produce possible relationships between variables and develop models based on these relationships (Saunders et al., 2009). Accordingly, a survey strategy was employed to collect the costs data and information on the design variables of commercial buildings.

Under the survey strategy, the data for this study were collected from a purposive sample of 30 out of 117 commercial buildings in the CBD in Colombo, Sri Lanka. Criteria for the purposive sample were commercial buildings with five floors or above and having gross floor area (GFA) of between 20,000 to 140,000m^2 and the number of occupants ranging from 500 to 3,500. A sample size of 30 or more, at a 5% confidence level is enough for quantitative studies (Geekiyanage and Ramachandra, 2018).

Data were collected using a structured questionnaire, where data relating to building design variables were extracted from detailed drawings and include shape, size, building height, storey height, circulation space, age, the grouping of buildings using common walls, foundations, roofs, circulation spaces, and service core of the selected commercial buildings. On the other hand, information on O&M costs collated from annual reports, records of administrative expenditure budgets and operating expenses assigned to right O&M costs elements and annualised maintenance costs through planned, reactive, and proactive maintenance activities. Others are maintenance contractor's management and administrative costs, as per the BS ISO 15686-5:2008 standard. The main O&M costs elements covered under both standards include; the operation costs under four subcategories such as insurance, utilities, administrative costs, and taxes. The maintenance costs include the costs for decoration, fabric and building services maintenance and repairs, costs for the cleaning, external works, maintenance management, and repairs and replacement of minor components and small areas. Accordingly, 71 O&M costs elements were identified and defined concerning the RICS New rules of measurement: NRM 3: Order of cost estimating and cost planning for building maintenance works, of which 59 elements were considered for the analysis. The selected buildings are owned and occupied by the same party, thus, rent and property management costs were not being found as the elements of running costs in commercial buildings in Sri Lanka. The selected buildings are not using gas and solid fuel for their utilities; therefore, the costs of gas, solid fuel, and gas installations were eliminated from the analysis. Further, the selected buildings are not including any outdoor water fountains, therefore, the cost for keeping water fountains were removed from the analysis. Additionally, costs for cyclical regulatory cost, laundry, porterage, hot water services, boiler/calorifier rooms, and hot work services were excluded due to the lack of O&M costs data on commercial buildings in Sri Lanka.

In the first stage of data analysis, significant elemental O&M cost elements were named using Pareto's 80/20 rule. As outlined by Horner and Zakieh (1996), the point that defines the significant cost items corresponds with the average item values. The annualised elemental costs of 30 buildings were normalised using the elemental cost per m^2 of the net lettable area of the respective buildings. Then the mean value of each elemental O&M cost was considered. The percentage contribution of each element to the mean value of total O&M costs was computed to show the significant cost elements in compliance with Pareto's rule.

The next stage of the analysis involved a detailed investigation of the effects of building design variables on all the O&M costs elements of commercial buildings in Sri Lanka. Correlation allows the measurement of the relationship between two variables based on their correlation coefficient values (Cho et al., 2018). The correlation coefficient (r) is the strength of a relationship, which varies from $-1 \leq r \leq +1$. A correlation coefficient value quite close to 0, but either positive or negative implies little or no relationship between the two variables whilst the correlation coefficient value close to +/-1 indicates a positive and negative relationship between the two variables respectively (Ricciardy & Buratti, 2015). The outliers in each cost element were first removed to minimize skewness, thereafter the analysis was run separately.

The type of correlation analysis used depends on the distribution of the data collected for the study. However, Zaid (2015) recommends that a partial correlation analysis could be performed on any distribution, regardless of the nature of distribution, i.e. normal or not normal.

Although there are no fixed rules for describing correlation strength, a threshold is defined in this study in line with Ricciardy and Buratti (2015), thus:

- $0 < |r| < 0.3$ Weak
- $0.3 < |r| < 0.7$ Moderate
- $|r| > 0.7$ Strong

In performing the partial correlation analysis, the elemental O&M cost per m^2 of the net lettable area was calculated and correlated with design variables. In the case of qualitative design variable: shape, the numerical values "1" and "2" were assigned to be "regular" and "irregular" shape, respectively. While similar values stand for "grouping" and "no grouping" respectively in the case of the grouping of buildings.

Finally, an O&M cost model was developed between total annualised O&M costs of a commercial building (per m^2 of net lettable building area) and building design variables using the stepwise multiple linear regression analysis in SPSS, which is a variable selection method where various combinations of variables are tested together. In the current study, the dependent variable is O&M cost per year, while the independent variables are commercial buildings' design variables.

