

DESIGN PHASE CONSTRUCTABILITY ASSESSMENT MODEL

ROSLI MOHAMAD ZIN

A thesis submitted in fulfillment of the
requirements for the award of the degree of
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To my beloved wife and children

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ABSTRACT

Constructability is an important feature of a design where it deals with the ability to build. Constructability problems that are encountered during construction are normally associated with design deficiencies. The problems are more common in the traditional contracting system where the design is separated from the construction. Recent study found that in the Malaysian construction industry constructability has been neglected for quite some times. Many designers have failed to give proper consideration to design constructability during the design process. In other studies it was established that various principles of constructability needed to be considered in order to improve design constructability. The focus of this study is to develop model that can be used to assess design constructability based on the different principles of constructability. Improvement can be made to design that fails to meet the minimum level of design constructability. The study was conducted in three phases that are literature review, questionnaire survey and model development. Artificial Neural Network (ANN) and regression techniques were used in the model development. An extensive review of the literature resulted in the identification of the design-related problems in construction, design phase constructability principles and constructability improvement methods. Through questionnaire survey, six out of eighteen design phase constructability principles identified from literature were found to be very important by the engineers and architects in the Malaysian construction industry. The outcomes of the literature review and questionnaire surveys form a basis for the formulation of a beam-design constructability assessment framework, which is based on the relationship between the degree of application of constructability principles and design constructability. The beam-design constructability assessment framework has enabled design constructability data to be collected. By applying Artificial Neural Network (ANN) and regression methods models of beam-design constructability assessment were developed. The best performance model was found to be the multiplayer back-propagation neural network model consisted of twelve input nodes, five hidden nodes and one output node. Test results indicate that the Artificial Neural Network (ANN) method can produce a sufficiently good prediction even with a limited data-collection effort, and thus provide an efficient tool for design constructability assessment. In this study it was concluded that the model based on the relationship between the level of application of constructability principles and design constructability can be used to assess constructability of project at the design phase.

ABSTRAK

Kebolehbinaan merupakan satu perkara penting dalam rekabentuk di mana ia melibatkan kemampuan untuk membina. Masalah kebolehbinaan yang ditemui semasa pembinaan biasanya berhubungkait dengan kelemahan rekabentuk. Masalah ini lebih ketara dalam sistem kontrak tradisional di mana proses rekabentuk dan pembinaan adalah berasingan. Kajian terkini mendapati kebolehbinaan telah sekian lama diabaikan di dalam industri pembinaan Malaysia. Ramai perekabentuk telah gagal mempertimbangkan kebolehbinaan rekabentuk semasa proses merekabentuk. Di dalam beberapa kajian lain terbukti bahawa berbagai prinsip-prinsip kebolehbinaan perlu dipertimbangkan untuk meningkatkan kebolehbinaan rekabentuk. Fokus kajian ini ialah membangunkan model yang boleh digunakan untuk menilai tahap kebolehbinaan berdasarkan prinsip-prinsip kebolehbinaan yang berbeza tersebut. Penambahbaikan boleh dilakukan keatas rekabentuk yang tidak mencapai tahap kebolehbinaan minimum. Kajian ini dilaksanakan dalam tiga fasa iaitu kajian literatur, soalselidik dan pembangunan model. Teknik-teknik Rangkaian Neural Buatan dan regresi telah digunakan dalam pembangunan model. Kajian literatur menyeluruh menghasilkan penemuan masalah-masalah berkaitan rekabentuk semasa pembinaan, prinsip-prinsip kebolehbinaan fasa rekabentuk dan kaedah-kaedah meningkatkan kebolehbinaan rekabentuk. Melalui soalselidik didapati enam daripada lapan belas prinsip-prinsip kebolehbinaan fasa rekabentuk adalah dianggap sangat penting oleh jurutera dan arkitek di dalam industri pembinaan Malaysia. Keputusan yang diperolehi dari kajian literatur dan soalselidik menjadi asas dalam pembentukan kerangka penilaian kebolehbinaan rekabentuk-rasuk iaitu berdasarkan perhubungan di antara tahap aplikasi prinsip-prinsip kebolehbinaan dan tahap kebolehbinaan rekabentuk. Kerangka penilaian kebolehbinaan rekabentuk-rasuk ini membolehkan data kebolehbinaan rekabentuk dikumpul. Dengan menggunakan kaedah-kaedah Rangkaian Neural Buatan dan regresi model-model penilaian kebolehbinaan telah dibangunkan. Model terbaik didapati merupakan model neural timbal-balik dengan duabelas nod input, lima nod tersembunyi dan satu nod output. Keputusan ujian menunjukkan kaedah Rangkaian Neural Buatan mampu menghasilkan ramalan yang agak baik walaupun dengan data yang terhad seterusnya menjadi satu kaedah cekap yang boleh digunakan untuk menilai kebolehbinaan rekabentuk. Di dalam kajian ini kesimpulan dibuat bahawa model berasaskan perhubungan di antara tahap aplikasi prinsip-prinsip kebolehbinaan dan tahap kebolehbinaan rekabentuk mampu digunakan untuk menilai kebolehbinaan projek di fasa rekabentuk.

