

*An Exploratory System Dynamics Model To  
Investigate The Relationships Between Errors  
That Occur In Construction Documents In  
Saudi Arabia And Their Possible Causes*

By  
Rukn Eldeen Mohammed

Submitted for the degree of Doctor of Philosophy

**Heriot-Watt University**  
**School of the Built Environment**

September 2007

This copy of the thesis has been supplied on condition that anyone who consults it is understood to recognize that the copyright rests with its author and that no quotation from the thesis and no information derived from it may be published without the prior written consent of the author or of the University (as may be appropriate).

The aim of the thesis is to reduce the occurrence of errors in construction documents by developing a theoretical model to capture the dynamics of processes that define the relationship between the factors causing errors in construction documents.

The research justified a mixed-mode research approach and the use of system dynamics as the modelling tool. Different types of errors in construction documents were identified that can be classified as follows, starting with the most serious: the erroneous; omissions; failure to conform to design parameters; failure to follow procedures; coordination problems; failure to address operability and constructability issues; and finally, the difficulty of biddability. Also factors affecting the occurrence of errors in construction documents were identified and classified. The classification was based on individual and includes project management, designer, client, and project characters. Using System Dynamics modelling tools each factor has been concluded, with experts' validated causal analysis diagrams that explain the highly dynamic relationship between the factors and the element(s) having a direct influence on the occurrence of errors in construction documents, using prior theoretical knowledge extracted from the literature, case-study projects and interviews. The developed model simulated the occurrence and behaviour of errors while producing construction documents. The focus of the model is based on an understanding of the internal mechanism of the occurrence of these errors, to avoid placing blame in favour of finding the true, long-term solution to a problem. Measuring the model's behaviour and using sensitivity tests for the correctly solved errors revealed two types of behaviour: one where the model shows reasonable behaviour up to a certain drop in the value of the factors, and the second where the model is under full control of the value of the factors when this value drops below 10%. Among the most sensitive factors were the designer's previous experience, the designer's education, the experience of the designer with similar projects, and the factor of the designer's reputation. These findings were validated and supported by case study projects.

The model can be used as a valuable tool in communicating the impact of complex structures on the behaviour of errors in construction documents, and has created opportunities for expanding the study of project dynamics in several potentially valuable directions. This research points to ways of improving performance through improved understanding of the occurrence and structure of errors in construction documents.

## ACKNOWLEDGMENT

---

ALL THANKS AND PRAISE TO ALLAH ALMIGHTY, THE CHERISHER AND SUSTAINER OF THE WORLDS, THE MOST MERCIFUL, THE MOST GRACIOUS.

I would like to thank the many individuals who have assisted in the development of this research. In particular, I would like to thank my supervisor Dr. Graeme Bowles for insightful and always helpful guidance, thoughtfully provided over many years during the writing of this thesis.

Many thanks and much appreciation are offered to those who have taught me since elementary school and who wished me a bright and prosperous future.

Profound thanks are due to my father, mother, brothers, sisters, relatives and friends for their continuous prayers and inspiration.

A final 'thank you' must go to my wife Safia and children Rawa, Mohammed, Judy, Maryam and Ayisha. If you had not taken the time actually to care all those years ago, I would never have got as far as this.

ACADEMIC REGISTRY  
**Research Thesis Submission**



Name:	Rukn Eldeen Mohammed T. Mohammed		
School/PGI:	School of the Built Environment		
Version: <i>(i.e. First, Resubmission, Final)</i>	Final Submission	Degree Sought:	PhD

**Declaration**

In accordance with the appropriate regulations I hereby submit my thesis and I declare that:

- 1) the thesis embodies the results of my own work and has been composed by myself
- 2) where appropriate, I have made acknowledgement of the work of others and have made reference to work carried out in collaboration with other persons
- 3) the thesis is the correct version of the thesis for submission\*.
- 4) my thesis for the award referred to, deposited in the Heriot-Watt University Library, should be made available for loan or photocopying, subject to such conditions as the Librarian may require
- 5) I understand that as a student of the University I am required to abide by the Regulations of the University and to conform to its discipline.

\* *Please note that it is the responsibility of the candidate to ensure that the correct version of the thesis is submitted.*

Signature of Candidate:		Date:	
-------------------------	--	-------	--

**Submission**

Submitted By <i>(name in capitals)</i> :	
Signature of Individual Submitting:	
Date Submitted:	

**For Completion in Academic Registry**

Received in the Academic Registry by <i>(name in capitals)</i> :			
<i>Method of Submission</i> <i>(Handed in to Academic Registry; posted through internal/external mail):</i>			
Signature:		Date:	

**CHAPTER 1: INTRODUCTION**

1.1	Introduction	2
1.2	Background	2
1.3	The problem	4
1.4	Statement of the problem	6
1.5	Scope of the research	6
1.6	Justification for the research	8
	1.6.1 Construction cost	8
	1.6.2 Scale of the problem	8
	1.6.3 Contractual	9
	1.6.4 Unrealistic inflated estimate	10
	1.6.5 Financial problems	10
	1.6.7 Reputation of consultant office	11
	1.6.8 Designer office profit	11
	1.6.9 Designer indemnity insurance	11
1.7	Research hypothesis	12
1.8	Aims	13
1.9	Objectives of the research	14
1.10	Contribution of the research	14
1.11	Structure of thesis	15

**CHAPTER 2: ERRORS IN CONSTRUCTION DOCUMENTS**

2.1	Introduction	19
2.2	Construction documents	19
2.3	Influence of construction documents on the success of the project	23
2.4	Definition of errors	25
2.5	Errors and construction industry	27
2.6	Discovery of errors in construction documents	28
	2.6.1 Design project team	29
	2.6.2 Tender queries	29
	2.6.3 Quality assurance documents	30
	2.6.4 On-site construction phase	30
	2.6.5 Correspondence	30
	2.6.6 Client feedback	30
2.7	Influence of procurement on the type and number of errors in construction documents	31
	2.7.1 Early award	32
	2.7.2 Traditional procurement	32
	2.7.3 Multiple prime contracts	33
	2.7.4 Fast track projects	33
	2.7.5 Construction management	34
	2.7.6 Design / build	34
2.8	Developing the quality of the construction documents	35
	2.8.1 Partnering	36
	2.8.2 Concurrent engineering	36
	2.8.3 Taguchi approach - quality by design	37
	2.8.4 Sequencing the work process	38

## TABLE OF CONTENTS

---

2.8.5	The principle of single statement	39
2.8.6	The REDICHECK method	40
2.8.7	Red-Green-Yellow checking technique	40
2.8.8	Developing a corporate memory	41
2.8.9	Design review management	42
2.8.10	Constructability	42
2.8.11	Value management	43
2.8.12	Quality function deployment	43
2.8.13	Failure mode and effect analysis (FMEA)	43
2.8.14	Activity-based costing	43
2.9	Measuring the number of errors in construction documents	44
2.9.1	Total quality project management	44
2.9.2	Variability in construction bids	44
2.9.3	Costs of construction change orders	45
2.9.4	Meeting the requirements	45
2.9.5	Quality performance tracking system	46
2.10	Conclusion	46

## **CHAPTER 3: RESEARCH METHOD**

3.1	Introduction	49
3.2	Definition of the problem and scope of the research study	49
3.2.1	Problem definition	49
3.2.2	Scope of research	50
3.3	Debates about the research methodology in construction management	51
3.4	Selection of research methodology	54
3.4.1	Pure statistical analysis approach	63
3.4.2	Causal structure analysis approach	64
3.5	System dynamics	68
3.5.1	Background of system dynamics	68
3.5.2	Application of system dynamics in construction industry	70
3.5.3	Application of system dynamics in the current research	71
3.6	Key to understand system dynamics modelling	75
3.6.1	Modeling process	76
3.6.1.1	Qualitative system dynamics	76
3.6.1.2	Quantitative system dynamics	76
3.6.2	Creating causal loop diagrams	78
3.6.3	Pattern of behaviour	80
3.6.4	Delays	82
3.7	Approach of developing the thesis's model using System dynamics	83
3.7.1	The conceptualization stage	86
3.7.2	The formulation stage	87
3.7.3	The testing stage	88
3.7.4	The implementation stage	89
3.8	Data collection and sampling	91
3.8.1	Literature review	92
3.8.2	Case study projects	93
3.8.3	Questionnaire	94
3.8.4	Interview	96

## TABLE OF CONTENTS

---

3.8.5	Other source for data collections	98
3.9	Conclusion	101

### **CHAPTER 4: ERRORS IN CONSTRUCTION DOCUMENTS OF THE SAUDI INDUSTRY**

4.1	Introduction	104
4.2	Procedures for producing construction documents	104
4.3	Research methodology used to collect data about errors	114
4.4	Types of errors in construction documents of the Saudi construction industry	117
4.4.1	Document does not conform to client's design criteria	118
4.4.2	Document does not conform to code	118
4.4.3	Document does not conform to calculations	119
4.4.4	Document does not conform to vendor data	120
4.4.5	Document does not conform to the law	120
4.4.6	Document does not conform with building regulations	120
4.4.7	Discipline coordination problems	121
4.4.8	Interdisciplinary coordination problem	122
4.4.9	Operability problem	122
4.4.10	Constructability problem	123
4.4.11	Document does not conform to drafting standards	123
4.4.12	CADD –related problem	124
4.4.13	Dimensional error	124
4.4.14	Symbol and abbreviation errors	125
4.4.15	Callouts incorrect or missing	125
4.4.16	Incorrect or missing notes	126
4.4.17	Additional views / details needed	126
4.4.18	Errors in capital cost estimating	127
4.4.19	Designer errors	127
4.4.20	Error in project contextual factors	128
4.4.21	Errors and omission in the bills of quantities	128
4.4.22	Errors in Specification	129
4.4.23	Biddability	129
4.5	Error classification	130
4.6	Conclusions:	134