The coefficient of determination (r^2) was used to show the best-fit model. A linear combination of a few X variables that correlated weakly with Y may have a larger correlation with Y than a linear combination of a few X variables that correlated strongly with Y. Recall that multiple regression is about linear combinations, not just individual effects (Chatterjee & Hadi, 2012). The three data analyses performed on the data collected are explained in the next section.

Findings and Discussions

Significant O&M costs elements in commercial buildings

As outlined in the methods section, the first step in the analysis is the determination of the O&M costs elements that contribute to the total O&M costs of commercial buildings. Accordingly, Table 2 presents the significant O&M costs elements and their respective costs. Pareto's 80/20 rule was employed to find the top 20% of cost elements that contribute to about 82% of total O&M costs. Arranging the 59 O&M cost elements in descending order of their values, 12 significant cost elements were extracted using the Pareto's rule (first 20%). A summary of the 12 significant cost elements is provided in Table 2.

The cost elements are similar to Al-Hajj and Horner (1998), who identified elemental O&M costs to include: internal cleaning, security insurance, water rates, fuel oil, electricity, and taxes as significant when predicting the total O&M cost of buildings. From Table 2, 7 (out of 12) significant cost elements are from the operation category, while 5 out of 12 elements are from the maintenance costs category.

Table 2: Significant elemental O&M costs

In summary, electricity is the major contributor and responsible for 36% of O&M costs, another 7% is due to taxes. On average security and service attendants, each contribute 5% to the total O&M costs. While other cost components: insurance and internal/external surface cleaning, water rates, internal decoration, air conditioning and ventilation, lifts and escalators, and fuel oil contribute less than 5% to the O&M costs. Remaining 18% of O&M costs is due to non-significant cost items. These findings are similar to what BOMA and Kingsley Associates (2017) and Yu and Chow (2001) concluded that allocate a higher percentage of operating costs of the building to utilities while major contribution comes from the electricity consumption of building systems and equipment.

Relationship between design variables and O&M costs

Having found the 12 most significant O&M cost elements, the next stage of the analysis is the correlation between design variables and O&M costs of commercial buildings. The accuracy of any regression model is influenced by the existing correlations between selected variables. Highly correlated variables would offer a statistically incorrect model. Therefore, the first step of the analysis is the detection of correlations between O&M costs and design variables as well as the correlations among the selected design variables. The results of the correlation analysis are presented in Table 3, shows the partial correlation between O&M costs and design variables along with their respective significance levels.

Table 3: Correlation of total annualized O&M costs and design variables

From Table 3, it could be seen that building size has a correlation (above +/-0.300) with total O&M costs. Further, circulation space and building height correlate significantly (above +/-0.300) with total O&M costs while storey height and grouping of buildings show a weak correlation with the same.

From literature, it was found that when buildings are longer and narrower or their outline made more complicated and irregular, higher O&M costs can occur due to building services maintenance and fabric for instance (Depecker et al., 2001). Similarly, the correlation analysis in the current study shows that the building shape has a positive relationship with O&M costs. Thus, the relationship shows that when the shape changes from regular to irregular, the maintenance costs of those elements increase.

Considering the correlation of building size with O&M costs, Ferry and Brandon (1991) suggest that the maintenance costs of buildings may rise eventually as the building needs regular maintenance for its building elements. Similarly, the correlation analysis in this study shown that there is a positive relationship with the O&M costs of buildings. In summary, it can be concluded that building size may affect the O&M activities of buildings.

The height of buildings could have an impact on maintenance costs because of the added costs of equipment e.g. scaffolding which is needed to carry out maintenance tasks such as external decoration and windows repairs (Catalina et al., 2011). Moreover, services and associated equipment become more sophisticated and costly with high-rise buildings, and their ducting can increase costs correspondingly. Lai et al. (2008) explained that plant that is more expensive is needed for the maintenance of high-rise buildings because maintenance work becomes costlier at higher levels. However, heating costs are likely to fall as the number of stories increases and the proportion of roof area to walls reduces (Catalina et al., 2011). Similarly, the results of this study show that building height has a positive relationship with O&M costs.

The variations in storey height could result in higher O&M costs due to high roof maintenance: including hoisting of materials and equipment, due to increased hoisting, extra payments are required by workers to cover risks involved in working at height (Cunningham, 2013). However, the current analysis shows that the storey height has a negative relationship with O&M costs.

As seen in Table 3, the circulation space of buildings and the grouping of buildings have a negative relationship with O&M costs. From the literature review, the grouping of buildings produces lower costs in running buildings (Ashworth, 2004), and reduces circulation spaces and service costs (Smith & Jaggar, 2007). Therefore, a negative relationship in the current study is acceptable.