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LIST OF SYMBOLS

ACC	-	Prediction accuracy
ANOVA	-	Analysis of Variance
MAPE	-	Mean absolute percentage error
MLP	-	Multi Layer Perceptron
RBF	-	Radial Basis Function
RMSE	-	Root mean square error
b_0, b_1, b_2, \dots	-	Regression Coefficients
e	-	Error estimate
f	-	Transfer function
f'	-	Derivative of the transfer function f
r	-	Euclidean radial distance
T_k	-	Target at output node
w_{0j}	-	Neural network weight propagate from the bias to hidden nodes
w_{0k}	-	Neural network propagate from the bias to output nodes
w_{ij}	-	Neural network weight between the input nodes and hidden nodes
w_{jk}	-	Neural network weight between the hidden nodes and output nodes
x_i	-	Input data
y_{inp}	-	Sum of weighted input signal and bias in the hidden node
y_j	-	Neural network signal from input layer to hidden layer after application of activation function (hidden layer output)
z_{inp}	-	Sum of weighted input signal and bias in the output node
z_k	-	Neural network signal from hidden layer to output layer after application of activation function (output layer output)
δ_k	-	Error information term at output layer

δ_j	-	Error information term at hidden layer
Δw_{jk}	-	Weight correction term of output nodes
Δw_{ij}	-	Weight correction term of hidden nodes
μ	-	Momentum
η	-	Learning rate
φ	-	Radial function
λ_{jk}	-	Weight connection between hidden and output nodes

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The construction industry in Malaysia as in any other countries is one of the driving forces of the nation's economy. Many other industries are dependent on the performance of the construction industry. Despite its importance the construction industry has been criticised for being quite slow in improving the approach to develop and deliver the facilities to the client. The construction industry is also renowned for its lack of integration between design and construction. This has been seen as one of the major factors contributing to the various problems in the construction projects. In the last three decades the integration of design and construction has been considered as the way to reduce some of the major problems in the construction industry ('National', 1975; CIRIA, 1983; Gray, 1983; Illingworth, 1984; CII, 1986; CIIA, 1993). The concept known as constructability was established and introduced to the industry with the aim to overcome some of these problems.

Constructability or buildability as it is known in the United Kingdom can be implemented throughout the entire project lifecycle i.e. from the preliminary stage to the maintenance stage. Since the development of a project evolves through different stages and involved many participants over its lifecycle thus the contributions of constructability improvements by each of the participants vary accordingly. Among many of participants involved in the project, the designers are expected to play the central role for constructability improvement (Hassan, 1997). Designers are seen to have significant roles as they are responsible for most technical problems which arise during project design, in the construction and commissioning of the project. Figure 1.1 illustrates the stages of

project life cycle and the designer level of influence on the project cost over the project time. It can be seen that the level of influence of the designer is higher at the beginning of the project and decreasing towards the end of project. On the other hand the expenditure is increasing as the project progresses. The figure also illustrates that the best time to achieve good constructability of project design is at the earlier stages of project development.

