SUSTAINABILITY ASSESSMENT MODEL FOR CONCRETE FORMWORK SYSTEM

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ABSTRACT

The construction industry is recognised as the world's least sustainable industries with high rates consumption of resources and contribution towards global pollution. A major contributor to the unsustainable construction is the use of concrete materials. The formwork system is the central technique in the construction discipline when concrete is used. However, the sustainability performance of concrete formwork system has not received the same amount of attention as in other construction activities because it lacks of suitable sustainability assessment tools. The aim of this research is to develop an assessment model for sustainability performance of concrete formwork system. A quantitative approach using multi-phases questionnaire is employed to identify the sustainability principles and indicators related to formwork system which are then linked to sustainability categories. Covariance analysis method is used to develop and validate the assessment model using structural equation modelling technique. A Formwork Sustainability Assessment Model (FSAM) is proposed which consists of three sustainability categories namely Economic, Environmental, and Social. A total of 20 sustainability performance indicators for the formwork system is identified. Results from the FSAM model validation indicated that the model is well fit with values of GFI=0.976>0.95, P=0.000; RMR=0.014, and RMSEA=0.033. The economic pillar is the major contributor to sustainability with direct effect of β=0.85 on an overall sustainability and indirect effect 0.31 and 0.22 through environment and social pillars respectively. The environment pillar is the second contributor with direct effect of β = 0.72 and indirect effect 0.18. The BREEAM is also used as standard tool to perform criterion validation using the receiver operating curve technique (ROC). The FSAM model and BREEAM are used to assess three types of formwork system i.e. conventional formwork, steel formwork, and aluminium formwork. The ROC shows that FSAM has high accuracy (ACC=0.98) with high sensitivity and specificity at 0.94 and 0.96. The FSAM results show that the aluminium formwork system is more responsive to sustainability with total score 69.15. Meanwhile, the steel formwork system achieved 59.93 and conventional formwork has 42.76. The research results demonstrate that the assessment model can provide evidence of a valid and reliable designed tool to assess the sustainability performance of the concrete formwork system. Significantly, this newly developed FSAM could become a useful tool to help engineers and other stakeholders to evaluate and select the most appropriate sustainable system for their projects as well as to improve and enhance the existing formwork systems.

ABSTRAK

Industri pembinaan diiktiraf sebagai industri paling tidak lestari di dunia dengan kadar penggunaan sumber dan pencemaran global yang tinggi. Penyumbang utama kepada pembinaan tidak lestari adalah penggunaan bahan konkrit. Sistem acuan adalah teknik utama dalam disiplin pembinaan apabila konkrit digunakan. Walau bagaimanapun, prestasi kelestarian sistem acuan konkrit tidak mendapat perhatian yang sama seperti aktiviti pembinaan lain kerana ia tidak mempunyai alat penilaian kelestarian yang sesuai. Tujuan penyelidikan ini adalah untuk membangunkan model penilaian untuk prestasi kelestarian sistem acuan konkrit. Pendekatan kuantitatif menggunakan soal selidik pelbagai fasa digunakan untuk mengenal pasti prinsip dan indikator kelestarian yang berkaitan dengan sistem kerja dan dikaitkan dengan kategori kelestarian. Kaedah analisis kovarians digunakan untuk membangun dan mengesahkan model penilaian menggunakan teknik pemodelan persamaan struktur. Model Penilaian Kelestarian Bekas (FSAM) dicadangkan yang terdiri daripada tiga kategori kelestarian iaitu Ekonomi, Alam Sekitar, dan Sosial. Sebanyak 20 petunjuk prestasi kelestarian untuk sistem acuan telah dikenalpasti. Hasil pengesahan model FSAM menunjukkan bahawa model tersebut sesuai dengan nilai GFI =0.976>0.95, P =0.000; RMR =0.014, dan RMSEA =0.033. Pertimbangan ekonomi adalah penyumbang utama kepada kelestarian dengan kesan langsung β =0.85 pada keseluruhan kelestarian dan kesan tidak langsung 0.31 dan 0.22 melalui pertimbangan alam sekitar dan sosial. Pertimbangan alam sekitar adalah penyumbang kedua dengan kesan langsung β = 0.72 dan kesan tidak langsung 0.18. BREEAM digunakan sebagai alat piawai untuk menjalankan pengesahan kriteria menggunakan teknik lengkung operasi penerima (ROC). Model FSAM dan BREEAM digunakan untuk menilai tiga jenis sistem acuan iaitu acuan konvensional, acuan keluli, dan acuan aluminium. ROC menunjukkan bahawa FSAM mempunyai ketepatan yang tinggi (ACC =0.98) dengan kepekaan dan kekhususan yang tinggi 0.94 dan 0.96. Keputusan FSAM menunjukkan bahawa sistem acuan aluminium lebih responsif terhadap kelestarian dengan nilai keseluruhan 69.15. Sementara itu, sistem acuan keluli mencapai 59.93 dan acuan konvensional mempunyai 42.76. Hasil penyelidikan ini menunjukkan bahawa model penilaian yang dibangunkan dapat menilai prestasi kelestarian sistem acuan konkrit yang boleh dipercayai. Menggunakan FSAM yang baru dibangunkan ini boleh menjadi alat yang berguna untuk membantu para jurutera dan pihak berkepentingan lain untuk menilai dan memilih sistem yang paling sesuai yang lebih lestari untuk projek-projek mereka serta untuk memperbaiki dan mempertingkatkan keberkesanan sistem acuan mereka yang sedia ada.