### **CHAPTER 5: FACTORS INFLUENCING THE OCCURRENCE OF ERRORS IN CONSTRUCTION DOCUMENTS**

5.1	Introduction	136
5.2	Causes of errors	136
5.3	The approach to identify factors and develop the causality relationship	137
5.4	Classification of factors influencing occurrence of errors in construction documents	148
5.5	Factors influencing the occurrence of errors in the pre-contract-stage	151
5.5.1	Management	151

## TABLE OF CONTENTS

---

5.5.1.1	Management organizational structure	153
5.5.1.2	Project manager experience	156
5.5.1.3	Project brief	157
5.5.1.4	Changes to key project personnel	161
5.5.1.5	Group organization	162
5.5.2	Designer	165
5.5.2.1	Design process	165
5.5.2.2	Design Management Experience	167
5.5.2.3	Designer professional education	168
5.5.2.4	Designer experience	169
5.5.2.5	Design fees	169
5.5.2.6	Design team efficiencies	171
5.5.2.7	Design time	172
5.5.2.8	Procedure for producing documents	174
5.5.2.9	Designer salary	175
5.5.2.10	Number of Designers	176
5.5.2.11	Concurrent design activities	177
5.5.2.12	Amount of work with the Designer	178
5.5.2.13	Reputation of designer	179
5.5.2.14	Availability of quality management	180
5.5.2.15	Effective design team	182
5.5.2.16	Communication	184
5.5.2.17	Availability of information	186
5.5.2.18	Transfer of knowledge and experience between designers	188
5.5.3	Client	191
5.5.3.1	Type of client (private, government, developer)	192
5.5.3.2	Client experience	194
5.5.3.3	Construction constraint time (start or finish)	196
5.5.3.4	Client Point of contact	198
5.5.3.5	Planning of the project	200
5.5.3.6	Identification of project risks;	203
5.5.3.7	Attitude of Client	205
5.5.4	Project Characters	208
5.5.4.1	Uniqueness of the project	208
5.5.4.2	Time schedule pressure	209
5.5.4.3	Project Budgeted cost	210
5.5.4.4	Procurement	211
5.5.4.5	Size	212
5.5.4.6	Quality	213
5.5.4.7	Compatibility with designer goals	214
5.5.4.8	Services provided	215
5.5.4.9	Authority Approval	217
5.6	Interaction between factors	221
5.7	Assessing the fitness of the causal diagrams	223
5.8	Conclusions	224



**CHAPTER 6: MODEL DESCRIPTION**

6.1	Introduction	226
6.2	Approach to developing the model	226
6.3	Factors within the scope of the system dynamics model	228
6.4	Model assumptions	230
6.5	Model equations	231
6.6	Description of the model	234
	6.6.1 Design process	239
	6.6.2 Number of designers	241
	6.6.3 Design management	243
	6.6.4 Designer education and experience	244
	6.6.5 Design fees	245
	6.6.6 Design time	247
	6.6.7 Procedure of producing documents	250
	6.6.8 Designer salary	251
	6.6.9 Concurrent design activities	252
	6.6.10 Amount of work with the designer	252
	6.6.11 Reputation of designer influence	254
	6.6.12 Availability of quality assurance	255
	6.6.13 Effective design team	257
	6.6.14 Communication	258
	6.6.15 Availability of information	259
	6.6.16 Transfer of knowledge	261
6.7	The basic structure of the system	262
6.8	Conclusion	273

**CHAPTER 7: VALIDATION OF THE STRUCTURE AND BEHAVIOUR OF THE MODEL**

7.1	Introduction	276
7.2	Validation and verification of the model	276
7.3	Validation of the research model	278
7.4	Behavioural validation of the model	283
	7.4.1 Total number of interactions and number of problems solved	284
	7.4.2 Types of error occurring while producing the construction documents	285
	7.4.3 Remaining number of interaction and number of errors solved.	287
	7.4.4 Quality of work	288
	7.4.5 Discovery of errors	289
	7.4.6 Flow of information	290
	7.4.7 Production of documents	291
	7.4.8 Share of knowledge and design experience	292
	7.4.9 Input to team	293
	7.4.10 Solving problems	294
7.5	Structure oriented behaviour validation using sensitivity analysis	295
	7.5.1 Factor of errors due to interaction	299
	7.5.2 Working hours per week per designer	301

## TABLE OF CONTENTS

---

7.5.3	Salary standard	303
7.5.4	Time required to produce a document	305
7.5.5	Number of disciplines	307
7.5.6	Number of phases	309
7.5.7	Procedure to produce documents	311
7.5.8	Previous designer experience	313
7.5.9	Number of documents produced	315
7.5.10	Availability of information	317
7.5.11	Availability of quality assurance procedure	319
7.5.12	Culture of the team	321
7.5.13	Experience of the designers	323
7.5.14	Designer Education	325
7.5.15	Reputation of the designer	327
7.5.16	Match of the goals	329
7.5.17	Contractual Design Time	331
7.6	Behaviour of factors affecting the generation of errors in the construction documents	336
7.6.1	Category 1: factors with deviation less than 10% between high and low value	339
7.6.2	Category 2: factors with deviation between 10%-15% for high and low value	340
7.6.3	Category 3: factors with deviation between 15%-20% for high and low value	341
7.6.4	Category 4: factors with deviation between 20%-25% for high and low value	342
7.6.5	Category 5: factors with deviation between 25%-30% for high and low value	343
7.6.6	Category 6: factors with deviation between 25%-30% for high and low value	344
7.6.7	Category 7: factors with deviation between 30%-35% for high and low value	345
7.7	Classification of sensitivity of the factors:	346
7.8	Validating the findings of the research model for the most sensitive factors	349
	7.8.1 Lack of professional education	349
	7.8.2 Lack of experience	351
	7.8.3 Lack of good reputation of the design office	353
	7.8.4 Lack of experience with similar projects	355
7.9	Summary	358

## **CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS**

8.1	Introduction	360
8.2	Recapitulation	360
8.3	Determination of research hypothesis validity	361
8.4	Major findings and discussions	362
	8.4.1 Source of errors in construction documents	362
	8.4.2 Major sources of errors in construction documents	363
	8.4.3 Errors in construction documents can be managed	363

## TABLE OF CONTENTS

---

8.4.4	The role of construction documents in project behaviour	364
8.4.5	The role of nonlinear relationships, feedback, and delays in project behaviour	364
8.4.6	Project constraints	364
8.4.7	System dynamics as a tool for research projects	365
8.5	Contributions	365
8.5.1	A new research tool	366
8.5.2	A new tool for practitioners and construction document production insights	367
8.5.3	Improved understanding of tangible and intangible factors	367
8.5.4	Improved understanding of the error occurrence structure and relationships	368
8.5.5	Improved understanding of consequences of decisions over time	368
8.6	Limitations of the research	369
8.7	Future research	371
8.8	Conclusions	371

## **REFERENCES**

## **APPENDIX A: FULL LIST OF THE MODEL'S EQUATIONS**

## **APPENDIX B: QUESTIONNAIRE**

1.1	Introduction.....	2
1.2	Background.....	2
1.3	The problem.....	4
1.4	Statement of the problem.....	6
1.5	Scope of the research.....	6
1.6	Justification for the research.....	8
1.6.1	Construction cost.....	8
1.6.2	Scale of the problem.....	8
1.6.3	Contractual.....	9
1.6.4	Unrealistic inflated estimate.....	10
1.6.5	Financial problems.....	10
1.6.7	Reputation of consultant office.....	11
1.6.8	Designer office profit.....	11
1.6.9	Designer indemnity insurance.....	11
1.7	Research hypothesis.....	12
1.8	Aims.....	13
1.9	Objectives of the research.....	14
1.10	Contribution of the research.....	14
1.11	Structure of thesis.....	15

## **1.1 Introduction**

This chapter introduces the problem and the justification for work in this particular area of knowledge, together with aims, objectives, and the contribution of the research toward existing knowledge in the field of the project management. The intention of the current research will be compared with the previously established technique of reducing errors in the construction documents.

This chapter will end with a brief overview of the structure of the research.

## **1.2 Background**

Successful project management is both an art and a science which attempts to control corporate resources within the constraints of time, cost, and performance (Kerzner, 1995). The triangle of time, cost, and performance is a combination that should be continuously pursued by the project team member throughout the life cycle of the project.

Keeping the project within these parameters in the construction industry does not have to be justified. Clients want projects to be built within budget, on time and to the required specification. Designers and contractors want to build a facility to meet the client's needs within the tender figure, but also ensure making a reasonable profit.

However, the situation in practice is that overruns in costs and delays to projects are severe. The cause and source of such deviations in projects varies, depending on project configurations and variables (Ashworh, 1994; AIA, 1994; and Love et al., 1998).

An initial investigation conducted for this research by comparing the budget cost with the final construction cost of 16 projects in Saudi (Table 1) indicated that there is a cost overrun with more than 60% (10 projects) of the projects studied. This has been supported by the research of Roberts (Roberts, 1992) which showed that there are substantial budget overruns in more than 50% of projects in the construction industry. In many cases the client is not prepared to pay this extra cost because of limited budget, feasibility study, government account and the financial requirements of the banks.

The importance of early control of the project during the design stage is not in doubt. The most effective benefits are gained at the beginning of the project, in establishing scope and levels of quality, making schedule decisions, selecting delivery options, and

translating requirements into design concepts. The project's big decisions are made up front, and these lay the groundwork for all the decisions that follow (AIA, 1994, P 684).