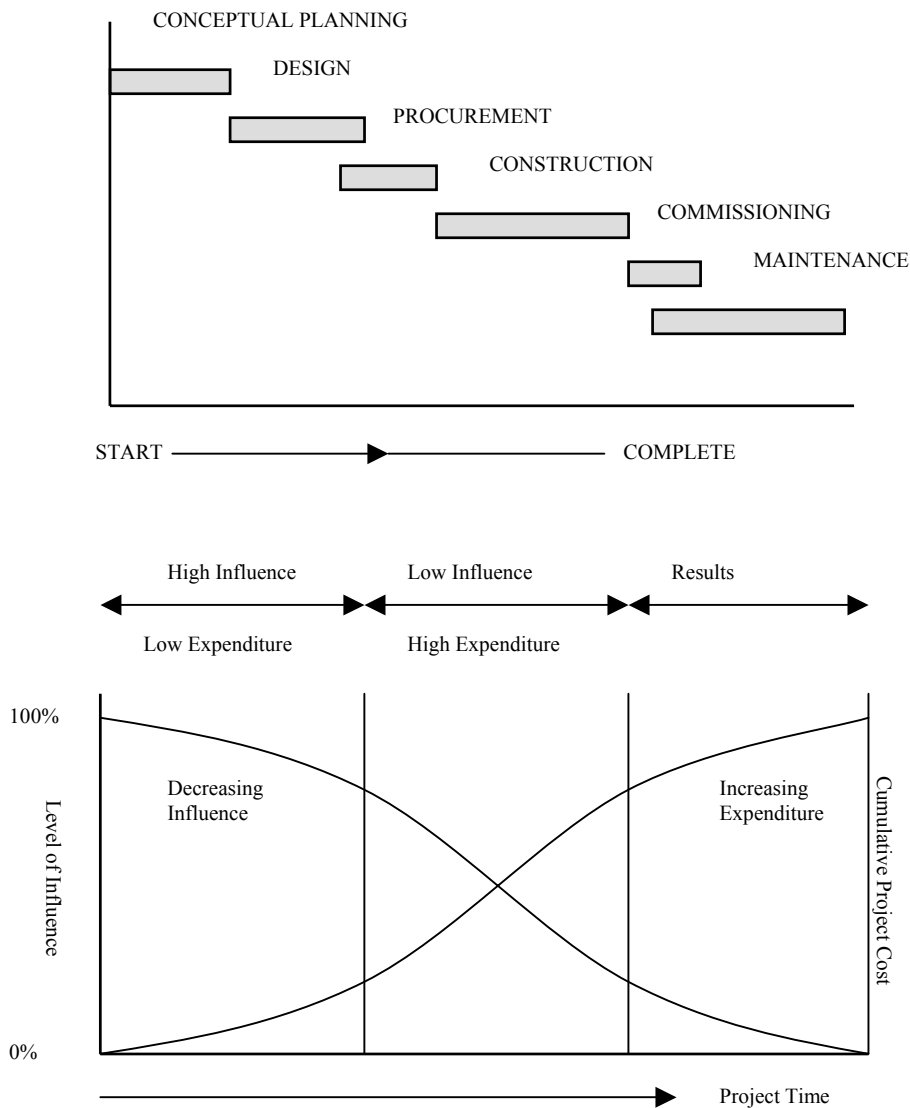


Figure 1.1: Project Life Cycle and Designers Level of Influence (Adapted from Hassan, 1997)

There have been reports that indicate many problems that are encountered during construction can be traced back to the design process (Jergeas, 1989; Alshawi and Underwood, 1994; Madelsohn, 1997; Griffith and Sidwell, 1995). These problems can be

as high as 75% of the total problems encountered during construction (Madelsohn, 1997). In Chapter 2 various problems related to design that are encountered during construction have been identified. The number indicates that the problem of design constructability cover a wide spectrum. In view of the variability of design constructability problems and the level of influence of designers toward constructability of project designs it is therefore necessary to look into the problem of design constructability in more detail.

