Merging building maintainability and sustainability assessment: A multicriteria decision making approach

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Abstract. Accurately predicting maintainability has been a challenge due to the complex nature of buildings, yet it is an important research area with a rising necessity. This paper explores the use of multicriteria decision making approach for merging maintainability and sustainability elements into building grading systems to attain long-term sustainability in the building industry. The paper conducts a systematic literature review on multicriteria decision analysis approach and builds on the existing knowledge of maintainability to achieve this. A conceptual framework is developed to bridge the gap between building operations and maintenance with green facilities management by forecasting green maintainability at the design stage.

1. Introduction

Maintainability of a building is its ability to perform optimally throughout the lifespan within the minimum life cycle cost [1]. Building maintainability is reflected in effective facility utilization over its lifetime; which is achieved through thoroughly detailed designs and good construction workmanship followed through with a comprehensive maintenance regime [2,3]. Traditionally, maintainability was involved in selecting building technologies and materials which require minimal maintenance, viz. cleaning, repair and replacement [4]. Which could be specified as an expression of various physical and functional maintenance parameters [5]. These strategies were aimed to create buildings with an efficient and effective operation and maintenance by using maintenance feedback data from existing buildings [1,6].

However, there is an apparent discrepancy between building scoring systems and maintainability [7]. Parida et al. [8] noted that not utilizing available data on maintenance management is a cause for this knowledge gap. Corry et al. [9] corroborates this in their study on current buildings incorporated with complex green technologies. They claim that greener designed buildings fall short of their projected expectations due to gaps between design and performance. A further knowledge gap is identified here between sustainability practices and building operation [10,11]. Ajukumar and Gandhi [12] identified the lack of tools to incorporate green maintenance or maintainability considerations at the early design stages to be a cause of lack of sustainability during maintenance stages. This agrees with studies [13,14] that shows how green building operation and maintenance has become impractical, costly and less sustainable due to ignoring the operations and maintenance considerations. Especially since the industry understanding of maintainability of novel green building technologies is still limited as they are yet to undergo the effects of degradation and weathering [15].

To attain long-term sustainability in the building industry, life cycle sustainability of buildings has to be incorporated into the existing building stock operation and maintenance [16]. Therefore, the need
to link maintainability principles with the principles of sustainability is identified; to evolve traditional maintainability to green maintainability [17,18].

2. Method
This study identifies the lack of green maintainability considerations in building project delivery as a decision making problem; proposing maintainability scoring as a fundamental approach for implementing green maintainability strategies. Figure 1 below illustrates the research framework for the current study. This paper presents findings from ongoing research in operationalizing this framework.

This paper reviews the literature on decision analysis and the potential use of multicriteria decision making techniques for this purpose. A comprehensive literature review on areas of building maintainability and sustainability has been conducted to identify green maintainability indicators which are used for the multicriteria decision making. These serve as the basis of the discussion on how to use decision making tools to model and score green maintainability by building professionals.

![Figure 1. Research framework: Merging building maintainability and sustainability assessment](image-url)

3. Overview of decision analysis
There are two kinds of decision makers; the rational and the intuitive [19]. The rational decision makers need to have sufficient knowledge and informed alternatives to operate while the intuitive decision makers tend not to reason logically when they do not hold perfect knowledge [20]. In light of these shortcomings of human decision making, computerized decision support systems can aid humans in finding solutions to problems which require systematic analysis [21].

Decision analysis can, therefore, be used as a guide to solve complex problems. Such as those often found in design and construction. Designers and builders can use decision analysis to structure these complex issues in order to foresee the consequences of their decisions (i.e. possible outcomes and likelihoods). This is made possible by identifying the uncertainty attached to a problem and presenting it in a useful way for decision makers to handle. Decision analysis also can show trade-offs of different decisions when working towards multiple objectives in a complex system. This is especially useful in instances where multiple stakeholders work together; each proponent with different values and objectives.

For an example, an architect’s objective in facility design may be to design an aesthetically pleasing iconic building; while the engineers may strive to make the buildings structurally stable and
safe. A facility manager involved at this stage would strive to minimize operating costs by optimizing the designs. Whereas a quantity surveyor may mainly be concerned to keep the construction costs in check. A decision analysis approach can be used to resolve the conflicting interests in such cases, and to make design decisions that are acceptable to all. This is carried out by using such tools to aid them in making informed decisions by presenting information in a structured manner [22].