	<b>Contract Value (Million SR)</b>	<b>Actual final cost (Million SR)</b>	<b>%</b>
Project 1	110	111	0.9%
Project 2	110	190	72.7%
Project 3	940	960	2.1%
Project 4	119	119	0.0%
Project 5	111	116	4.5%
Project 6	110	110	0.0%
Project 7	10.5	10.86	3.4%
Project 8	11	11	0.0%
Project 9	115	118	2.6%
Project 10	1150	1100	-4.3%
Project 11	10.1	8.9	-11.1%
Project 12	10	19.1	91.0%
Project 13	800	800	0.0%
Project 14	110	116	5.5%
Project 15	22	24	9.1%
Project 16	21	53	152.4%

**Table 1 : Comparison of costs for initial projects surveyed in Saudi**

All decisions and actions of the project team must be communicated with the contractors for the purpose of construction.

During the stages of preparation of the construction documents, most parameters influencing the construction projects are conducted before commencing the work on site. For example, researchers have shown that most of the product cost (75%) is committed during the product design process (Weustink et al., 2000 p141-148).

Despite the advisory role of designers in providing professional advice to the client, many researchers indicate that consultants play a major role in project cost overrun,

owing to the lack of adequate information by them (Rukn, 1999), errors in contract documents (Love et al., 2000; Kirby, 1988; Morgren, 1986) and quality of contract documents (Tilley et al., 1999; Stasiowski, et al., 1994). This has been supported by the investigation of the frequency and severity of claims on federally funded and administrated projects which found that design errors were the single most common cause of contract claims, accounting for 46% of the additive claims that were reviewed (Diekmann and Nelson, 1985). In Australia, Choy, et al. (1991, p29) indicate that 51% of significant variations generated are from design documentation. Furthermore, the research of Burati et al. (1992) found that design deviations accounted for 67-90% of the total number of deviations on the project and that the design deviations generally accounted for the greatest increase in total project cost, ranging from 0.4% to 20.6% of the total project, with an average of 12.4%.

In the Saudi construction industry, Al-Ghafly (1995) found that the design stages are very important to the performance of the project. Most of changes that cause delays during construction result from poor design of the project. Also, Al-Subaiey (1987) concluded that design documents are a very important part of the contract. The survey results show that the documents of the contracts are not usually well written. There are many errors and omissions in many parts of the contract and specifications, which results in several problems or claims during construction.

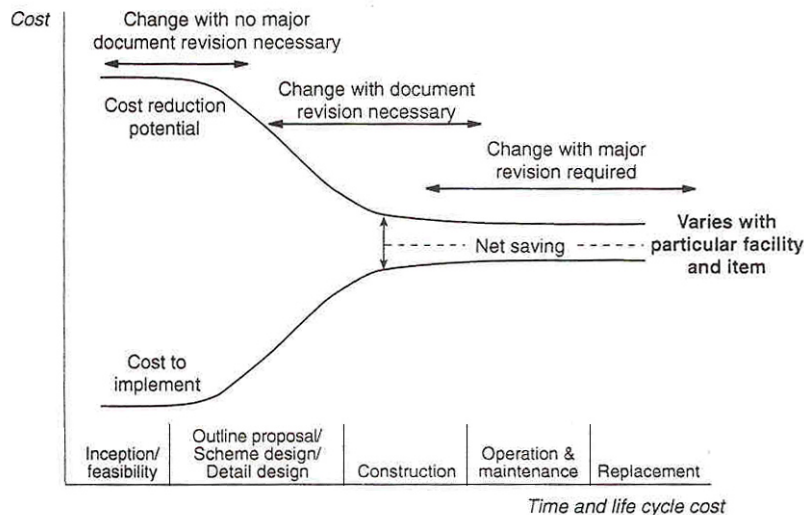
### **1.3 The problem**

Early control in the life of the construction project is particularly crucial, as decisions made during the early stages of the development process carry more far-reaching consequences than the relatively limited decisions which can be made later in the process.

During the early stages, many objectives of the project regarding cost, time, and quality can be achieved as the design is sufficiently flexible to incorporate relatively significant changes. Once the project has reached the construction stage, the potential for achieving the objectives is significantly lower and will have resultant cost or time for implementation.

In fact, some changes will not be implemented as the net effect on the total cost is nil or negative. This is because any changes to the project will require alternations to construction documents (drawings, specifications, bills of quantities, schedules...). During the early stages of the project design, changes are unlikely to result in

significant document revisions, particularly prior to the production of detailed drawings. More documentation will be produced and the potential for disruption is increased during subsequent stages of the project's life cycle.



**Figure 1: Cost of Change in Stages of Project**

(Reference -Cost Control in Building Design by Flanagan pp8)

Many causes of poor project performance can be traced to some type of errors in the decisions during the pre-contract stages (Stasiowski, 1994). The most pernicious cases of lost time and cost in construction projects are the result of errors and omissions in the construction documents. Many of these errors, unwanted by any of the design team, unforeseen but not unavoidable, could throw site work into disarray (NEDO 1988, p76-77).

Elimination of errors in construction documents plays a major role in achieving the objectives of the project. A study (Kirby, 1983; Morgren, 1986) found that 56% of all contract modifications are made to correct design deficiencies. In the UK, Hibberd (Hibberd, 1980) found that the major source of variations on construction works is the result of inadequate consideration of design (25%), design initiated (19%), and defect in contract documents (16%). Also in the UK, research by Langford et al. (Langford et al. 1986) showed that 72% of variations were caused by the design team.

Another study (Stasiowski et al. 1994, p76) found that change orders reduced from 7% to 3% of the construction cost by the use of a system called the REDICHICK method for conducting design reviews. Also, a publication prepared by the



Construction Industry Institute (1986) suggests that savings on the order of 2-6% of original estimate are achievable through proper constructability review only.

Therefore, controlling errors during the pre-contract stages is crucial for improvement of the construction industry.

To be able to control the objectives of the project properly, the owner – or his representative - and the designer must have a mechanism to reduce the likelihood of design errors occurring in a project, and practitioners need to have a mechanism to test various alternative scenarios so that the design and documentation process can be managed more effectively. The analysis of the interrelated factors in the design can assist industry professionals in making rational decisions as to which factors need the most attention in reducing the number of errors to prevent or at least to minimize their influence.

#### **1.4 Statement of the problem**

Some researchers have identified different factors which induce errors in the construction documents in general, without discussing the mechanism of such influence (Walker, 1994; Burbridge, 1987, p16; NEDO, 1988, p3). Also, there have been many other investigations in the field of detecting errors in construction documents and their influence on the project (Kirby, 1988; Stasiowski, 1994). These researchers did not investigate the factors which might lead to the generation of the errors in the construction documents. They have set up procedures for detecting errors in construction documents. Detecting errors is an important step in controlling and achieving the objectives of the project, but identifying the sources and causes of errors is just as important. Controlling the factors which lead to the generation of errors in the early stages of the project will result in a substantial reduction in errors and lead to more control of the project in the construction stage.

There has been a lack of means to determine the relationship between the causes and effects, i.e. the major factors (causes) which induce the occurrence of errors in the process of producing the construction documents and the number of errors (effects) that exists in the construction documents.

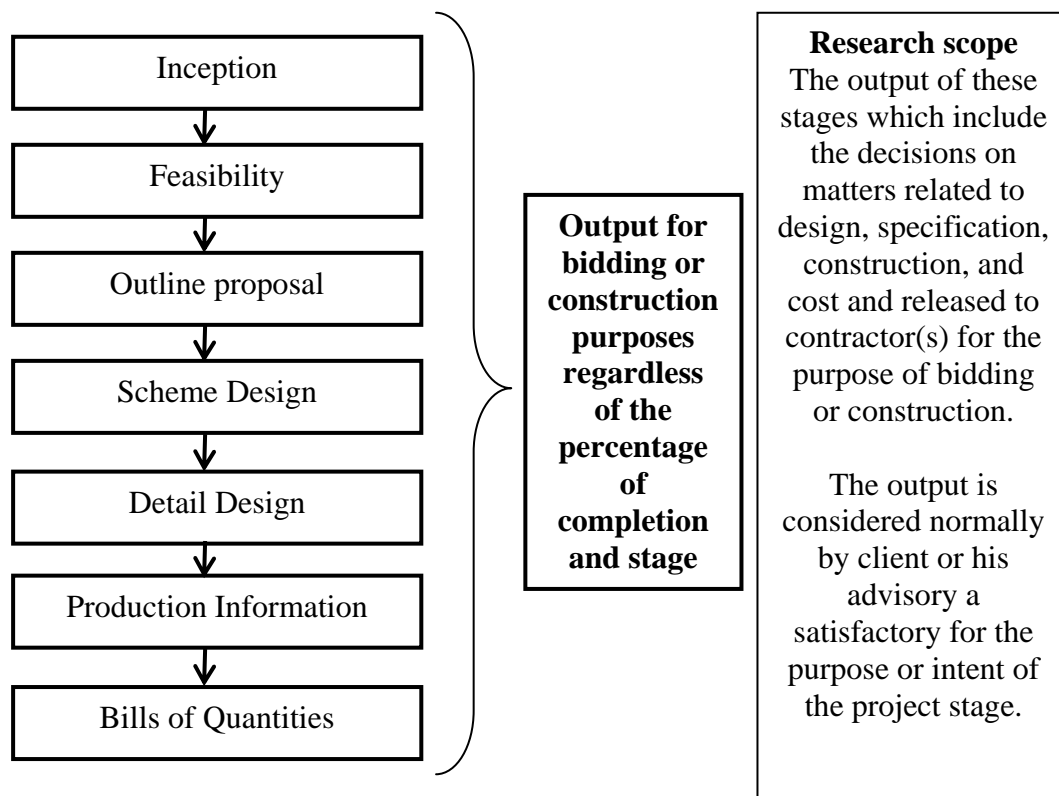
#### **1.5 Scope of the research**

Owing to the international nature of the problem, research in this area is relevant to any construction industry; however, the research scope has been limited to Saudi

Arabia as the collection of data and case studies has been extracted from Saudi Arabia construction projects. For the purpose of the present research, the definition of construction documents and errors, as they have been defined in chapter 2, will be used.