In this study the impact of design solutions on constructability has been investigated. A framework that can be used by designers to measure the degree of application of constructability principles during the design process was formulated. The relationship between the application of constructability principles and design constructability were modeled using Artificial Neural Network and Multiple Linear Regression techniques. The result of this research provides a tool to assess design constructability of any design elements such as beams, columns or walls in building construction. By using the design constructability assessment tool designers will be able to evaluate their design with respect to constructability and improvement can be made. This will minimise problems that are encountered during construction due to design deficiencies and thus facilitate ease of construction.

1.2 Background and Justification of Research

The prominent arrangements available to the client for the procurement of construction project can be broadly grouped into traditional contracting, design and construct and management-based methods. These procurement options can accommodate both building works as well as other engineering projects.

The traditional contracting system is a common procurement method used in Malaysia. Preliminary interviews with a few project owners, contractors, and consultants as highlighted in Chapter 6 indicate that more than half of projects tendered out in the last five years used this type of contracting system. Many project owners separate planning, design, and construction when building new or reconstruction of old facilities. The contractors usually would not be involved until the design has been completed. In line with this view Griffith and Sidwell (1995) has mentioned that the traditional contracting

system, where responsibility for the construction design lies exclusively with the client's chosen consultants and the contractor is selected through a tendering process has been a typical method of procurement for many years. The traditional approach imposes contractual segregation between those with actual construction expertise and the design team.

Due to the separation of design and construction a lot of problems arise during construction where buildings or facilities could not be built as designed, or could not be constructed efficiently. It is common that construction projects exceeded budget and schedule (Gray, 1983; Griffith and Sidwell, 1995; Hassan, 1997). Constructability is one of the potential solutions to minimise the problems faced by the construction industry.

Constructability is the extent to which the design of a building facilitates ease of construction subject to the overall requirements for the completed building (CIRIA, 1983). There are a lot of benefits that can be gained through constructability. The studies by the Construction Industry Institute (CII) in the US and others have demonstrated that improved constructability has led to better project performance (Gray 1983; O'Connor 1985, CII, 1986, O'Connor and Tucker, 1986; Russel et.al. 1993, O'Connor and Miller 1993, Francis et. al., 1996). Gray (1983) indicated that a reduction of between 1% to 14% of the capital cost could be achieved if advised upon practical aspects of constructing a building is incorporated in the design thinking. The Construction Management Committee, ASCE Construction Division (1991) on the other hand found that constructability pay off 10-20 times the cost of constructability efforts. In a report produced by the Construction Industry Institute (CII) specific projects were reported to achieve 6-10% savings of construction cost as a result of proper constructability implementation (CII, 1986). O'Connor and Miller (1993) found that formal constructability implementation increased the probability of outstanding project performances from 8% to 40%. Russell et al. (1993) reported that the benefit/cost ratio of the constructability program in their case study was 10:1. A survey carried out by Jergas and Van der Put (2001) indicated that significant gain in term of cost, schedule and safety can be achieved through proper constructability implementation in projects. These are some of the examples that show constructability has significant impact on project performance. In another case study Francis et al., (1996) reported that constructability resulted in the enhancement of the original project objectives in term of reduction of construction cost and early completion of the project.

At present, the construction industry in Malaysia suffers from the absence of constructability. The findings from literature review highlighted in Chapter 2 shows that that so far there are very limited numbers of constructability studies have been carried out in this country. Nima (2001) and Nima et al. (2001) highlighted that many construction personnel in the Malaysian construction industry do not apply constructability principles in their practice. There is no formal constructability program implemented in construction projects. Integration between design and construction has been neglected. As identified by the Center for Innovative Construction Engineering (CICE) task force and other studies in the UK, the separation of design and construction has been suggested as being responsible for the lack of constructability in construction projects (Hassan, 1997).