Model to predict the O&M costs of commercial building

The last aspect of the study investigation involves the development of a model that could predict the O&M costs of commercial buildings. The best model is selected considering the highest fit model. Table 4 includes the possible models derived through regression analysis. Altogether two (2) different models were obtained from the analysis as is seen in Table 4. The second model was selected as the best-fitted model based on the adjusted R^2 value (0.755). Table 5 presents the coefficients of the selected model for predicting the O&M costs.

Table 4: Summary of the developed models

Table 5: Coefficients of the regression models

The goodness of the fit of the selected model is over 73%. Therefore, based on the statistics, the O&M costs of commercial buildings is represented by:

O&M costs = 101614948.80 + 9918.81 *(Gross Floor Area) - 2609312.77 *(Building Height)

From the regression model, Gross Floor Area and Building Height influence the O&M costs of commercial buildings. Thus, the O&M costs of commercial buildings increase as the gross floor area increases, but this decreases as the building height increases as the model indicates positive (+) sign with gross floor area and negative (-) sign with the building height.

The adjusted R^2 value of 73% says that 73% of the variation in O&M costs is explained by the two design variables contained in the model, which are GFA and height of the building. Unlike previously developed models by Al-Hajj and Horner (1998); Kirkham et al. (1999) and Mack and

McWilliam (2013), the model developed in the current study has its applicability at the early stage of the building design and construction in Sri Lanka. Furthermore, the findings contend that the accuracy levels realised in the current study are higher than those earlier models. These reasons give credence to the results of the current study investigation.

Conclusion

The current study investigation aims to develop a model that could aid in the prediction of O&M costs from the knowledge held at the design stages about building design variables. This aim has been achieved with the developed regression model. The study has found that key design variables of building shape, size, building height, storey height, the grouping of buildings, and circulation space are moderately correlated with various O&M cost elements. Further, the O&M costs of buildings are classified into a total of 59 elements. Amongst, twelve (12 out of 59) elements, which include electricity, taxes, external decoration, security, service attendants, insurance, internal/external surface cleaning, water rates, internal decoration, air conditioning & ventilation, lifts & escalators, and fuel oil contribute to 82% of total O&M costs of commercial buildings. The operational cost of commercial buildings handles a large share (68%) of total O&M costs while maintenance contributes 32% for the same. From the current study, electricity is the major contributor and responsible for 36% of O&M costs while another 7% and 6% of O&M costs are due to the taxes, internal decoration, and security, respectively.

Furthermore, the developed model can predict over 73% proportion of variance in O&M costs of commercial buildings from two building design variables (gross floor area and building height). However, the O&M costs might be varying due to the usage, building age, the systems used, and building envelope characteristics. Therefore, the developed model along with knowledge on significant O&M cost elements and its correlations with design variables could enable designers to indicate and compare O&M costs of potential design options and offers more efficient designs for commercial buildings. This would in return, ensure building owners or users value for money as the design variables could control the O&M costs of commercial buildings during the use phase. From a sustainability perspective, reduced energy costs/consumption helps the environment and contributes to the achievement of global sustainability goals. The model developed in the current study has its applicability at the early stage of the building design and construction in Sri Lanka. Further, the study recommends that this model be confirmed in other tropical climates.

This study was limited to six design variables: shape, size, building height, storey height, circulation space, and grouping, excluding building perimeter. It was difficult to determine the areas of enclosing walls to GFA, due to inaccessibility of drawings for some of the selected buildings. Furthermore, the focus of the study was limited to the relationship between the O&M cost of commercial buildings and selected design variables. Other factors like usage, building age, the systems used, location, markets, and building envelope characteristics, were not considered in the current study. The building age and number of occupants were considered as the controllable variables for the correlation analysis. Finally, the developed model should be applied with caution considering the limited dataset (30 selected commercial buildings). Future study investigations on other building types would be complementary to the current study on commercial buildings.