Construction documents normally cover the period from the inception of the project up to and before signing the contract with the contractor. The amount of details and information available in these documents varies, depending on the selected construction procurement.

Although construction documents are a continuation of the early stages of the design, for the purpose of this research, only errors in documents that are passed to the contractor for the purpose of bidding or construction will be considered. It is very difficult to trace errors which are considered a normal procedure for developing the project between the designer and the client (see figure 3).



**Figure 2 : Scope of Research**

## **1.6 Justification for the research**

The present research was considered important and has been justified for the following reasons:

### **1.6.1 Construction cost**

Construction is a major industry in nations around the world, with \$3.22 trillion spent in 1998 in 150 countries around the world. It represents about 10% of the world's economy. The Saudi Arabia construction sector spent US\$20,280 billion in 1998, which accounts for 15.36% of its GDP.<sup>1</sup>

Errors represent a major economic loss, and their total cost probably exceeds that of tragic failure (Rollings and Rollings, 1991).

The argument is also supported by the potential for significant improvement which has been demonstrated by Stoekel and Quirke (1992, p41). Their analysis indicates that a 10% construction industry productivity improvement will lead to a 2.5% increase in Gross Domestic Product.

Sir Michael Latham concludes in his 'Constructing the Team' report that there is substantial scope for eliminating unnecessary costs from the construction process, and that a target of 30% reduction in real costs is realistic and achievable.

Most decisions which influence the project take place during the preparation of the construction documents. Our attempt in this research is to reduce the number of errors generated in these decisions and consequently this will lead to savings in the overall cost of the project.

### **1.6.2 Scale of the problem**

There have been major criticisms on the performance of the construction industry. Errors in construction documents were considered as one of the major factors which contribute to the escalation of the problem. For example, design variations have been argued as one cause of poor building contract time performance. In Australia a research work (Choy and Sidwell, 1991, p29), based on 32 Australian projects and 6,266 contract variations, has indicated that the two most significant categories of

---

<sup>1</sup> ENR magazine, Nov 30 / Dec 7 1998 issue

variations generated are design documentation (51% of the total number of variations), and client sources variations (16% of all variations).

NEDO (1987) also draws attention to the extent of poor design detailing that can render a building design complex to work with. Valuable construction time may be lost with temporary “holds” being placed on parts of a project while design details on inconsistencies, errors or confusions are resolved. This type of delay can break continuity in construction activities and disrupt workflow. NEDO (1987, p18-19) presents evidence to support strong association between poor design detailing and construction delays.

In the Saudi construction industry; the research of Darwish (2005), indicated that poor quality design and documentation were costing owners and developers an average of 9% more on the estimated project cost and a similar amount in time for the project duration.

Finding the cause of errors in construction documents will help reduce such problems and will enhance the performance of the construction industry.

### **1.6.3 Contractual**

In AIA documents “the owner-architect agreement may establish a fixed limit of construction cost as a condition of the architect’s performance. That is, the agreement may include projects such as: “A new village town hall of 10,000 gross square feet floor area with a construction cost not to exceed \$900,000.”

Including such a fixed limit in the owner –consultant agreement establishes meeting the cost figure as a goal of the consultant’s performance. This immediately raises a number of questions that, in the interest of both owner and architect, should be addressed in the agreement. The identification of the source of errors and these influencing factors is an important step in reducing the liability of the design team for any errors conducted in the design stage, as most owner / designer agreements include the statement of the liability for mistakes and errors in the contract documents.

Such inclusions will increase the pressure on designers to eliminate errors and mistakes, and the starting point will be to find the factors which lead to the generation of such errors in the decisions during the preparation of the contract documents.

#### **1.6.4 Unrealistic inflated estimate**

Because of the poor performance of the construction industry, contingency allowances have to read “There is nothing absolute about construction prices”, as evidenced by the widespread variations among bids on a given project. Pre-contract estimating, therefore, is a hazardous business. An estimator who can bring 60% of the project estimate within 5% of the low bid is probably doing better than expected, and it is statistically probable, on average, that one project in five will fall outside a 10% range. The architect (designer) can avoid some of this danger by including adequate contingencies and by cooperating with the owner in designing contingent features into the plans to allow for additions or deletions depending on bid results” (AIA-1994, P695).

Reduction of errors in construction documents will increase the performance of project in respect of time and cost, and will also lead to a reduction of contingency allowable costs because of certainty created in the construction documents.

#### **1.6.5 Financial problems**

Many clients seek guarantees that they will get what they want at the price and time they set. Construction represents a substantial outlay of funds, and any unplanned increase in cost may create very real business or other problems for clients. Because they have no control over the contractor, designers guaranteeing construction cost should understand that this is their choice and that they are offering to perform at a level beyond the standard of reasonable care.

Elimination of errors in construction documents will help clients to stay within the cost plan and will avoid financial problems for clients and designers.

#### **1.6.6 Rework**

Rework is the unnecessary effort of re-doing a process or activity that was incorrectly implemented the first time. It is an endemic feature of the construction procurement process and is a primary factor in contributing to time and cost overruns in projects. The direct costs of rework in construction projects are considerable and have been found to be 10-15% of contract value (CIDA, 1994, Burati et al., 1992); Gardiner (1994) estimates that the costs related to the rework of design consultants could be as high as 20% of their fee for a given project. Such costs could be even higher as they do not represent the latent and indirect costs and disruption caused by schedule

delays, litigation costs and other intangible aspects of poor quality. The primary sources of rework in construction, naturally, are the documentation on which the construction activity is based. These largely consist of design changes, errors and omissions (O'Connor and Tucker, 1986; Burati et al., 1992; Love et al., 1999).

Reduction of errors in construction documents would reduce the rework at the construction phase and will improve the performance of the construction industry.

#### **1.6.7 Reputation of consultant office**

The incidences of errors in construction documents create a poor impression of consultants and possible loss of future business. It has been found in an interview with some clients (this will be discussed in chapters 3 and 4) that the main reason of breaking the relationship with the consultant's office was the number of errors in the construction documents, particularly those related to the designer.

Having a mechanism for reducing the number of errors would improve the reputation of the consultant office and will enhance future business.

#### **1.6.8 Designer office profit**

Most design firms spend 25-50% of design man-hours redoing work that has already been done once, redesigning details already designed for other projects, and correcting errors discovered during design reviews (Stasiowski et al., 1994, p48). Gardiner (1994) estimates that the costs related to the rework of design consultants could be as high as 20% of their fee for a given project.

Minimizing this number of errors in the construction documents would lead to an increase in the profitability of the designer and may increase the chance of competition by reducing the design fees.

#### **1.6.9 Designer indemnity insurance**

The Saudi Government (as a litigation body) is, like many other countries, implementing indemnity insurance (for example AIA standard contracts) against design consultant offices, and holding them responsible for errors in the design documents. This means they bear full responsibility for any errors in the construction documents. Simple transfers of all risks to contractors will no longer apply. Therefore, identifying the causes of errors in the construction documents will help the design

office to prevent any court cases that might be raised regarding their performance. It will also help to maintain good records with insurance companies.

In light of the above, it was essential for the thesis to investigate deeply and thoroughly the following issues:

- What are the sources of errors in the construction documents from the early stages of the project? This will be discussed in detail in chapters four and five.
- What is the relationship between the decision-makers during the preparation of the contract documents and the number of errors? This will be discussed in detail in chapter five.
- What is the influence of the design team in simulation of the occurrence of errors? This will be discussed in chapters five and six.
- Where are the areas of deficiencies? This will be discussed in chapter seven.

Therefore it is necessary to cover this gap of knowledge and identify and quantify the relationship between the different factors from the early stage of the project which influence the occurrence of errors in construction documents.

### **1.7 Research hypothesis**

Our aim in this research is to improve the construction industry, through the development of a strategy for eliminating - or at least reducing the number of - errors in the construction documents.

It is believed that reduction of errors in construction documents is achievable by finding the root cause and developing the means for representing the relationships between causes and effects. In so doing, the number of errors found in the construction documents can be largely explained by the characters of the project and the actions and decisions of the project team members. The project team includes Client / Client representative, Management, and Designers. Furthermore, accomplishment of the objectives of the project can be achieved through controlling the attributes which induce errors by the project team members in the pre-contract stages.

From the synthesis of a potential solution to the need to improve the construction documents, three research hypotheses were extrapolated. This hypothesizing allowed subsequent work to be structured in a manner that would allow them to be tested. The hypotheses derived were:

1. Reduction in the number of errors will follow when the design management of projects gives greater emphasis to removing the causes of problems rather than trying to counteract the symptoms.
2. Factors stimulating errors in the construction documents can be mapped. The output of these maps can be utilized to produce archetypes that illuminate the structures and behaviours behind the occurrence of errors for the purpose of reducing/eliminating errors while producing the construction documents.
3. Owing to the complex nature of the factors that stimulate the occurrence of errors in the construction documents focus of the research will be toward finding the internal factors that could be controlled by the party producing the construction documents.

## **1.8 Aims**

The extent of errors in construction documents leading to poor project performance has been identified by many researchers (Love et al., 2000; Burabi, 1992; Choy et al., 1991; NEDO, 1987). The aim of the thesis is to identify the cause of errors in construction documents, and develop a theoretical model which defines the relationship between the cause of errors and the effects. The model can be used to quantify the influence of any factor that stimulate occurrence of errors and number of errors found in the construction documents.

It is believed that application of the model will improve the quality of construction documents and increase the performance of the project in respect of time, cost, and quality. It is also envisaged that understanding will stimulate the identification of effective prevention strategies that can be implemented to improve the performance of the construction industry.



