Augmenting Cost and CO_2 Efficiencies In Building Structures Using An *A Posteriori* Decision Framework

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1. Introduction

In construction industry sustainability assessments for the optimisation of building structures are increasingly popular [1, 2, 3]. To address the current advancements in material technologies and future economic and environmental policies the existing methods of life cycle sustainability, Multi-criteria Decision Making (MCDM) and optimisation techniques in the context of building structures would need to be further developed and integrated [4]. Integrated frameworks that take into consideration stakeholder preferences and subjective knowledge can not only improve the quality and efficiency of the decision processes but also enrich the human-computer interaction [5]. Based on the time the engineering knowledge is introduced into the optimisation procedure, three integration schemes have been identified in the literature: 1) A *priori*, 2) *A posteriori* and 3) Interactive [6]. The research proposes an a posteriori framework for the evaluation of optimised structural design solutions. The proposed framework consolidates group decision-making processes for the prioritisation of decision requirements, sustainable structural optimisation algorithms for the generation of cost and carbon efficient designs and MCDM techniques for the final assessment of the structural alternatives. To demonstrate the application of the proposed framework a common structural system typology is used: reinforced concrete (RC) buildings with flat slabs and concrete columns.

2. Methods & Models

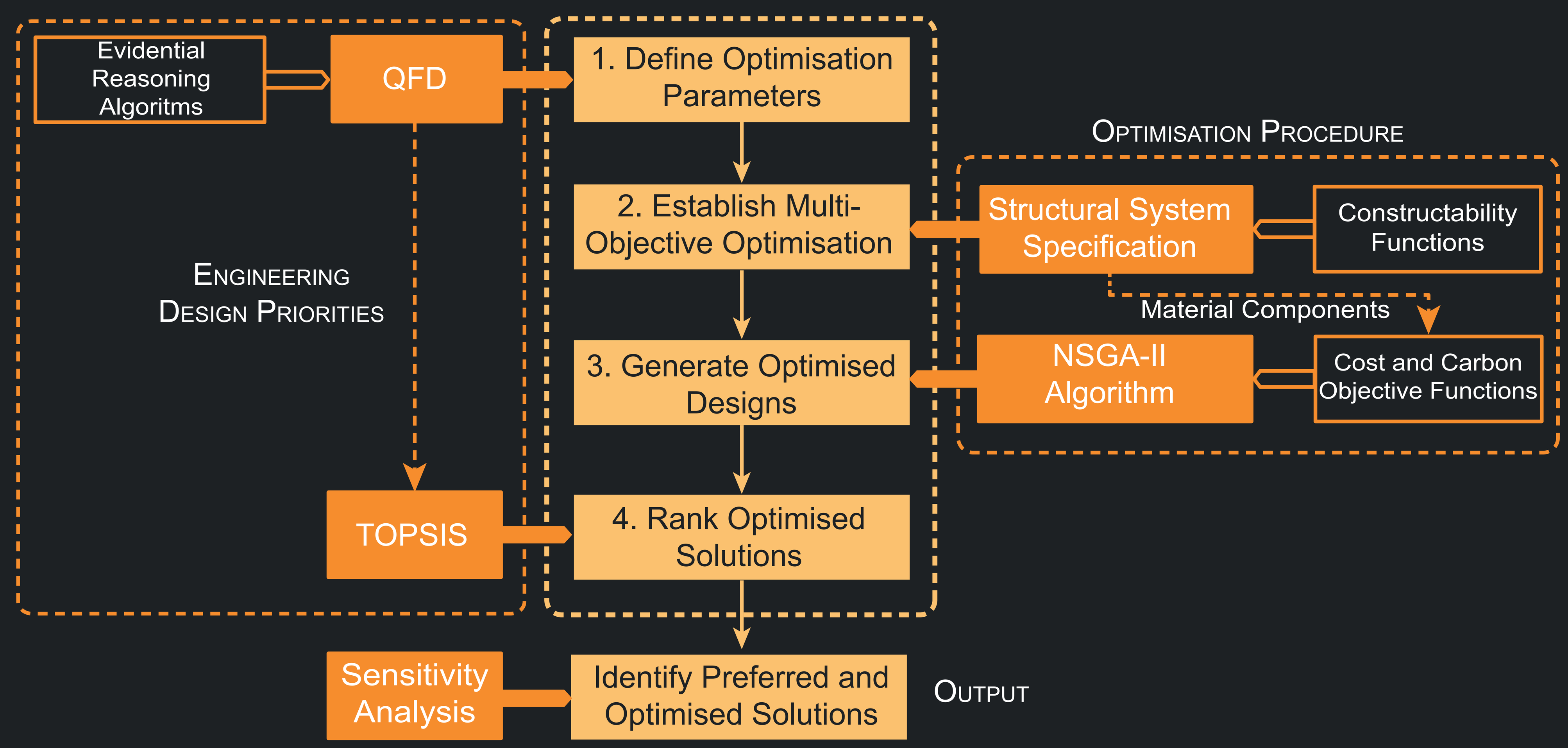