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Table 1. The impact of design variables on O&M costs of buildings

Design variable	Impact on O&M costs of buildings	Source
Building shape	• Building shape significantly affect on its O&M costs	Krem (2012)
	• Irregular shapes increases cooling energy demand, specially in hot climates that have higher solar radiation and outdoor temperature values • Deeper rooms reduce maintenance and heating costs	Catalina et al. (2011)
	• The relationship between building shape and total building energy consumption also depends on window to wall ratio (WWR), relative compactness and glazing types	AlAnzi, Seo, and Krarti (2009)
	• There is a direct correlation between building shape and O&M costs/total building energy use/space cooling energy demand	Ourghi, Al-Anzi, and krarti (2007)
	• The building that have a large square structure with certain functional areas in the center of the building would face deficiencies in natural lighting	Ashworth (2004)
Builing size	• A costs advantage may accrue in high rise buildings due to lifts serving a larger floor area and greater number of occupants but with an increased plan area.	Ferry and Brandon (1991)
Storey height	• Increased costs of applying finishes to soffits of ceilings	Demkin (2008)
Building height	• Increase of building height decreases the heating costs	Catalina et al. (2011)
Wall-to-Floor-Ratio (WFR)	• The increase of WFR reduces costs of building energy	Ayyad (2011)
	• The reduction of floor area ratio increases costs of lighting and reduces building heating and maintenance costs	Catalina et al. (2011)
Circulation space	• The operation and maintenance of circulation spaces often add an extra cost for the building user. For example, if the number of lifts designed for a building is inadequate, it is obvious that the lifts would be operating continuously, resulting in higher maintenance costs than normal.	Lai, Yik and Jones (2008)
Grouping of buildings	• Coupling of two or more buildings together reduces circulation spaces and associated service costs	Smith & Jaggar (2007)
	• Reduce cost of maintaining grouped buildings	Ashworth (2004)
	• Grouped buildings significantly influence on its total costs	Ferry and Brandon (1991)

Table 2: Significant elemental O&M costs

O&M costs Element			Cum. No of Items (% of total items)		Elemental O&M costs per area (Mean Value)	Cum. Value (% of total value)	
Main	Sub	Sub-sub					
O	Utilities	Electricity	1	2%	4,396	4,396	36%
O	Taxes		2	3%	855	5,251	43%
M	Decoration	External Decoration	3	5%	763	6,014	50%
O	Administrative Costs	Security	4	7%	738	6,752	56%
O	Administrative Costs	Service attendants	5	8%	722	7,474	62%
O	Insurance		6	10%	536	8,010	66%
M	Cleaning	Internal/External Surface Cleaning	7	12%	515	8,525	71%
O	Utilities	Water Rates	8	14%	396	8,921	74%
M	Decoration	Internal Decoration	9	15%	306	9,227	76%
M	Services	Air conditioning & Ventilation	10	17%	255	9,483	78%
M	Services	Lifts & Escalators	11	19%	246	9,729	81%
O	Utilities	Fuel Oil	12	20%	201	9,930	82%

Table 3: Correlation of total annualized O&M costs and design variables

	O&M costs	Building Shape	Building Size	Building Height	Storey Height	Grouping of Buildings	Circulation Space
O&M costs	1.000	0.275	0.675	0.289	-0.241	-0.062	-0.124
Significance (2 tailed)		0.157	0.000	0.136	0.217	0.753	0.528
Building Shape	0.275	1.000	0.348	0.251	0.027	0.049	0.082
Significance (2 tailed)	0.157		0.070	0.198	0.891	0.803	0.679
Building Size	0.675	0.348	1.000	0.748	-0.107	-0.084	0.371
Significance (2 tailed)	0.000	0.070		.000	0.586	0.673	0.052
Building Height	0.289	0.251	0.748	1.000	0.003	0.004	0.418
Significance (2 tailed)	0.136	0.198	0.000		0.986	0.985	0.027
Storey Height	-0.241	0.027	-0.107	0.003	1.000	-0.100	0.167
Significance (2 tailed)	0.217	0.891	0.586	0.986		0.614	0.395
Grouping of Buildings	-0.062	0.049	-0.084	0.004	-0.100	1.000	0.087
Significance (2 tailed)	0.753	0.803	0.673	0.985	0.614		0.660
Circulation Space	-0.124	0.082	0.371	0.418	0.167	0.087	1.000
Significance (2 tailed)	0.528	0.679	0.052	0.027	0.395	0.660	

Table 4: Summary of the developed models

Model	R	R^2	Adjusted R^2	Change Statistics R^2 Change	F Change	Sig. F Change
1 (Constant) Building Size	0.838	0.701	0.691	0.701	65.786	0.000
2 (Constant) Building Size Building Height	0.869	0.755	0.736	0.053	5.853	0.023

Table 5: Coefficients of the regression models

Model		Un-standardized Coefficients (B)	Partial Correlation	Significance
2	(Constant)	101614948.80		0.012
	Building Size	9918.81	0.773	0.000
	Building Height	-2609312.77	-0.422	0.023