### **1.9 Objectives of the research**

The objectives of this research will be to define at the early stages of the project, the attributes which stimulate the occurrence of errors in the construction documents, and define the relationship between errors and attributes. These relationships will be used to develop a theoretical model to define the relationship between cause and effect in construction documents and which will lead to a reduction in the likelihood of pre-contract errors occurring in a project.

So the objectives of the present research are as follows:

- Identify types of errors occurring in the construction documents of Saudi construction industry.
- Identify the factors which influence the occurrence of those errors.
- Develop a theoretical model that provide an insight into and better understanding of the factors that influence the occurrence of errors in the construction documents.
- Using the above established model to identify the major factors that cause errors in the construction documents.
- The circumstances, if any, under which these relationship between factors and errors could be improved and which will represent a feasible way to reduce the occurrence of errors in the production of the construction documents.

### **1.10 Contribution of the research**

This research attempts to contribute to the body of knowledge in construction management relating to the design team decisions/actions and project characteristics influencing the number of errors generated in the contract documents.

As mentioned before (Section 1.8), factors influencing the occurrence of errors in construction documents have been studied by many researchers. This investigation aims to identify the types of errors and factors stimulating their occurrence, and to create a model which will identify the relationship between errors and attributes and the influences of attributes on each other.

The model will detect the influence of particular factors on the generation of errors in the construction documents.

The model will also provide the knowledge on important mechanisms acting in particular situation of design work in a positive or negative way which will help to develop suitable precautions in a company, and allow a practical relevant design education at university.

Furthermore, the work contributes an investigation approach to this area of research with which one can analyse both factual and expert-opinion data.

### **1.11 Structure of thesis**

This chapter has introduced the background, the problem, the main aim and objectives of the research, the justification of the research, and has explained the contribution of the research in improving the performance of the construction industry. It also presented the principal research hypothesis.

The contents of the remaining chapters are structured as follows:

#### **Chapter Two: Errors in Construction Documents**

This chapter will define the scope of the thesis. To understand the problem and to put the research in context; definitions and the purpose of the construction documents will be discussed. Then errors will be defined in the construction documents, how they are discovered within different stages, the impact of procurements on the types and the number of errors discovered in the construction documents.

#### **Chapter Three: Research Method**

The most appropriate methodology will be selected for the research after identifying / justifying the problem of the research. This chapter will focus on the formulation of the research methodology and the justification of the research approach adopted for the research.

#### **Chapter Four: Errors in the Construction Documents in the Saudi Construction Industry**

The existing established procedures in developed countries such as the USA (through the American Institute of Architects AIA) and the UK (through the Royal Institute of British Architects RIBA) will be studied and compared with those of Saudi Arabia

consultants. Such understanding will help the research in the development of the model later. The following step will be to carry out an extensive literature review in conjunction with data collected from case study projects, interviews, and questionnaires to identify types of errors in the construction documents. This chapter will therefore provide the definition and identify the nature of errors occurring in the construction documents of Saudi Arabia.

### **Chapter Five: Factors Influencing the Occurrence of Errors in the Construction Documents**

In a similar manner to the previous chapter the following step will be to carry out an extensive literature review in conjunction with data collected from case study projects and interviews to identify different factors which stimulate the occurrence of errors in construction documents.

This chapter will therefore determine the major factors that stimulate the occurrence of errors in the construction documents, how the factors are influencing the occurrence of errors in the construction documents and what are the factors that should be included in the research model.

### **Chapter Six: Model Description**

Based on the knowledge gained so far, a theoretical model will be produced to measure the influence of different factors on the number of errors in the construction documents.

The objective of this chapter is to provide a full description of the proposed model that explains the relationships proposed between different factors and the occurrence of errors. The chapter will subsequently explain the methods used to quantify the variables and nature of the relationship between variables that determine the number of errors in the construction documents. In the last part of the chapter the behaviour of the proposed model will be discussed to establish how much confidence can be placed in them.

### **Chapter Seven: Validation of the Structure and Behaviour of the Model**

Confidence in the usefulness of a model will be established with respect to its purpose. Validation of the model structure and behaviour is an important part of the simulation validation in general and system dynamics model validation in particular.

Validity of the results of a given study is crucially dependent on the validity of the model.

After establishing evidence in the usefulness of the model, it is important to understand how sensitive the model is to changes in parameter value and apparently how much each factor can be dropped while maintaining the number of correctly solved problems. Then how sensitive the research model will be studied to variations in the factors identified as the root cause of the problem. It is important to know what factors have the highest influence on the model and to validate these finding by using case study projects.

### **Chapter eight: Conclusions and Recommendations**

This chapter will provide the conclusions and findings of the research and the influence of the model on minimizing the errors during the pre-construction stages.

2.1	Introduction.....	19
2.2	Construction documents.....	19
2.3	Influence of construction documents on the success of the project.....	23
2.4	Definition of errors .....	25
2.5	Errors and construction industry .....	27
2.6	Discovery of errors in construction documents .....	28
2.6.1	Design project team .....	29
2.6.2	Tender queries.....	29
2.6.3	Quality assurance documents.....	30
2.6.4	On-site construction phase .....	30
2.6.5	Correspondence.....	30
2.6.6	Client feedback .....	30
2.7	Influence of procurement on the type and number of errors in construction documents .....	31
2.7.1	Early award .....	32
2.7.2	Traditional procurement.....	32
2.7.3	Multiple prime contracts .....	33
2.7.4	Fast track projects .....	33
2.7.5	Construction management .....	34
2.7.6	Design / build.....	34
2.8	Developing the quality of the construction documents.....	35
2.8.1	Partnering .....	36
2.8.2	Concurrent engineering.....	36
2.8.3	Taguchi approach - quality by design.....	37
2.8.4	Sequencing the work process.....	38
2.8.5	The principle of single statement.....	39
2.8.6	The REDICHECK method .....	40
2.8.7	Red-Green-Yellow checking technique.....	40
2.8.8	Developing a corporate memory.....	41
2.8.9	Design review management.....	42
2.8.10	Constructability.....	42
2.8.11	Value management.....	43
2.8.12	Quality function deployment .....	43
2.8.13	Failure mode and effect analysis (FMEA).....	43
2.8.14	Activity-based costing .....	43
2.9	Measuring the number of errors in construction documents .....	44
2.9.1	Total quality project management .....	44
2.9.2	Variability in construction bids.....	44
2.9.3	Costs of construction change orders .....	45
2.9.4	Meeting the requirements .....	45
2.9.5	Quality performance tracking system .....	46
2.10	Conclusion .....	46

## **2.1 Introduction**

The research is related to the preparation of the construction documents, quantity and type of errors generated in these documents. It is necessary to put the research in context, as there is differing terminology and meaning for construction documents and errors. Researchers and practitioners refer to construction documents as the design stages, design documents, the contract documents, or the construction documents. The purpose of the first part of this chapter is to clarify the meaning of documents used in this research through clear description of the contents, purpose, and the various procedures used to produce the documents for the procurement of projects. These documents translate the needs and wants of the client, as expressed in the brief, into a technical design solution which can be realised on site. In the second part, the research will define errors within the scope of the research and show how they are discovered through an investigation of the literature related to errors within the construction documents.

## **2.2 Construction documents**

Design has been described as the most critical period of the project life cycle and its effective management as crucial to the success of a project (Latham, 1994). The purpose of the design stage is to carry out the following tasks (AIA 1994, p641):

- 1- Describe the project requirements
- 2- Prepare a design solution based on the approved project requirements.
- 3- Upon the owner's approval of the design solution, prepare the construction documents of the project.
- 4- Help the owner file the documents required for the approval of governmental authorities.
- 5- Help the owner obtain proposals and award contracts for construction.

The main purpose and output of the design stages are to generate documents which translate the needs and wants of the client as expressed in the brief into reality. The process of producing the documentation that will be used for tendering purposes occurs within a specific stage recognized under different names by national professional institutes (production information for the British RIBA, construction documentation for the American AIA and contract documentation for the Australian

RAIA). Furthermore, some references (AIA, 1994; Murdoch et al., 1997; CPIC 2003) refer to the construction documents stages as the design documents stages and others refer to construction documents as a separate stage within the process of developing the documents. For this research, and based on the definition of these terms in the literature, all these terminologies refer to the same subject.

However, these definitions are not sufficiently specific to define the scope of the current research. For example, the AIA (AIA, 1994, p703) and RIBA (CPIC, 2003) define (with respect to their terminology) the construction documents as the written and graphical documentation prepared or assembled by the designer for communicating the design and administrating the project. It is obvious that the definition is unclear, as by contractual literature the production of such documents applies to all stages of the designer's basic services, starting from the pre-brief stage of the project through to its completion on-site. Also, the definition misses out what type of data are needed to be communicated, for what purpose, what type of communication is needed, and what are the maximum objectives which need to be addressed to fulfil the purpose of the construction documents. Furthermore, Murdoch's definition was considered (Murdoch et al., 1997, p141); he defines the contract documents as the means by which designers' intentions are conveyed to the client, the statutory authorities, the quantity surveyor, the contractor and the sub-contractors. He added that the contractor's basic undertaking is to carry out the works in accordance with these contract documents. However, it is clear that it is not the design intention only that will be conveyed, it is also the requirement of the client and statutory bodies that should be reflected in these documents. Tilley's (1998) definition, "The ability to provide the contractor with all the information needed to enable construction to be carried out as required efficiently and without hindrance", has some shortcomings, like the others.

For clarity with respect to the purpose of this thesis, the research defined Construction Documents as "the written and graphical documentation which communicates in a professional manner and in compliance with regulations and laws for the tendering purpose all needs, wants, and knowledge of the project stakeholder to contractor(s) for the purpose of construction of the project and which enable the client and/or designer a smooth and effective administration during the construction stage within the set objectives of time, cost, and quality".