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LIST OF ABBREVIATION

ACC	-	Accuracy
AFS	-	Aluminium Formwork System
AIC	-	Akaike Information Criterion
AUC	-	Area Under Curve
BCA	-	Building and Construction Authority
BRE	-	Building Research Establishment
BREEAM	-	Building Research Establishment Environmental Assessment Method
CF	-	Conventional (timber) Formwork
CFI	-	Comparative Fit Index
CIB	-	The International Council for Research and Innovation in Building and Construction
CIDB	-	Construction Industry Development Board
Cn	-	Condition negative
Cp	-	Condition positive
Df	-	Degree of freedom
EA	-	Energy and Atmosphere
ECO	-	Economic
ECVI	-	Expected Cross Validation Index
EE	-	Energy Efficiency
EFA	-	Exploratory Factor Analysis
EnSF	-	Environmental Sustainability Factors
ENV	-	Environment
EQ	-	Indoor Environmental Quality
ESF	-	Economic Sustainability Factors
FN	-	False Negative
FP	-	False Positive
FSAM	-	Formwork Sustainability Assessment Model

GBI	-	Green Building Index
GFI	-	Goodness-of-Fit Index
GPD	-	Gross Domestic Product
GSB	-	Green building index Sdn Bhd
IBS	-	Industrial Building System
IN	-	Innovation
Ind	-	Indicator
KMO	-	Kaiser-Meyer-Olkin Measure of Sampling
LEED	-	The Leadership in Energy and Environmental Design
LT	-	Location and Transportation
LV	-	Latent Variable
MR	-	Materials and Resources
MV	-	Manifest Variable
NFI	-	Normed Fit Index
OECD	-	The Organisation for Economic Co-operation and Development project
PCFI	-	Parsimony-adjusted CFI
PCn	-	Predicted Condition negative
PCp	-	Predicted Condition positive
PM	-	Project Manager
PNFI		Parsimony-adjusted NFI
Pr	-	Principle
RE	-	Residential Engineer
RMR	-	Root Mean Square Residual
RMSEA	-	Root Mean Square Error of Approximation
ROC	-	Receiver Operating Characteristic
RP	-	Regional Priority
SE	-	Site Engineer
SEM	-	Structural Equation Modelling
SEN	-	Sensitivity
SFS	-	Steel Formwork System
SM	-	Sustainable Site Planning & Management
SOC	-	Social

SPC	-	Specificity
SPSS	-	Statistical Package for the Social Sciences
SS	-	Sustainable Sites
SSF	-	Social Sustainability Factors
SUS	-	Sustainability Performance
TN	-	True Negative
TNR	-	True Negative Rate
TP	-	True Positive
TPop	-	Total Population
TPR	-	True Positive Rate
UN	-	United Nation
USGBC	-	U.S. Green Building Council
WCED	-	World Commission on Environment and Development
WE	-	Water Efficiency

LIST OF SYMBOLS

θ	-	Type I error probability of rejecting the hypothesis
φ	-	Type II error probability of fail to reject the null hypothesis
r	-	Pearson’s correlation coefficient
X^2	-	Pearson's Chi-Square
η_i	-	The observed variable “Manifest Variable”
α	-	The intercept vector in measurement model
Λ	-	The factor loading of manifest variable to the latent variable
ζ	-	The unobserved variable “Latent Variable”
ϵ	-	The measurement error
ν	-	The intercept vector in structural model
β	-	The path coefficient between latent variables
ε		The residual “structural error”

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Sustainable development had been defined by the world commission on environment and development as: “meeting the basic needs of the public and satisfying a better life without compromising the ability of future generations” (Conca and Dabelko, 2010 and Strong and Hemphill, 2006). This concept was breakdown into three main categories or pillars namely environment, economy and society. Despite that other researchers added other aspects such as political, technical or institutional, these three aspects remain (Plessis, 2006). A sustainable concrete structure aimed to ensure that the total impact on environment during the lifecycle of the concrete (from manufacturing the cement to the demolition and disposal of the concrete) will be minimum (Naik, 2008).