As a result of design and construction separation, problems that are occurring during construction due to design deficiencies have been identified as one of the common issue in projects (Hassan, 1997). In many occasions, the project could be delayed by variation orders, which would normally be issued to rectify design problems. There are different types of problems that are normally encountered during construction but originated during the design process. This study has classified these problems into fourteen different types and they are listed in Table 2.1. These so called design-related problems are a result of lack of construction input during the design process. In an article ‘The Constructability Review Process: A Constructor’s Perspective’ (Madelsohn, 1997), the author highlighted that 75% problems in the field are generated in the design phase. Kirby et al. (1987) reported that design deficiencies are the major cause of contract modifications. This is in line with the findings of Ratchliffe (1985), Jergeas (1989), Adams (1989), and Griffith and Sidwell (1995) that some building designs are inherently inefficient.

In view of the problem it is necessary that constructability of project designs be improved in order to minimise the design-related problems during construction. The need is more critical especially in the context of the Malaysian construction industry where constructability has been neglected for quite sometimes. The constructability improvement will eventually improve the efficiency of the construction industry. This early constructability improvement is desired, as the benefits of constructability that can be gained is high and the ‘early cost influence’ can be taken advantage off. The ‘early cost influence’ is a concept where the ability to influence the project cost decreases with the

project lifetime. Figure 1.2 depicted the cost influence of constructability implementation throughout the project lifecycle.

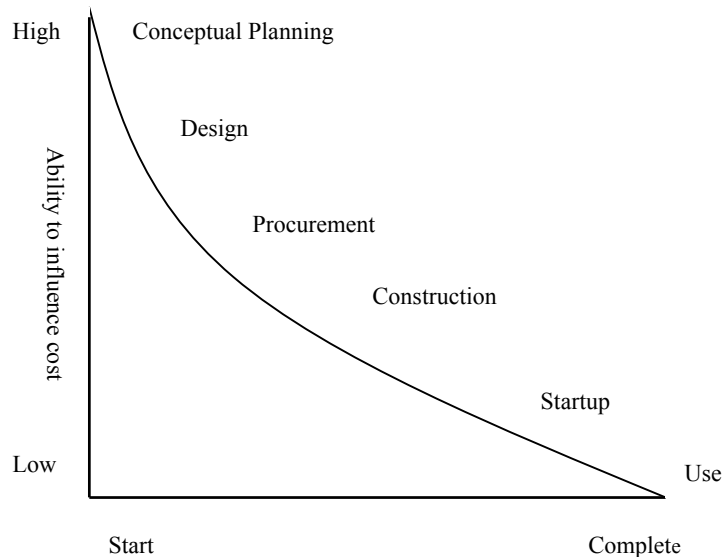


Figure 1.2: Constructability Cost-influence Curve (Adapted from CII, 1986)

The integration of good constructability into a good overall design is the responsibility of the design team. According to Adams (1989) to design for good constructability requires ingenuity, knowledge and experience of construction. New design solutions have to be carefully studied especially with respect to the impact on project performance. Since the aim of constructability is to improve efficiency of the overall building process by developing construction sensitive designs (Hon et al., 1989), the expected results from improving constructability of project designs are efficient and effective construction of a building. There are various ways where constructability improvement could be made on project designs. As highlighted in Chapter 4 there are three different types of improvement methods that can be used: guidelines, computerized systems, and manual systems. Majority of the improvement methods provide assessment of the level of constructability of the selected designs and actions or improvement is then made based on the assessment results. The guidelines provide the industry with general recommendations for implementing constructability in projects. It is intended to stimulate thinking in term of constructability rather than to be a complete checklist. The computerised systems provide designers with an automated assessment of various aspects of design constructability. The approaches used to improve design constructability vary between one system to another with some using knowledge based expert systems while others using artificial intelligence such as fuzzy logic. The constructability improvement