4. Multicriteria decision making (MCDM)

In an effort to come up with most appropriate alternatives based on multiple criteria (i.e. maintainability considerations and sustainability considerations) multicriteria decision making (MCDM) can be used [23]. The decision support provided by multicriteria decision making approach is useful in problems with high complexity, uncertainty, and other challenges such as, varied data forms and different stakeholder with multiple interests, perspectives, and objectives which can be conflicting; such as in integrated building design domain [24]. Studies have integrated environmental sustainability considerations into decision frameworks in building related research [24–27].

4.1. Multiobjective decision making (MODM)

MODM concentrates on continuous decision spaces with several objective functions [24]. MODM tools can be used even in cases where objectives are conflicting and non-commensurable. MODM models find a unique solution to the problem by creating a vector based on the parameters pertaining to the decision, objective functions, and problem constraints. These solutions can be considered as alternatives where decision makers can choose an alternative based on how much it satisfies the multiple objectives [23].

MODM problems can be described by use of multiobjective linear programming tools which use real world factors in explaining the objective functions and constraints. These are further classified into parameters which are quantified based on expert opinions [28]. These parameters are used to approximate the Pareto frontier that indicates non-dominated solution sets (i.e. a state where a solution does not have any other alternatives which will improve one objective without negatively affecting another objective) [29]. This is achieved by calculating the vector values for the objectives for the decision parameters and by comparing each vector for its relative dominance. This is an optimization process where the objective values are deterministic if the entire problem space can be calculated in this way [29].

4.2. Multiattribute decision making (MADM)

The MADM approach centers on taking decisions based on preferences with discrete decision spaces [24]. The use of MADM is characterized by the selection of solutions from a predetermined finite number of alternatives using various traits. The number of alternatives is dependent on achievement levels of the different traits and the generation of these alternatives are constrained by the information availability and domain knowledge [28].

The MADM process usually begins by determining the evaluation criteria for the alternatives. These criteria are used to generate possible alternatives. Heuristic techniques can also be used in this regard. Afterwards, the most suitable alternative is selected based on the multiple attributes identified. Inter-attribute and intra-attribute comparisons can be made to determine these alternatives [28].

A key challenge faced by decision makers herein is when dealing with qualitative attributes as they are imprecise and problematic to quantify as human judgement is subjective [24,27]. Fuzzy set theory is therefore used to express such information, by coding the subjective parameters in linguistic terms to bring them to the decision models [24]. Fuzzy set theory fused with MADM methods are increasingly found in literature as it provides an opportunity to systematically evaluate the subjective input data [24,27].

5. Discussion

Two main approaches to multicriteria decision making are reviewed, namely MODM and MADM. In the context of the current study, a MODM approach would look at the building design with objectives of sustainability and maintainability in mind. The criterion used herein will then be used to convert the objective functions to a final utility value (e.g. life cycle cost, life cycle environmental impact). Figure 2 below presents typical indicators for green maintainability; which incorporates both sustainability
and maintainability considerations in building project delivery. At this point decision makers can make the best design decisions in order to optimise the objectives, by considering trade-offs among the various objectives. Alternatively, the MADM approach uses a set of predefined design options to measure the end result of using these options in terms of sustainability and maintainability. This can be seen as a ranking approach to choose from a finite number of design alternatives.

Both approaches aid decision makers with useful information on the possible consequences of their decisions. MADM approach looks at the design issues from prior experiences of the industry, which can be useful during early design stages where project objectives can be ambiguous. However, this approach limits the creativity and innovation of the design teams as it is a more prescriptive approach to design. On the other hand, MODM is used to optimise a level of satisfaction among the objectives and constraints which allow for the design teams to innovate to find the best solution. Even so, it should be noted that various challenges still remain in using MODM in this regard. Most notably are the issues of quantification of certain parameters such as aesthetics appearance or practicality of construction methods. Methods need to be developed in order to express such criterions in a useful manner for MCDM.

