ESTABLISHING A BIM FRAMEWORK FOR INTEGRATING PASSIVE DESIGN STRATEGIES FOR DESIGNING ENERGY-EFFICIENT RESIDENTIAL HIGH-RISE BUILDINGS IN SRI LANKA

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Degree of Master of Science

Department of Civil Engineering

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DECLARATION

I hereby witness that this thesis represents my original research work conducted after registration for the degree of M.Sc. at the Department of Civil Engineering, University of Moratuwa. It has not been submitted elsewhere or for any degree or diploma, and the collaborative contributions and previous work related to the current study have been stated and properly acknowledged.

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The above candidate has carried out research for the Master's degree under my supervision

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ABSTRACT

Sri Lanka expects a surge in demand for residential high-rise buildings (RHBs). Energy-intensive heating, ventilation, and air conditioning (HVAC) systems are relied on for the indoor thermal comfort of these buildings. The HVAC dependency can be minimized by integrating Passive Design Strategies (PDS) that leverage natural resources to control heat transfer and ventilation. Despite their potential, the efficacy of PDS is sparsely studied for Sri Lankan buildings. Addressing this knowledge gap, this study introduces a novel Building Information Modeling (BIM)-based Building Performance Analysis (BPA) framework for an energy-efficient building design workflow. Eight popular PDS were identified through a questionnaire survey among local building designers. These strategies were then applied to a typical RHB in three distinct sub-climates in Sri Lanka. The comparison between the survey findings and simulation results highlights a discrepancy between the popularity of PDS and their actual performance, emphasizing the need for enhanced awareness among Sri Lankan building designers. The local and global sensitivity analyses revealed low e-coating glasses and solar reflective wall paints as the energy-efficient PDS for Colombo and Kandy. In contrast, low conductivity walls and multiple/thick glazing are the most effective PDS for Nuwara Eliya. The multi-objective optimization of this study demonstrated that the optimum PDS design could substantially reduce operational energy consumption by 41.4%, 61%, and 29.4% and investment costs by 7.5%, 4%, and 4% compared to original designs in Colombo, Kandy, and Nuwara Eliya. Importantly, prioritizing low operational energy PDS design over the investment cost proves crucial for achieving sustainable metrics, such as carbon emission reduction and green rating scores. While the output of this study sets basic guidelines for Sri Lankan building designers in integrating passive design strategies for RHBs, the novel BIM-based BPA framework stands as a solution for existing technical gaps in BIM-based building design workflows.

Keywords: Passive design strategies, Building Information Modelling, Energy Simulation

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LIST OF ABBREVIATIONS

RHB – Residential High-rise Building

PDS – Passive Design Strategies

BIM- Building Information Modelling

BPA – Building Performance Simulation

EUI – Energy Use Intensity

LSA – Local Sensitivity Analysis

GSA – Global Sensitivity Analysis

LHS – Latin Hypercube Sampling

OH – Window Overhang

SF- Window Sidefin

EC – Reflective Walls

GU – Multiple/thick glazing

WS – High thermal walls

CW - Low conductivity walls

WC – Low-E glazing

WAPE – Weighted Absolute Percentage Error

MAE – Mean Absolute Error

MSE – Mean Squared Error

OE – Operational Energy

IC – Investment Cost

HVAC – Heating, Ventilation, and Air Conditioning

EE – Elementary Effect

CC – Construction Cost

MOO – Multi-Objective Optimization

R^2 – Coefficient of Determination

$E_{equipment}$ – Annual Energy Demand for equipment

$E_{lighting}$ – Annual Energy Demand for lighting

E_{hvac} – Annual Energy Demand for HVAC

CC_r – Construction Cost of r^{th} PDS design

MC_r – Material Cost of r^{th} PDS design

OC – Construction and Material Costs of the rest of the building element

FA – Total area of a typical floor

D_i – Euclidian Distance

f_{IC} – Investment Cost function

f_{OE} – Operational Energy function

NDS – Non-Dominated Solution

EF- Emission Factor

EPD – Environmental Product Declaration

AUC – Additional Upfront Carbon Emission

ANNEXURE