Figure 1. Flow Diagram of the Proposed Decision Framework

3. Results & Discussion

3.1 QFD Model

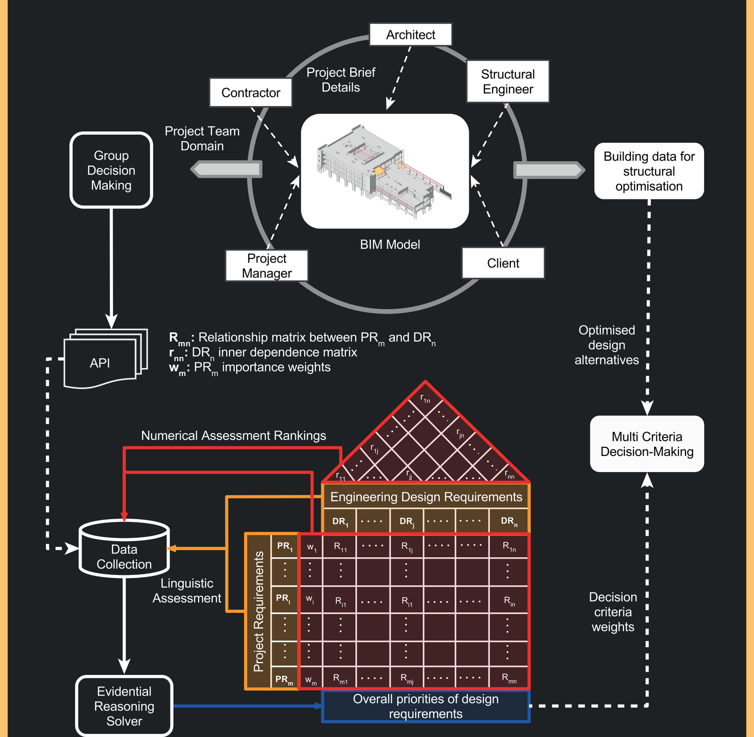


Figure 2. Computational Workflow

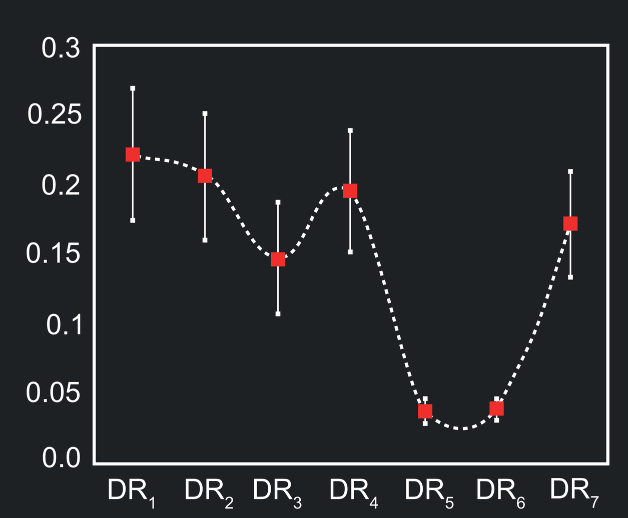


Figure 3. Normalised Engineering Design Requirements Rankings

3.2 Structure

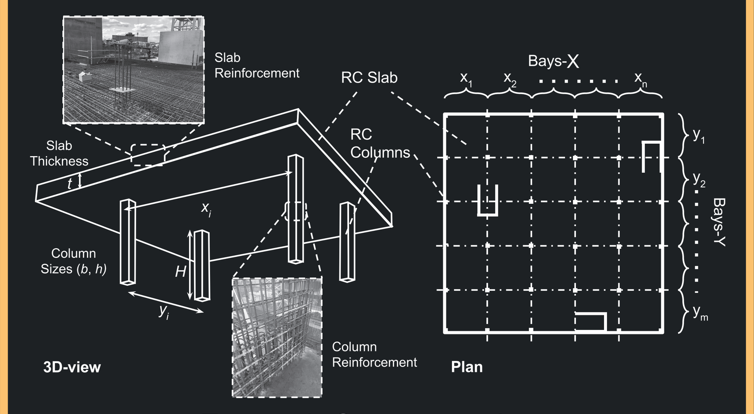


Figure 4. Structural Levels

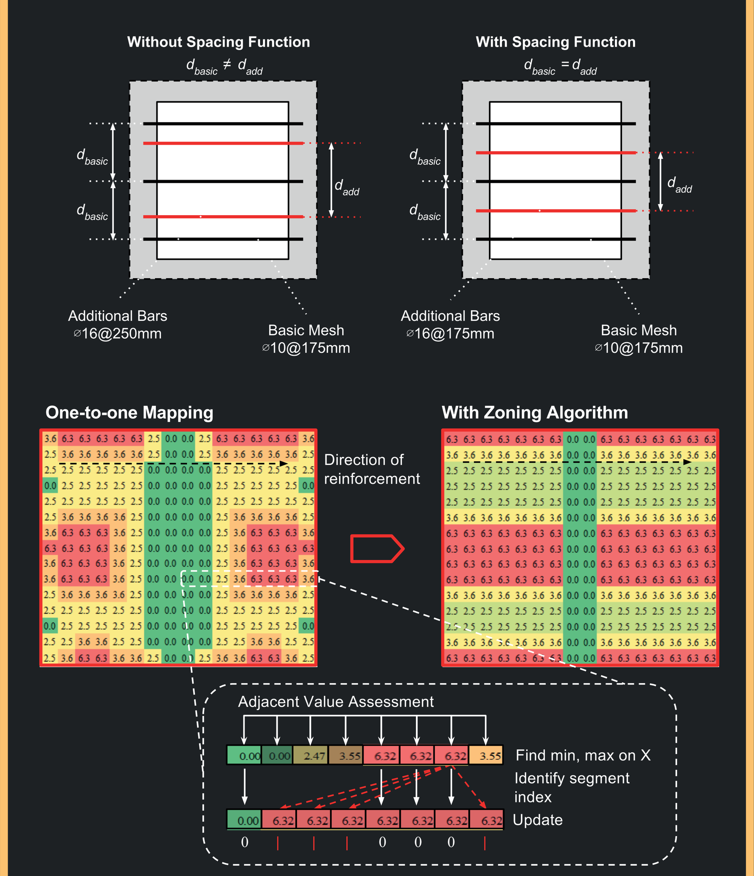


Figure 5. Slab Reinforcement Spacing & Zoning Algorithms

3.3 NSGA-II

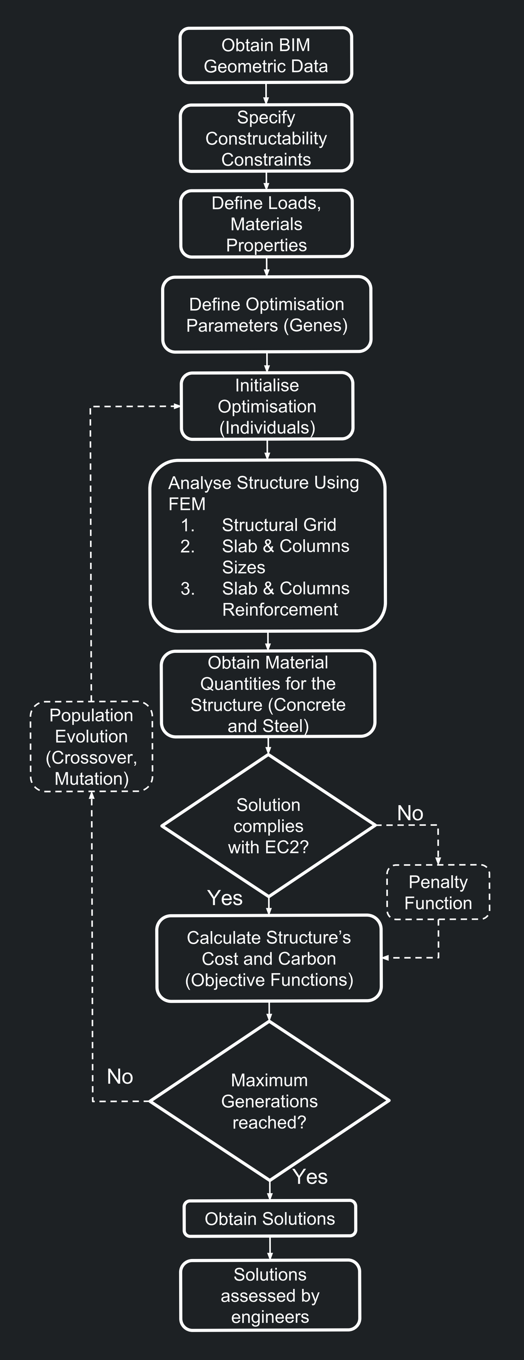
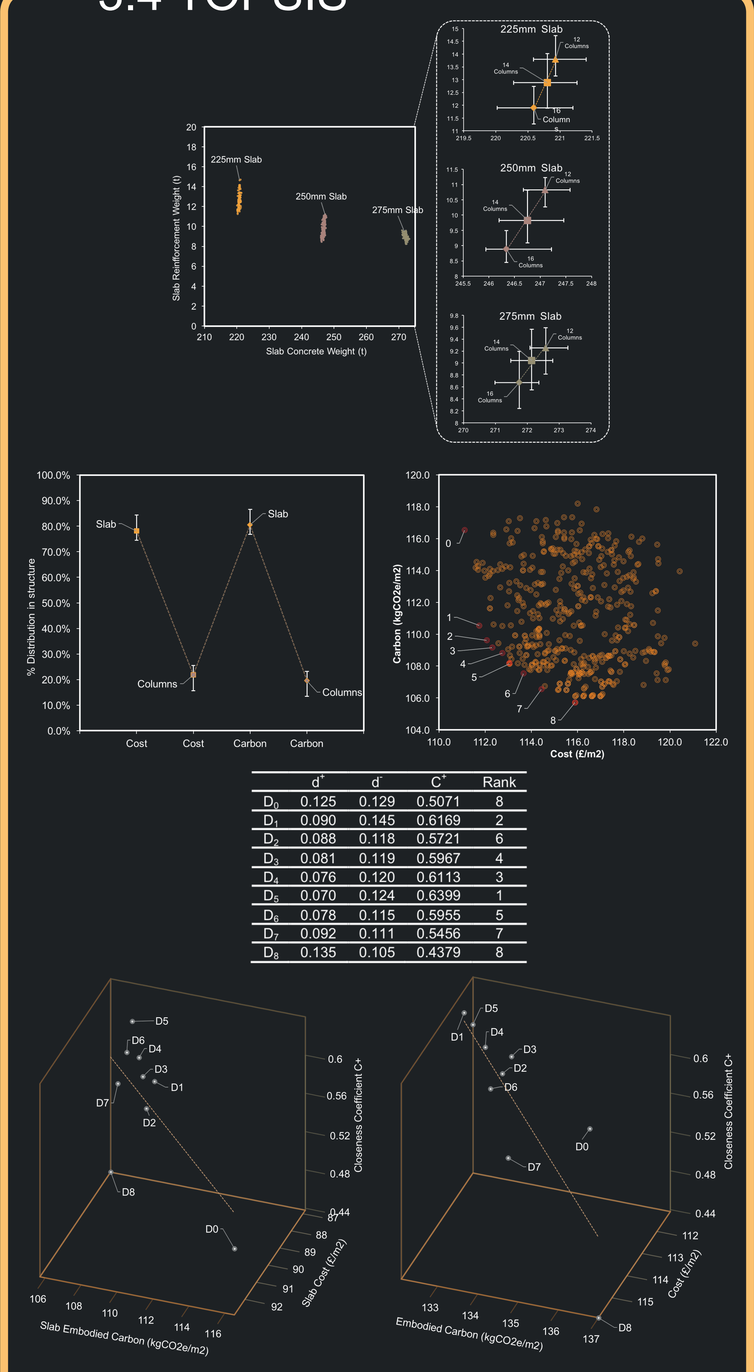