Notwithstanding the various definitions (CPIC, 2003; AIA 1994; Murdoch et al., 1997, p141), there are agreements among them on the content, grouping of data and level of detail that consultants/designers should address in construction documents. These agreements extend to the Saudi construction as the current research found in the investigation, interview of project personals and the output of the case studies (this will be discussed later in the next chapter).

The construction documents include typically the following (ibid):

- Drawings

The drawings document the architectural, structural, mechanical, electrical, civil, landscape, and interior design of the project. They show, in graphical and quantitative form, the extent, configuration, location, relationship, and dimensions of the work that the contractor and/or his subcontractors will perform. They generally contain site and building plans, elevations, sections, details, diagrams, and schedules. In addition to drawn information, they may include photographs, graphics, and in case of small projects, the specifications as well.

- Schedules

Designers show information which is best presented in tabular form in schedules, not in drawings. There may be schedules for doors, windows, hardware, room finishes, equipment, fixture, and similar items; schedule formats vary according to office or project requirement practices.

- Bills of quantities

The designers use bills of quantities for the purpose of cost estimation, tendering, pricing or administrating the construction stage of the project, depending on the procurement selected to execute the project.

- Specifications

The specifications present written requirements for materials, equipment, and construction systems as well as standards for products; they outline the levels of quality and the construction services required to produce the work.



- Contract forms and conditions

These documents include the form of agreement between owner and contractor, the form for any bonds and certificates, and general conditions outlining the rights, responsibility, and duties of owner and contractor as well as others involved in the construction process (including the designer).

- Bidding requirements

These documents include the information and forms for bidding.

In addition to the above documents; the designer may issue addenda to any of these documents during the bidding or negotiation process; these are also considered part of the construction documents.

These documents may have to stand on their own for certain purposes but for the purpose of procuring the building they must interact and this interaction must be consistent and dependable; they are taken as mutually explanatory, as stated in clause of contracts; see, for example, clause 5 of ICE 6 (ICE,1994).

However, for small projects the literature and current practice limit the content of the construction documents. Designers may print the specifications, BOQ, door, window and finish schedule on the drawing sheets, and contract forms and conditions may take the form of letter of agreement (CPIC 2003, AIA 1994, p703).

Once the owner signs the agreement with the contractor, there may be contract modifications in the form of construction change directives and change orders, which are not part of this study.

Regardless of the contents of construction documents, they have to serve the following purpose (AIA 1994, p703; Murdoch et al., 1997, p143):

- They form a model for the designer's ideas and help to articulate and predict problems with construction and with appearance.
- They communicate to the owner, in detail, what the project involves.
- They establish the contractual obligations, how much the owner and contractor owe each other during the project, and lay out the responsibilities of the

designer or any other part of the administrating or managing construction contracts for the owner.

- They may be the basis for obtaining regulatory and financial approval needed to proceed with construction.
- They communicate the quantities, qualities, and configuration of the work required to construct the project. The contractor, in turn, uses the documents to solicit bids or quotations from subcontractors and suppliers.

Any violation of the above-mentioned definition or the intent of purpose of producing the construction documents may be considered an error, as discussed in section 2.4.

### **2.3 Influence of construction documents on the success of the project**

The previous section showed the influence of the construction document stage on the final cost of the project and the expected quality of the projects. However, the process of producing construction documents consists of a large number of decision-making processes. These decision-making processes finally lead to a complete project model representing a physical object that has to be realised on site. During the subsequent decision-making process, the freedom for each decision is restricted by the constraints imposed by preceding decisions. In the embodiment phases, these decisions are concerned with all aspects of project shape, size, material selections, details, etc. All these decisions are mutually dependent. The consequences of all such decisions have to be taken into account while preparing the construction documents.

Construction documents go through different stages; the early efforts to manage building objectives offer, conceptually, the best opportunities to meet the owner's needs from the project. Programme decisions establishing the project's use, scope, quality, site, and scheduling have a large impact and set the stage for what can be done during later stages of producing the construction documents. Studies have shown (AIA, 1994, P 685) that the greatest potential for cost reduction is at the early design phase, where as much as 80% of the cost of a product is decided. Construction documents provide some opportunities for improvement, but most of the critical decisions have been made by this time. Similarly, another study (Jo et al., 1993, pp 3-23) found that design decisions made early in the project development stage can have a significant effect on the constructability, quality, cost, time delivery and the ultimate

success of the project. Furthermore, the corrective cost of engineering change orders increase logarithmically as orders are placed later in the project life cycle.

As the construction document stages account for a relatively small percentage of the total project development cost, devoting a greater effort to control the objectives of the project is a reasonable and necessary step towards optimizing the project. For example, an effective means of encouraging the designer to design to cost is to provide cost estimates at the design synthesis phase of the design process, where design alternatives are considered. An additional benefit of this approach is that the management is provided with an early indication of the scale of the project cost. This enables the management to make more informed bid estimates at the conceptual design phase (Rehman et al., 1998 pp 623-626).

The GAO (1978) suggests that significant cost saving can be achieved in the construction industry during the construction documents development process. Techniques such as value engineering / management, constructability and partnering (Weston et al., 1993, p410-425) have been successful in construction, but the design input of key subcontractors such as building services subcontractors has been typically excluded from the development process (Lam et al., 1997, pp345-355), even though the cost of building services can be as high as 50-60% of construction costs. Similarly, Dissanayaka and Kumaraswamy (Dissanayaka et al., 1997, p157-167) found the lack of involvement of key subcontractors in the partnering process had a negative impact on project performance. As decisions made during the construction documents stage have a significant influence on the final cost and time of project, the early input of building service sub-contractors would certainly reduce project time and cost.

However, such objectives can be achieved when the project team includes construction considerations as early as possible along with structural, functional, and aesthetic requirements. In other words, such considerations must be designed in rather than inspected in to avoid the costly design iterations. Therefore, all organization-wide information should be used to augment design information to arrive at the finalized construction documents of the design for construction purposes (Jo H. et al., 1993, pp 3-23).

## 2.4 Definition of errors

As the current research revolves around errors, it is necessary to define and make clear what is meant by the word "errors" for the purpose of the investigation.

In its conventional sense, the term error relates to those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency (Reason, 1990). As per this definition, many types of errors, such as constructability and dimensional errors, will not be considered, in addition to the fact that the incidence of errors - regardless of cause - occurring in the construction documents will require compensation. Senders (Senders et al., 1991) excluded not-intended errors from his definition, since he defined errors as "something that has been done, which was: not intended by the author; not desired by a set of rules or an external observer; or that lead the task or system outside its acceptable limits". Furthermore, Busby (Busby, 2001, p236) defines errors as the occurrences which were unexpected – involve surprise and which could not be attributed entirely to chance or circumstance. However, the unexpected and surprise may result in good or bad output. Most people tend to accuse occurrences of errors to circumstance that were surrounding the project. Furthermore, even if they occur because of circumstance, the client/contractor will consider them as errors, and that someone has to bear its consequence contractually. Similar concerns arise in Stewart's definition (Stewart, 1992) where he defined human errors as an event or process that departs from commonly accepted competent professional practice; it excludes such unforeseen events. Competent practice will vary among individuals based on the imposed codes and standards, and any error can be attributed to unforeseen causes which had not been considered while doing the work. For these reasons, the research went back to Oxford dictionary for a description of error. It is a "thing done wrongly, the state of being wrong in belief or behaviour, the amount of inaccuracy and the mistake in one's assessment of a situation". Also, the ISO 8402 definition of quality defines quality as the totality of characteristics of a product, process, organization, person, activity or system that bear on its ability to satisfy stated and implicit needs.

From these definitions and for the purpose of this research, error in construction documents is defined as a non-desired condition and the non-fulfilment of intended requirements (stated or implicit) - as defined previously - in the construction

documents which will have an influence on one or more of the time, cost, and quality objectives of the project.

The changes which are made because of new requirements or changes in needs during the document production stages are beyond the scope of this research.

This definition is supported by Hollnagel (1993, p29) and Wood ((Wood et al., 1994, p26) who have defined erroneous action as an action that fails to produce the expected result and/or which produces an unwanted consequence or the outcomes are undesirable.

The important issues that the error' literature (Wood et al., 1994; Rasmussen, 1986) emphasizes relate to the following:

- It is fundamental to see that erroneous actions and assessments are the starting point for an investigation, not an ending. The label 'error' should be the starting point for investigation of the dynamic interplay of a larger system and contextual factors that shaped the evolution of the incident.
- It is the investigation of factors that influence the cognition and behaviour of groups of people, not the attribution of error in itself, that helps us find useful ways to change the system in order to reduce the potential for error and to develop a reliable contract document.
- Some researchers (Wood et al., 1994, p100) are of the opinion that description of an incident as an error will suffer from hindsight bias and to say that something should have been obvious, when it manifestly was not, may reveal more about our ignorance of the demands and activities in this complex world than it does about the performance of its practitioners.
- It is possible to generate lists of "should" for practitioners in large systems but these lists quickly become unwieldy and in any case will tend to focus only on the most salient failures from the most recent incidents.
- The research may not be in a position to toss error occurrence into a neat causal category as a result of an understanding of erroneous action and assessments in the real world.

The conclusion was that human performance is as complex and varied as the domain in which it is exercised. Credible evaluations of human performance must be able to account for all the complexity that confronts practitioners and the strategies they

adopt to cope with the complexity. The term "human error" should not represent the concluding point but rather the starting point for studies of accident evolution in large systems.

These issues will shape to a certain degree the structure and method used to conduct the current research.