1. Design
   - Maintainability potential
   - Long-term adaptability
   - Integration
   - Constructability/Buildability
   - Design detailing
   - Good specifications
   - Compatibility of building systems
   - Accessibility for maintenance/Access to work
2. Construction/Fabrication and Supply
   - Material durability / Good selection of materials
   - Embedded energy
   - Structural integrity
   - Construction quality
   - Green Merchant/Supplier
3. Maintenance capacity
   - Building automation (BMS, CAFM)
   - User friendliness
   - Easy maintenance
   - NSF considerations
   - Maintenance policies and strategies
   - Availability of spare parts
   - Local-regional material (OEM, spare)
   - Use of standard tools and instruments
4. Financial and Project management
   - Economical and financial efficiency / reasonable cost / Budgets
   - Sustainable asset usage
   - Mechanical system reliability
   - Documentation risk
   - Knowledge risk
   - Maintenance management
5. Resource management
   - Energy efficiency
   - Water use and conservation
   - Material efficiency
   - Recyclable material usage
   - Renewable material usage
   - Waste reduction and reuse
   - Green Procurement
6. Environmental conditions
   - Micro environment considerations
   - Macro climate considerations
   - Biological effects considerations
7. Environmental impact
   - Pollution prevention
   - Greenhouse gas emission
   - Climate energy resources
   - Environmental impact of materials
8. User related
   - Safety
   - Security
   - Health and wellbeing (Thermal comfort, lighting comfort, Acoustic comfort)
   - Indoor performance
   - Convenience
   - Privacy
   - Acoustic and noise control
   - User acceptance
   - User satisfaction
   - User ownership and accountability
9. Community related
   - Occupational health & safety
   - Green Jobs
10. Community related
    - Adjacent buildings and neighborhood
    - Socio-cultural practices
    - Green sustainability
    - Community involvement
11. Regulator
    - Standards
    - Quality certifications
    - Environmental sustainability
    - Energy (EHS)

**Figure 2.** Green maintainability indicators for a building project

Based on these approaches, Figure 3 below illustrates the proposed MCDM workflow for green maintainability assessment. The process starts by defining project requirement and this includes inputs from all project proponents. The defined requirements are later used as objective functions for rating alternatives. Secondly, the different maintainability and sustainability criteria (e.g. technical, economic, etc.) and sub criteria are identified for different building systems and subsystems. Based on project goals, possible alternative design strategies are then evaluated. The different variables for components under building sub systems are analysed to measure cumulative weights and rank alternatives. It is proposed to view final results from the model in monetary terms to make objective comparisons by decision makers. The final result for alternatives is then used to determine the alternative which best fits project requirements.
Considering a scenario of designing a wet area, the maintainability depends on various factors such as water tightness, spatial, integrity, ventilation, material, and plumbing maintainability [30]. These factors are based on different variables which are affected by design decisions such as detailing, material selection, or construction workmanship. Furthermore, these decisions have impacts on environmental (e.g. embodied energy) and social (e.g. safety) aspects which also needs to be considered when planning for life cycle sustainability. In order to aid the decision makers to achieve this goal, MCDM is envisioned as the solution for modelling as it has been repeatedly to solve construction-related problems [5,31–33]. However, there are features of MODM and MADM that are both desirable and challenging for use as discussed above. Therefore, a possibility of a hybrid decision making model addressing these issues is worth taking note of in further studies. Building upon that, the future direction of the current study can be listed as below:

i. Identify green maintainability criteria for different building subsystems
ii. establish parameters to measure variables based on national/international standards
iii. Develop MCDM model to calculate equivalent cost for each alternative based on existing cost benchmarks

6. Conclusions and future work
This paper briefly reviewed multicriteria decision analysis approaches used in the construction industry which potentially be used to aid building design teams in the effort to incorporate sustainability and maintainability strategies in their designs. Each approach is useful in different kinds of decision problems, which can largely vary on available information, the criterions considered and objectives of the decision makers. As the most desirable building performance is achieved when maintainability is fused with sustainable principles early on in facility design; these decision making tools will influence the building’s performance to accrue economic, environmental and social benefits over all its operation stages.

The current study is part of a study on developing a green maintainability appraisal framework which integrates maintainability and sustainability principles to elicit green maintainability. It is envisioned that this will lead to reduced failures and maintenance issues in buildings leading to reduced life cycle costs and environmental impacts to achieve a lasting sustainability in the built environment.