Figure 6. Optimisation Framework

3.4 TOPSIS



	d^+	d^-	C^+	Rank
D_0	0.125	0.129	0.5071	8
D_1	0.090	0.145	0.6169	2
D_2	0.088	0.118	0.5721	6
D_3	0.081	0.119	0.5967	4
D_4	0.076	0.120	0.6113	3
D_5	0.070	0.124	0.6399	1
D_6	0.078	0.115	0.5955	5
D_7	0.092	0.111	0.5456	7
D_8	0.135	0.105	0.4379	8

Figure 7. TOPSIS Ranking & Resulting Solution Space

4. Conclusions

As the complexity of building design increases the need for new sustainable decision paradigms in building structures would become critical in the future. Taking a comprehensive decision approach this study advanced structural optimisation as a practical and integrated way of not only establishing sustainable design solutions but also assessing them based on expert knowledge. The proposed decision framework:

(1) Defines design and decision criteria using a QFD model with evidential reasoning,
(2) Establishes structural multi-objective optimisation using constructability constraints,
(3) Generates optimised structural designs using detailed cost and carbon objective functions within an NSGA-II algorithm,
(4) Ranks optimised solutions using TOPSIS algorithms and the decision priorities computed in stage (1).

The outputs from the decision framework include structural design solutions that are not only optimised but also enhanced with engineering expert knowledge. Results show that the integrated framework could help structural engineers not only identify relationships between cost and embodied carbon optimum designs but also help them evaluate the most preferred solution based on expert knowledge.

5. References

[1] A. Takano, M. Hughes and S. Winter, "A multidisciplinary approach to sustainable building material selection: A case study in a Finnish context," Building and Environment, vol. 82, pp. 526-535, 2014.
[2] O. Pons and A. Aguado, "Integrated value model for sustainable assessment applied to technologies used to build schools in Catalonia, Spain," Building and Environment, vol. 53, pp. 49-58, 2012.
[3] U. Abeysundara, S. Babel and S. Gheewala, "A matrix in life cycle perspective for selecting sustainable materials for buildings in Sri Lanka," Building and Environment, vol. 44, pp. 997-1004, 2009.
[4] RILEM TC 172-EDM/CIB TG 22, "Environmental design method in materials and structural engineering," Materials and Structures, vol. 32, no. 224, pp. 699-707, 1999.
[5] M. Babbar-Sebens, S. Mukhopadhyay, V. Singh and A. Piemonti, "A web-based software tool for participatory optimization of conservation practices in watersheds," Environmental Modelling Software, vol. 69, pp. 111-127, 2015.
[6] L. Thiele, K. Miettinen, P. Korhonen and J. Molina, "A Preference-based Evolutionary Algorithm for Multiobjective Optimization," Journal Evolutionary Computation , vol. 17, no. 3, pp. 411-436, Fall 2009.

6. Acknowledgements

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