methods based on manual systems are aimed at providing designers with simple procedure to manually evaluate the level of constructability by using scales or formula. The formula enables designers to evaluate any completed building designs within a short period of time. Improvements can be made to any design elements that fail to meet the minimum constructability score at ease. One of the common weaknesses among the improvement methods is the inability of the methods to optimise design based on several aspects or principles of constructability. Thus constructability improvement is only made on specific principle of constructability such as assembly difficulty, standardisation, construction tolerance, and accessibility needs. It is believed that design constructability should be optimised based on various aspects of constructability. This is because any improvement made to a particular principle of constructability may have resulted in undesirable overall level of constructability. In Chapter 3 eighteen principles of constructability have been identified. Take for example, standardisation, which is one of the principles of constructability suitable for implementation at the design stage. It is observed that standardisation can be achieved by specifying design element such as beams or columns of having similar material type for the entire design project. In general it was identified that the application of this principle of constructability, enhanced the constructability quite significantly. However there must be adequate consideration to the impact of standardisation on other aspects of constructability such as availability of skills labour to execute the job. If skills labour needed to do the work is very limited then the benefit of using a single type of materials may not improve the overall design constructability. In worse case a negative overall impact on constructability might be the end result. In view of this problem methods should be developed whereby the impact of various aspects of constructability can be assessed so that improvement can be made to the design. This is an area remain to be investigated, which is also the focus of this study. To achieve the aim of this study several objectives have been identified which are presented in the following section.

1.3 Aim and Objectives of the Study

The aim of this study is to improve constructability of projects that are tendered out within the traditional contracting system in the Malaysian construction industry through proper constructability assessment of the designs produced by the designers. The improvement method which if implemented would minimise or overcome the design-related problems that are occurring during construction.

To achieve the above aim the following objectives have been identified:

- (i) To identify and establish the design-related problems within the traditional contracting system;
- (ii) To identify and establish the degree of importance of constructability principles that are suitable for implementation at the design phase;
- (iii) To formulate a framework for the assessment of beam-design constructability; and
- (iv) To develop constructability assessment models for beam-design using Artificial Neural Network (ANN) and Regression techniques.

1.4 Research Methodology

Research methodology guides the researcher in the process of collecting, analyzing, interpreting observations. It is a logical model of proof that allows the researchers to draw inferences concerning relations among the variable under investigation. To respond to the aim and objectives of this research, Figure 1.3 outlined the methodology for this study. There are three distinct phases of the study: Phase 1 involves literature review and preliminary interview; phase 2 deals with data collection and analysis using questionnaire surveys and phase 3 comprises of developing a framework and models to assess beam-design constructability. Detail discussions of the research methodology are given in Chapter 6. In brief the research methodology is as follows:

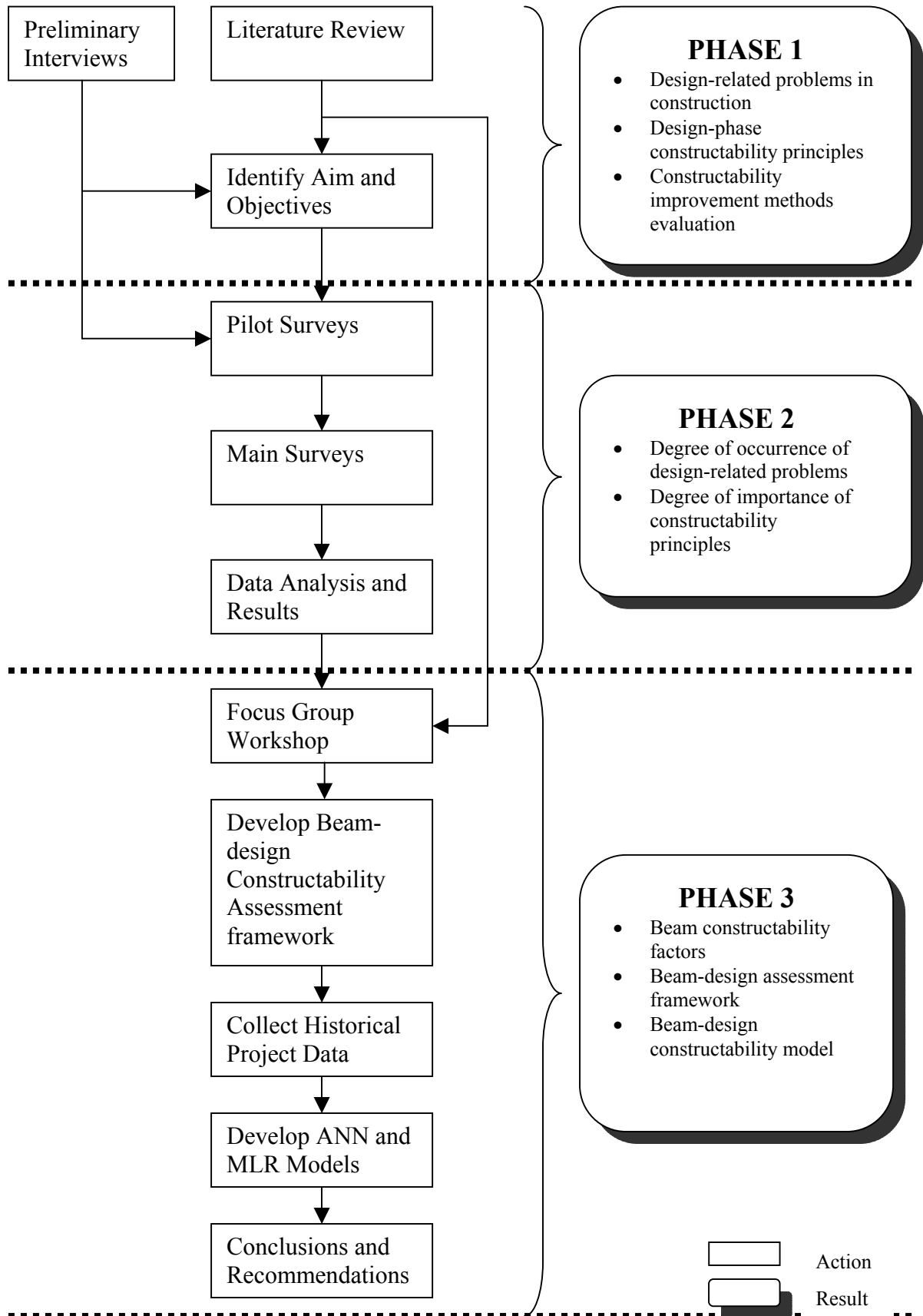


Figure 1.3: Research Methodology

1.4.1 Phase 1: Literature Review and Preliminary Interview

Phase 1 is aimed at reviewing information on design-related problems, constructability principles, and constructability improvement methods to establish the problem area. Preliminary interviews as described in section 6.2.2 of Chapter 6 with the construction industry participants especially the contractors were also conducted to find evidence and to establish that the design-related problems are common constructability issue.

1.4.2 Phase 2: Questionnaire Survey

In order to determine the degree of occurrence of design-related problems in construction and degree of importance of the design phase constructability principles, the following surveys were performed.

- A self-administered questionnaire survey was used to investigate the engineers' and architects' perception on the level of occurrence of design-related problems in construction; and
- A self-administered questionnaire survey was used to investigate the engineers' and architects' perception on the degree of importance of design phase constructability principles.

Data obtained from the survey was tested in a series of statistical test which include frequency analysis, mean score analysis, and ANOVA (Analysis of Variance – Kruskal Wallis Test) using SPSS software package.