## **2.5 Errors and construction industry**

Hammarlund et al. (1990) investigated the source of quality failures in a building project, and found the cost of correcting failures to be 6% of production costs, and the time taken to rectify these errors was estimated to be 11% of the total working hours allocated for the project. In another study (Josephson et al. 1999), the analysis indicates that, on average, 32% of the defect costs originated in the early phases; i.e., in relation to the client and the design, approximately 45% of the defect cost originated on the site; i.e. in relation to the site management, the workers and the sub-contractors and approximately 20% of the defect cost originated in materials or machines. Moreover, the Building Research Establishment (BRE, 1981) found that 50% of errors in buildings had their origin in the design stage and 40% in the construction stage.

The consequences of human errors in design deficiencies, such as catastrophic failure or death and safety, have been frequently reported in many professional publications and newspapers (Andi et al., 2003). Such examples are the Hyatt Regency walkway collapse in Kansas City (Luth, 2000) and the Teton dam failure in Idaho (Sowers, 1993).

Therefore, the influence of errors in design documents is large, as Koskela (1992, p35) suggests that it "sometimes seems that the wastes caused by design are larger than the cost of the design itself". A survey in Kuwait (Kartam et al., 2000) reported that defective design is one of the most significant risks to project delays. Similar results were also obtained from studies in Japan (Sawada et al., 2000), the US (Kangari, 1995) and Hong Kong (Ahmed, 2000). Defective design is considered a critical risk in these countries. More specifically, Burati (Burati et al., 1992) indicates that deviations on the projects accounted for an average of 12.4% of the total project costs, and design deviations average 78% of the total number of deviations, 79% of the total deviation costs, and 9.5% of the total project cost. He also found that design errors are the result of mistakes or errors made in the project design. He concluded

that the deviation costs of the design change categories amounted to an average of 54.2% of the total deviation costs. In another study, Stasiowski et al. (Stasiowski et al. 1994, p48) found that most design firms spend 25-50% of design man-hours redoing work that had already been done once, redesigning details that have already been designed on other projects, and correcting errors caught during design reviews. Similarly, a survey conducted by Nikkei Construction involving 79 Japanese contractors (Anon, 2000) shows that 44% of respondents often experienced a significant number of design documents problems. The common problems experienced were constructability, conflicts in structural designs, inadequate temporary work designs, improper construction methods, and information on differing site conditions. He concluded that these design problems are ongoing issues in the Japanese construction industry and of major concern to many parties within the industry.

However, the occurrence of errors at the design stage is not limited to construction industry only; evidence has shown that errors in design occur in other industries. For example, Phal (Phal et al. 1996) stated that up to 80% of all faults in engineering projects can be traced back to insufficient planning and design work. Furthermore, up to 60% of all breakdowns that occur within the warranty period are caused by incorrect or incomplete product development. Also, the recent withdrawal of many cars from the market in order to change some systems in the cars (NHTSA, 6th Dec. 2000) and the court decision against the manufacturer of tyres which proved that the design of the tyres was causing the explosion of some tyres, leading to accidents. This was supported by the press release of the American National Highway Traffic Safety Administration: "the official death toll related to faulty Firestone tires and suspension system: 148 deaths and more than 525 injuries". These statistics are clear evidence that errors in design influence other industries also. Our role in the construction industry is to find the means to prevent errors or at least limit the effect of the errors that occur during the design stages.

## **2.6 Discovery of errors in construction documents**

The discovery of errors within construction documents show different scale and character during different stages of producing the construction documents (full descriptions of types of errors occurring in the construction documents will be

discussed in detail in chapter four). This can be attributed mainly to the function of the construction documents at such stages and the people discovering such errors. In particular, the nature of error' types discovered in the construction documents showed the following behaviour at each stage:

### **2.6.1 Design project team**

The design project team includes all participants involved in the production of the construction documents. The members of the team encounter different sources of errors (e.g. client, identifying project requirement, time constraints, design management etc.) during the process of producing the construction documents. The design process is a stagewise refinement of specifications where vague needs and wishes are transformed into requirements, then via a varying number of steps, to detailed designs. Simultaneously, this is a process of problem detection and solving (Koskela, 1992).

The design team discovers these types of errors in the process of preparing the construction documents and before the tendering process. However, the quantification of such errors is difficult, as designers consider such lack of details and inconsistency as part of the process of developing the documents. It will depend mainly on the availability of members of the design team and retaining good records for documents during different stages.

### **2.6.2 Tender queries**

Tender queries are a good source of estimating the extent of errors in the construction documents. It is normally easier to calculate the cost of these errors.

The disadvantage of this process – especially in the case of lump sum contracts - is that the contractor might hide some errors that are in his favour, or he can claim later during the construction stage.

These types of errors are related mainly to those which have cost and time implications for the contractors. They will be collected from the analysis of the case studies to determine those types of errors that are related to the pre-contract stages.



### **2.6.3 Quality assurance documents**

Quality assurance (QA) documents are also a good source for getting the number of errors in the construction documents where QA approaches exist.

QA is normally carried out by the design team as an internal quality assurance and control (Stasiowski et al., 1994), or it can be carried out by the client if he has the experience.

The disadvantage of this is that it does not discover all types of errors and missing items, particularly when the reviewer(s) do not have enough experience. QA normally concentrates on coordination problems and the general look of the drawings as per the office procedure.

These types of errors will be collected from the analysis of case studies to determine those types of errors which are related to the pre-contract stages.

### **2.6.4 On-site construction phase**

These relate to errors discovered during the construction phase. They are discovered either by the supervision team or by the contractor. They are normally recorded in variation lists to claim either money or extension of time. The errors are normally a place for dispute between client, contractor and the supervision team. Some errors are not usually registered because they have been sorted out between the supervisor and the contractor.

These types of errors will be collected from the analysis of case studies (specifically from the variation lists feedback) to determine those types of errors which are related to the pre-contract stages.

### **2.6.5 Correspondence**

Some errors may be identified in the correspondence between client and consultant regarding the project. The correspondence may include letters, faxes, emails, reports, and minutes.

### **2.6.6 Client feedback**

These relate to errors only discovered by the client during the operation phase of the project. Hammarlund and Josephson (1991) estimated quality failures that have occurred after a project has been completed to be as high as 4% of the actual project's

production cost. Interestingly, the origin of defects occurring during maintenance is principally in design; 51% of these failure costs were found to be design related, while 26% were related to poor installation of materials and 10% to material failure. These errors are related mainly to designer errors, lack of knowledge and experience. The occurrences of this type of errors are few compared with other types of errors.

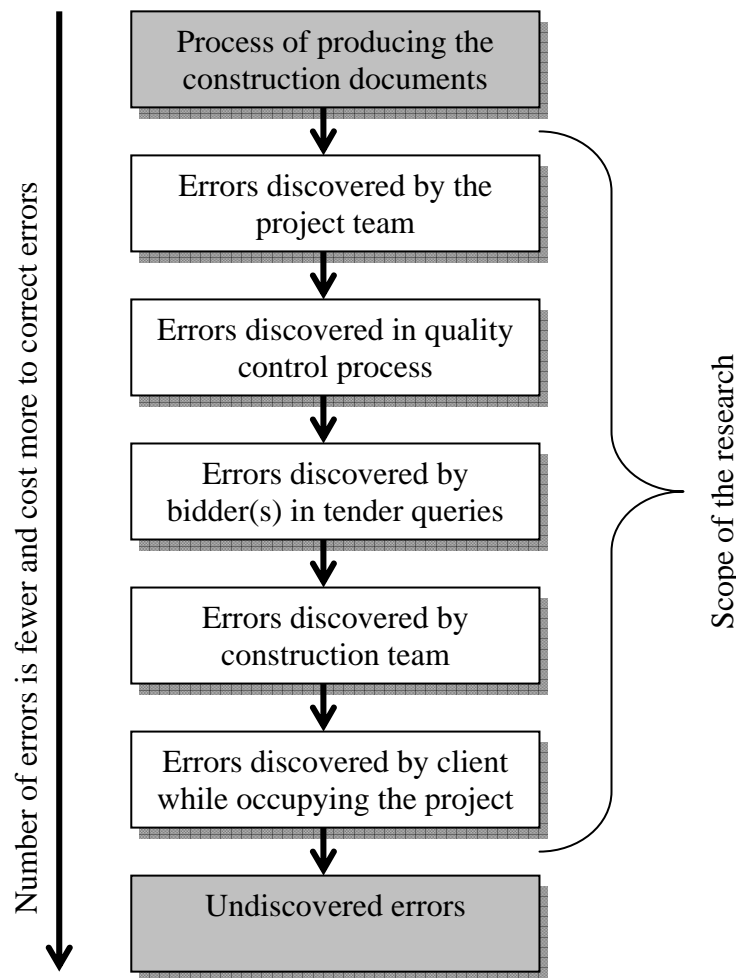


Figure 1 : Process of discovering errors in the construction documents

## 2.7 Influence of procurement on the type and number of errors in construction documents

Even though the literature agrees on the content of the construction documents as outlined above, the construction documents will differ from one project to another depending on the nature and procurement path. The procurement selected for the

project will affect the content, level of development and packaging of the construction documents (Murdoch et al. 1997; AIA 1994, p707-8). Consequently, the number and types of error occurring will be different. Accordingly, the means of dealing with errors occurring in the documents in different procurements will vary.

### **2.7.1 Early award**

If the construction contract is to be negotiated, the contractor may be selected on the basis of early "pricing documents" which include only the items the contractor needs to develop a price, i.e. preliminary design documents. One of the apparent advantages (Turner A. 1997, p56) is that a contractor's expertise in buildability and procurement skills can be used to his and his client's advantage, potentially bringing economics to both. Also, the early participation of the contractor in the process provides the project team with access to the experience of the contractor at an early stage (AIA, 1994, p707-8; Murdoch et al., 1997, p64) which will reduce the number of errors related to the constructability of the project.