References

[1] Chew M Y L 2015 *Maintainability of Facilities: Green FM for Building Professionals* (Singapore: World Scientific)
[2] Lindsey T C 2011 Sustainable principles: common values for achieving sustainability *J. Clean. Prod.* 19 561–5
[3] Wood B 2006 The role of existing buildings in the sustainability agenda *Facilities* 24 61–7
[4] Chew M Y L and De Silva N 2003 Maintainability problems of wet areas in high-rise residential buildings Build. Res. Inf. 31 60–9
[5] Das S, Chew M Y L and Poh K L 2010 Multi-criteria decision analysis in building maintainability using analytical hierarchy process Constr. Manag. Econ. 28 1043–56
[6] Kumar S, Khan I A and Gandhi O P 2015 A theoretical framework for extraction and quantification of psychological attributes in design for maintainability: a team-inspired approach Res. Eng. Des. 26 289–308
[7] Chew M Y L and Das S 2008 Building grading systems: A review of the state-of-the-art Archit. Sci. Rev. 51 3–13
[8] Parida A, Kumar U, Galar D and Stenström C 2015 Performance measurement and management for maintenance: a literature review J. Qual. Maint. Eng. 21 2–33
[9] Corry E, Pauwels P, Hu S, Keane M and O’Donnell J 2015 A performance assessment ontology for the environmental and energy management of buildings Autom. Constr. 57 249–59
[10] Meng X 2014 The role of facilities managers in sustainable practice in the UK and Ireland Smart Sustain. Built Environ. 3 23–34
[11] Sim Y L and Putuhena F J 2015 Green building technology initiatives to achieve construction quality and environmental sustainability in the construction industry in Malaysia Manag. Environ. Qual. An Int. J. 26 233–49
[12] Ajukumar V N and Gandhi O P 2013 Evaluation of green maintenance initiatives in design and development of mechanical systems using an integrated approach J. Clean. Prod. 51 34–46
[13] Lai J H K 2010 Building operation and maintenance: education needs in Hong Kong Facilities 28 475–93
[14] Zainol N N, Mohammad I S, Baba M, Woon N B, Ramli N A, Nazri A Q and Lokman M A A 2014 Critical Factors that Lead to Green Building Operations and Maintenance Problems in Malaysia: A Preliminary Study Adv. Mater. Res. 935 23–6
[15] Chew M Y L, Tan S S and Kang K H 2005 Contribution analysis of maintainability factors for cladding facades Archit. Sci. Rev. 48 215–28
[16] Aaltonen A, Määttänen E, Kyrö R and Sarasoja A 2013 Facilities management driving green building certification: a case from Finland Facilities 31 328–42
[17] Asmone A S and Chew M Y L 2016 Sustainable facilities management and the requisite for green maintainability In proc. SMART Facilities Management Solutions Regional Focus Group Session (Singapore)
[18] Chew M Y L, Conejos S and Asmone A S 2017 Developing a research framework for the green maintainability of buildings Facilities 35 39–63
[19] Simon H A 1991 Bound rationality and organizational learning Organ. Sci. 2 125–34
[20] Wason P C 1978 Hypothesis testing and reasoning. Unit 25, Block 4 Cogn. Psychol.
[21] Norman D A 1978 Notes toward a theory of complex learning Cognitive psychology and instruction (Springer) pp 39–48
[22] Clemen R T and Reilly T 2013 Making hard decisions with decision tools (Cengage Learning)
[23] Pedrycz W, Ekel P and Parreira R 2011 Fuzzy multicriteria decision-making: models, methods and applications (John Wiley & Sons)
[24] Wang J-J, Jing Y-Y, Zhang C-F and Zhao J-H 2009 Review on multi-criteria decision analysis aid in sustainable energy decision-making Renew. Sustain. Energy Rev. 13 2263–78
[25] Klemm K, Marks W and Klemm A J 2000 Multicriteria optimisation of the building arrangement with application of numerical simulation Build. Environ. 35 537–44
[26] Marks W 1997 Multicriteria optimisation of shape of energy-saving buildings Build. Environ. 32 331–9
[27] Wright J A, Loosmore H A and Farmani R 2002 Optimization of building thermal design and control by multi-criterion genetic algorithm Energy Build. 34 959–72
[28] Lu J and Ruan D 2007 Multi-objective group decision making: methods, software and applications with fuzzy set techniques vol 6 (Imperial College Press)
[29] Kennedy M C, Ford E D, Singleton P, Finney M and Agee J K 2008 Informed multi-objective decision-making in environmental management using Pareto optimality J. Appl. Ecol. 45 181–92
[30] Chew M Y L, De Silva N and Tan S S 2004 Maintainability of wet areas of non-residential buildings *Struct. Surv.* **22** 39–52

[31] Armacost R L, Componation P J, Mullens M A and Swart W W 1994 An AHP framework for prioritizing customer requirements in QFD: an industrialized housing application *IIE Trans.* **26** 72–9

[32] Chen C C, Chiang C M, Horng R S and Lee S K 2011 Multicriteria evaluation of the selection of green glazing material by using the analytic hierarchy process (AHP) *Advanced Materials Research* vol 224(Trans Tech Publ) pp 152–8

[33] Skibniewski M J and Chao L-C 1992 Evaluation of advanced construction technology with AHP method *J. Constr. Eng. Manag.* **118** 577–93