Subsequently, a list of guidelines and sustainability tools have been developed and implemented to ensure the achievement of the sustainable construction and building. The Leadership in Energy and Environmental Design (LEED) USA introduced in 1996 and Building Research Establishment Environmental Assessment Method (BREEAM) which introduced in UK in 1990 are examples of the sustainability tools. Likewise, Singapore produced GREENMARK in 2005 then the Green Building Index (GBI) rating index had been introduced in Malaysia in 2009 (Mun, 2009).

Meanwhile, the construction industry is one of the major industries that contributed to gross domestic product (GPD). It represents up to 6.5% with 6.3% of the job total in United Kingdom (Infrastructure and Projects Authority, 2016). Meanwhile, the Construction Industry Development Board (CIDB) in Malaysia in their report for 2016 mentioned that construction industry represents 4.4.% of Malaysia GPD (CIDB, 2016). Along with this influence on economy, the construction industry has its impact on the environment because construction is considered as one of the least sustainable industries with high rates of resources consumption (45-50% of energy, 50% of water and 60% of materials for building) and global pollution (23% of air quality, 40% drinking water pollution and 50% of land fill waste) (Dixon, 2010). In Malaysia, CIDB annual report in 2015 cited that the highest number of projects obtained on 2014 with total value RM 172 billion with 48% are non-residential projects while 27% are residential projects as shown in Figure 1.1

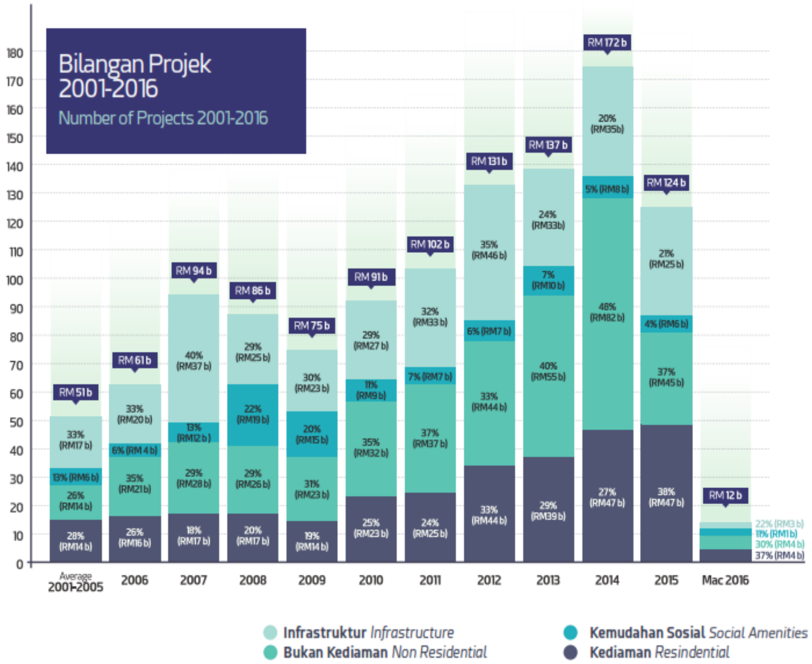

Figure 1.1 Number of construction projects from 2001 till March 2016 in Malaysia (CIDB, 2016)

Furthermore, this report stated that precast concrete is the highest number of Industrial Building System (IBS) components where it had been verified until January 2016 with 166 components, while the formwork system comes in the second place with 73 components (CIDB, 2016). The significant role of construction industry on economic and environment motivates the development of sustainable construction.

The concrete formwork system is considered as one of the most common and important techniques in building construction and concreting. The formwork system has an impact on the construction duration and quality and also counted as a large portion of concrete structural frame total cost (35-60%) (Kim *et al.*, 2005). The concrete formwork system also defined as the structure used to hold and maintain the concrete shape and dimensions until it becomes self-supporting including the mould, framing and supporting members (Australia, 2012 and York and Pallett, 2015).

The increasing acceptance of concrete as a major construction material led to development of a variety of formwork system types based on the function, materials used, or assembly methods (Mishra, 2016 and Nemati, 2007). Meanwhile, the selection of the adequate formwork system is crucial as Yip and Poon (2008) stated in their studies that "Different formwork systems for construction projects achieve different sustainable construction objectives"

1.2 Problem Statement

Although, sustainability becomes one of the important factors that play role in construction management as well as the formwork system (Kurakova, 2018), the current practice of sustainable construction has overlocked the significance of formwork system selection as a sustainability factor. Significantly, there is a gap in the current literature on the studies that corelate the sustainable construction principles with the type of formwork system. Several sustainable principles such as reusing, protecting the nature and conserving are affected by the formwork system due to material used or the installation method that may lead to less sustainability performance (Mah, *et al.*, 2017). Currently, there are several types of formwork systems that claim environmentally friendly and high sustainable performance according to its developers. Although, there are plenty of sustainability performance assessment tools, all of these tools are assessing the overall process with more generalise principles and elements with no specific corelating to formwork system. (Marzouk *et al*., 2017, Tahmoorian, *et al*., 2020).