1.4.3 Phase 3: Models Development

The results that were obtained from phase 2 formed the basis for the development of the design constructability assessment models. The following steps were performed before the final model of beam-design constructability assessment was established.

- Identification of beam constructability factors based on information collected through literature and the outcome of focus group workshop as described in Chapter 6;
- Formulation of a framework to assess beam-design constructability based on the relationship between the degree of application of design phase constructability principles and design constructability;
- Collection of beam-design constructability data from contractors that have several years of experience in building projects; and
- Modeling of beam-design constructability assessment using Artificial Neural Network (ANN) and Regression methods.

1.5 Scope of the Study

The scopes of the study are as follows:

- (i) The types of project included in this study were projects carried out based on the traditional contracting system i.e. the design is separated from the construction. Therefore, the respondents of the questionnaire survey were engineers and architects who have experience in this type of contracting system. Likewise the historical project data were also focused on projects of similar nature. The data used to develop the constructability assessment models were those related to beam-design only.
- (ii) Even though the definition of constructability signifies that constructability can be implemented throughout the entire project lifecycle, the focus of this study is on constructability improvement at the design phase. As such constructability improvements for other phases throughout the project life cycle are not covered.

1.6 Structure of the Thesis

This thesis consists of ten chapters and eight appendices. A review of the relevant literature is given in Chapter 2, 3, 4 and 5. In Chapter 2 the overview of the design-related problems and related definition, types of design-related problems, and impacts of design-related problems to projects are described.

In order to determine the principles of constructability suitable for implementation during the design phase various sources were referred particularly from publication of the Construction Industry Institute (CII) and Construction Industry Research Information Association (CIRIA). Other important sources of reference were journals and conferences papers. The discussion on the development of constructability principles and details of the design phase constructability principles are given in Chapter 3.

Chapter 4 discusses the various constructability improvement methods that are available and comparisons are made. The findings from this literature review form a basis for the formulation of the design constructability assessment framework.

Chapter 5 concentrates on the theoretical basis to constructability assessment models using Artificial Neural Network (ANN) and regression methods. Two neural computational techniques namely the Multi Layer Perceptron (MLP) and Radial Basis Function (RBF) are discussed. The architectures of these two networks are described in details. The beam-design constructability assessment models developed in this study are based on the MLP and RBF networks. At the end of the chapter the theoretical aspects of regression method is discussed.

Chapter 6 describes the research methodology adopted in the study. In this chapter detail discussion on the research methodology, which cover three distinct phases of the study namely literature reviews and preliminary interviews, questionnaire surveys and model development are made. The data collection methods and analytical methodologies used in each stages of the study are described.

Chapter 7 presents the questionnaire data analysis. Results are presented in table forms. Based on the results obtained discussions are made at the end of the chapter. This enables the establishment of the level of occurrence of design-related problem in

construction and identification of the degree of importance of constructability principles that are suitable for implementation at the design stage.

Chapter 8 presents the proposed framework to assess beam-design constructability. This framework is based on literature review made in Chapter 4 coupled with the results obtained from questionnaire survey highlighted in Chapter 7. The constructability principles that have high degree of importance are broken down to into a more specific constructability factors. Since beam design element has been selected in the study therefore only beam-design constructability factors are identified. Based on the identified constructability factors methods of measuring the level of application of constructability principles and design constructability are formulated. The framework enables beam-design constructability assessment models to be developed.

Chapter 9 describes the development of design constructability assessment models. Two methods namely the Artificial Neural Network (ANN) and Regression are used to model the beam-design constructability assessment. In the ANN modeling two neural computational techniques are investigated. The first method is the Multi Layer Perceptron (MLP) while the second method is Radial Basis Function (RBF). In this chapter pre-analysis of the data is also described. At the end of the chapter discussion on the outcome of the results are made and the network with best performance is identified.

Finally the summary and conclusions derived from this study are presented in Chapter 10 together with recommendations for future work.

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