RISK ANALYSIS IN MAINTAINABILITY OF BUILDINGS UNDER TROPICAL CONDITIONS

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DECLARATION

I declare that this my own work and this thesis does not incorporate without acknowledgment any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except whether the acknowledgement is made in the text.

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ABSTRACT

The cost of scheduled and unscheduled maintenance contributes to a significant portion of the whole life cost of high rise building. However, such maintenance is essential to maintain the expected performance of the building throughout its lifespan and the related costs arise from several factors, including the building's lifelong exposure to environmental factors as well as those due to design, construction and maintenance processes. The future maintenance requirements of buildings depend on the levels of risk associated with these factors as ignoring such risks results in high maintenance costs. As such, the analysis of such risks aimed at reducing future maintenance costs is of paramount importance from an early stage of a building project.

This study addresses the above research problem by a framework based on risk analysis to forecast the level of maintainability by (1) deriving and quantifying maintainability risk domain, (2) quantifying maintainability and (3) developing a model.

The derived maintainability risk domain consists of ten significant risk factors, extracted from 58 risk-causing variables/ issues. The significance and impact from these ten risk factors on maintainability were evaluated using data collected from thirty high-rise buildings which are of 10 or more storeyed high in Colombo metropolis. Field surveys and interviews were used for the collection of data which captured the existing maintainability issues in these high-rise buildings. The respective building managers, who are considered as substantive experts were interviewed to assess these risks factors.

Maintainability was quantified using an indicator, "*Maintenance Efficiency Indicator – MEI*" which is the ratio between equivalent value of maintenance cost and equivalent value of initial construction cost. Maintenance cost was established using the past maintenance records and present maintenance cost needed to improve the existing performance of the building when it falls below the required level. The required level of the performance is derived using five performance mandates such as stability, tightness requirements, durability, tactile requirements and safety in use.

An ensemble neural network architecture that combines small, individually trained networks into a larger network is used to develop the model for this framework. The ensemble architecture allows the individual expert networks to be representative of major components of the building. This facilitated the network to be trained with limited data samples. Furthermore, the structure is also capable of managing unforeseen correlations in input variables. The prototype used in this research uses four expert networks representing four building components; roof, façade, basement and internal areas. The final output of the ensemble network is used as an indicator of Maintenance Efficiency (*MEI)*. Data collected from the sample of 30 high-rise buildings is used to train these neural networks. Low error margins (<0.005) and generalization error (<0.05) of these neural networks indicate high level of accuracy in their predictions.

The accuracy and validity of the proposed framework is tested using two case studies of high-rise buildings which were not used for training of the neural networks. A high-rise hospital building and a high-rise bank building are selected for these case studies. Validity of the proposed framework is tested under different risk scenarios as follows,

- Validation 1: Framework is used to forecast the *MEI*. These results are compared to the *MEI* computed based on actual cost data.
- Validation 2: Framework is used to estimate changes required in the Risk inputs for a general improvement of the maintenance efficiency (*MEI*). These changes are compared with expert's opinion on achieving the same goals.
- Validation 3: Using the framework, risk input levels corresponding to the best possible maintenance efficiency are determined. These values are compared with the belief elicited from experts.

Hence the proposed framework is suitable for forecasting the level of maintainability of high-rise buildings and the *MEI* established from whole life maintenance cost is an effective measure to quantify maintainability of high-rise buildings. Further, maintenance efficiency can be improved by controlling and

managing the maintainability risks described by the ten risk factors identified in this research study.

Keywords: Maintainability, Risk analysis, Buildings, Maintenance, Building defects.

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LIST OF ABBREVIATIONS

Abbreviation	Description
AHP	Analytic Hierarchy Process
ANN	Artificial Neural Networks
BMI	Building Maintenance Information
BMS	Building Management System
BOI	Board of Investment
BOO	Build Operate and Own
BOT	Build Operate and Transfer
BPG	Building Performance Group
CAFM	Computer Aided Facilities Management
CAS	Constructability Appraisal System
CIBSE	Chartered Institution of Building Services Engineers
CMA	Condominium Management Authority
CMC	Colombo Municipal Council
CMMS	Computerized Maintenance Management Systems
CONQUAS	Construction Quality Assessment System
FDI	Foreign Direct Investment
HAPM	Housing Association Property Mutual Limited

IRR	Internal Rate of Return
MC	Management Corporation
M&E	Mechanical and Engineering
MSE	Mean Squired Error
NPV	Net Present Value
PeBBu	Performance Based Building Thematic Network
RICS	Royal Institute of Charted Surveyors
RBS	Risk Breakdown Structures

LIST OF APPENDICES