At the same time, the indicators and elements of sustainable performance have not been highlighted or corelated to the formwork system. Recent sustainability tools are introducing several indicators for construction project phases without linking it to certain particular process (BREEAM, 2018, and Green Building Index, 2013). However, despite the influence of these elements on the sustainable construction performance, linking these elements to formwork system still undiscovered area.

Currently, there are several types of formwork system that claim providing a better sustainability performance and environmentally friendly without any scientifically proof. Hence, the selection of the formwork system is crucial to achieve more sustainable construction and the current practice of sustainability assessment is not properly covering the formwork system. the existence of such tool is significant.

Hence, the sustainability assessment of formwork system is critical for a sustainable project, many issues are raised related to formwork and sustainability when it comes to choosing the most sustainable type.

This study seeks to examine the following questions:

Q1. What are the sustainability principles that are considered related to concrete formwork system?

Q2. What are the sustainability elements that are required to assess the sustainable of formwork system?

Q3. How can these sustainable principles and indicators corelated and linked together in a valid model to assess the formwork system performance and help construction managers in achieving high sustainable construction?

1.3 Research Aim and Objectives

The aim of this research was to develop a formwork sustainability assessment model to help decision makers to select the best formwork system to achieve high sustainability performance.

This model should contribute to the most appropriate balance between the three sustainability dimensions, at the same time being practical, and flexible to use for different types of formwork system. The model also should be easily adaptable to different formwork types and to technological development. The research objectives can be detailed as:

1. To identify the sustainability principles related to concrete formwork system.
2. To determine the sustainability elements that are required to assess the sustainability of formwork system.
3. To develop a sustainable formwork system assessment model.
4. To validate the assessment model for sustainability of formwork system.

1.4 Research Scope and Limitations

This research focused on and limited to the sustainability of the concrete formwork system in the prospective of the three sustainability categories; i.e. environment, economic, and social. This research is targeting the concrete formwork system selection process by providing assessment tool that indicates the sustainability of the formwork system. The research had been carried out in Malaysia with the aid and cooperation of the Green Building Index (GBI) and Construction Industry Development Board (CIDB) by helping in the distribution of the questionnaire surveys to their members. Also, the targeted respondents background is limited to engineers and architectures who works for any type of companies in the construction industry sector with adequate knowledge on formwork and sustainable construction.

1.5 Research Significant and Contributions

Mainly, this research had provided a valid and practical assessment model for the sustainability of the concrete formwork system. Furthermore, the study had identified a list of sustainability principles and elements that will help in developing a better understanding of the relation and contribution of formwork system to the sustainable construction objectives. The research findings added to the literature body by integrating the formwork sustainability indicators to the general sustainable construction.

Theoretically, the developed model would be used as base information for further studies on other construction activity sustainability, or for an extension studies on the formwork sustainability. This model also determined the influence, contribution and relationship of each element to the main domains of sustainability development. Moreover, the developed assessment tool will provide assistance for decision makers in construction management to select the most sustainable formwork system with clear and readable results.

1.6 Thesis Structure

This thesis consists of five chapters. The chapters contents are briefly described below.

- **Chapter 1 (Introduction)**, this chapter covers the background of the study and discussion on the research justifications as well as statement of the study aim and objectives. Then it followed by description of the significance and contribution of the research outcomes.

- **Chapter 2 (Literature Review)**, the second chapter reviews the accessible literature associated to the topic of this study. It provides information and elaborating of the sustainability development management and focus on the sustainable construction with comprehensive discussion on the sustainability problems in construction industry. This chapter also discuss the formwork system literature with explanations of its properties, specification and classification. Finally, it critically reviews the sustainability assessment tool available for sustainable building and construction performance and extract the sustainability indicator consider related to formwork system.

- **Chapter 3 (Research Methodology)**, this chapter explains the research framework used for this study and the research methods adopted for the data collection, data analysis techniques and the justification of using these methods.

- **Chapter 4 (Data Analysis and Discussion)**, the fourth chapter presents the analysis and result gathered from the data collected and provides discussion on these results in order to answer the first and second research questions. Then it presents the results of model development and validation followed with tool development addressing the third and fourth research question.
- **Chapter 5 (Conclusion)**, this last chapter in this thesis. It provides summary of the major findings, discuss the general conclusion, label the significant of the study and recommendations for future work.

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