On the other hand, the documents are at an early stage or the engineering systems are still under development. The contractors normally allow a percentage of the fees to cover any risks that may rise because of potential variations, uncompleted or undeveloped construction documents. Therefore the main concerns here are related to the incompleteness and undeveloped documents which the contractor is aware of when pricing.

In conclusion, this procurement is criticized (Turner A. 1997, p57) for its lower quality of project because "too much" has been thought to have been left to a contractor to develop; delay of the project is the result of the period of "approval" of the development of the design, and disputes during the development stages of the project.

### **2.7.2 Traditional procurement**

As the programme allows sufficient time, the client appoints a main contractor to carry out the construction work after the designer has fully developed and completed the construction documents. The quality of the documents is high because the designer has been given the time before appointment of the contractor (Turner A., 1997, p66) which will produce a reduced number of errors, especially while addressing the requirements of the client and the project.

On the other hand, it is claimed that separation of design from construction in complex project will increase the number of errors related to constructability and buildability of the project (Turner A., 1997).

### **2.7.3 Multiple prime contracts**

When the construction contract is divided into multiple prime contracts, there will be multiple construction document packages. Each package must clearly spell out the requirements for the portion of the work, including the relationship with other project packages. The summary of work and the article on related work are the major vehicles for clarifying the relationship between packages. Related packages should be available to all contractors for reference.

The documents are substantially completed by the proprietor's building system designers (Murdoch et al., 1997, p64; Turner A., 1997, p58) which leads to a lower rate of errors in the documents, depending on the experience of the designer. On the other hand, as the procurement entails changing the client's requirements during the project life (Turner A., 1997, p72), coordination problems will arise between different packages, especially when the design team feels that there is less time than appropriate to develop the design documents.

### **2.7.4 Fast track projects**

The need for coordination among document packages is particularly important in fast track projects because the various packages are not bid or negotiated at the same time. Because of the acceleration of tasks in the fast track procurement, the number of errors is deemed to rise (Williams et al., 1995) as schedule pressure and parallelism between tasks carried out by different designers increase. In other words, as tasks are performed concurrently, the number of interactions increases and the likelihood for errors occurring also increases. Problems occurring from fast tracking design include (NEDO, 1987, p18-19,31) lack of coordination owing to design instability, unclear or missing information owing to unavailable finalized documentation, and design details that will not work because of hasty design production, betraying a lack of proper considerations. In addition, the overlapping of the design with construction slows down the construction because of the increase that it brings in variations, disputes, and the escalation of disputes (Murdoch et al., 1997, p66).

### **2.7.5 Construction management**

While the drawings for a construction management project may correspond to those for traditionally contracted work, the other construction documents must reflect administrative and contractual differences. The bidding requirements, conditions of the contract and some parts of the specification may vary substantially from those otherwise used.

Projects involving construction management are often fast-tracked (Murdoch et al., 1997, p81). They may also involve "scope documents" done before all construction documents are fully developed, as a basis for providing the owner with a fixed price or a guaranteed maximum price. Thus they must be sufficiently developed to indicate material qualities and to provide both owner and construction manager with reasonable assurance that the construction manager's price will be accurate. Since the price, based on incomplete documents, always leaves room for interpretation, a strong working relationship between the client, construction manager, and the designer is required to overcome any of these situations.

If the fast track option is used, the quality of documents will face problems similar to fast track procurement, but because of management and the contractual nature of the construction management procurement, the consequences of errors are managed in a better way.

The advantage lies in the structure of the procurement path which allows the freezing of the design decisions to be left to a later stage – at cost coverage - than is possible under the traditional process (Murdoch et al., 1997, p67).

### **2.7.6 Design / build**

When the owner contracts with a single design/build entity, the commitment to construct the project may be based on a schematic design or even on a performance specification that involves no design (AIA, 1994, p708). The owner needs to develop a set of documents to describe the project, secure code approvals, and procure design/build services. In smaller or more straightforward projects, the drawings and specifications developed by the designer (who is part of the design/build entity) are more like shop drawings or contractors' coordination drawings for facilitating construction and controlling the quality of work by subcontractors (ibid) .

The advantage in this procurement during the stage of production of the construction documents lies in harnessing the benefit of the contractor's experience for buildability and constructability (Murdoch et al. 1997, p50), and avoids the occurrence of such errors in the documents. Even in the case of errors in the documents, the contractors will bear all the consequence of such errors and they will manage the project instead of the owner, who has already paid the contractors.

The above review of various procurements of construction documents indicated that rates, types, and management of errors are different owing to the contractual arrangement among the parties and obligation of such commitments.

However, these contractual techniques do nothing to provide a better understanding of the complexities involved in a major construction project, nor do they offer any new management methods to provide better control of large contacts (Williams, 2000).

These findings support the hypotheses of the research, that there are certain factors which stimulate the occurrence of errors in the construction documents. Finding such relationships between an error and the factors stimulating its occurrence is panacea for reduction of errors in the construction documents.

In this research, as outlined in chapter one; the focus is on the documents which have been handed to the contractor for the purpose of constructing the project, regardless of the procurement selected for executing the project.

## **2.8 Developing the quality of the construction documents**

The quality of the design and documentation provided has a major influence on the overall performance and efficiency of construction projects (Burati et al., 1992; Lutz et al., 1990; Kirby et al., 1988), and any improvements in design and documentation quality can only lead to corresponding improvements in the efficiency of the construction process (Tilley et al., 1999). Defective designs bring an adverse impact on project performances and the participants (Andi and Minato, 2003) and are responsible for many construction failures (Sowers, 1993). Efforts are therefore made to reduce them.

Many researchers have studied the detection of errors and realized the effect of errors during the design stages on the performance of the project in its later stages. The factors influencing the effectiveness of construction documents and the subsequent

impact of changes on construction cost and schedule have been documented in the construction management literature over the last ten years (Andi et al., 2003; Anon, 2000). Despite these problems being well known and understood by industry practitioners, very few improvements have been made in the construction industry.

The following are some of the practices that have been suggested as a vehicle to improve the performance of the construction industry through increasing the quality of construction documents.

### **2.8.1 Partnering**

In an attempt to achieve dramatic improvements in project performance, researchers and practitioners in construction have suggested that business process re-engineering could be the panacea for success (Mohamed and Tucker, 1996; Ireland, 1994).

Partnering, strategic alliances, innovation, quality and environmental management have become fundamental components of government purchasing policies as well as the most experienced private industry clients (Franks, 1990; Hillbrandt et al., 1990). Partnering has been recommended by many agencies as a possible solution for reducing the adversarial nature of construction. As a result, partnering has become a popular phenomenon for achieving specific project objectives such as dispute avoidance and resolution, safety performance, quality improvement and time and cost saving. Partnering may be used to improve contractual relations and communication, and increase understanding between participants (Cook, 1990, pp 431-446). Similarly, Weston and Gibson found that the use of partnering has a positive impact on reducing project time and cost (Weston et al., 1993, pp410-425). These quality improvements are the result of the sharing of knowledge between the contractor and the designer about buildability and constructability.

### **2.8.2 Concurrent engineering**

One of the key elements arising out of the introspection process has been a review of current procurement strategies and how they might be improved, giving rise to fewer disputes and generally making them more efficient and effective.

This strategy can be used for reducing the overall time and cost of a project by minimizing potential causes of rework and errors that are often attributed to poor

design and documentation (Love et al., 1998). Winner (1988) found that rework could be reduced by 75 per cent through product and process design optimisation. Furthermore, Evbuomwan et al. (Evbuomwan et al., 1996, pp 73-78) suggest that if a project is procured utilizing a team-based Concurrent Engineering (CE) approach, project cost and time could be reduced by as much as 30%. Likewise, Ireland suggests that 40% and 25% time and cost saving can be achieved (Franks, 1990). Research undertaken by Walker (Walker, 1994) found that the quality of the relationship between client, client representative, the design team and construction management team is a major factor governing construction time performance. Therefore, encouraging participants to change their attitudes and behaviour and work in a cooperative team-based environment is a necessary prerequisite for reducing project time and cost.

The successful application of CE is dependent upon the ability of project participants to interact, exchange ideas, have common goals, and take a holistic approach to the design and construction process.

On the other hand, there is fear that it will increase the rework if it is not carried out properly, where there are increasing cross-relations between parallel activities developing cross-related parts of the products. This implies increasing difficulty in providing a system freeze, since changes in one component will increasingly cross impact on other components, creating a ripple effect across the system. This lack of system freeze, when again combined with rigorous timescale constraints, forces design management to work on items for which the surrounding system is not yet frozen, items on which they would normally wish to work. This has a number of effects, not least of which is that the design staff are dis-incentivised as they work with unclear or undefined parameters and with the knowledge that their work may turn out to be nugatory. The main effect of interest here, however, is that the design of such items will have to be reworked if there are changes in the as-yet-unfrozen surrounding system (Terry et al., 1995).

### **2.8.3 Taguchi approach - quality by design**

The previous sections showed that a project's design has a significant impact on life cycle cost and quality. Taguchi emphasizes pushing quality back to the design stage,



since inspection and statistical quality control can never fully compensate for a bad design (Bendell, 1988).

The quality engineering methods of Dr. Taguchi seek to design a product/process which is insensitive or robust to causes of quality problems. The three steps of quality by design are system design, parameter design, and tolerance design (Taguchi, 1986). In the system design a system is developed to function under an initial set of nominal conditions. The next step is parameter design where the objective is to select the optimum levels for the controllable system parameters such that the product is functional, exhibits a high level of performance under a wide range of conditions, and is robust against noise factors that cause variability. Studying the design parameters one at a time or by trial and error until a first feasible design is found is a common approach to design optimization (Phadke, 1989). Taguchi's approach to parameter design provides the design engineer with a systematic and efficient method for determining near optimum design parameters for performance and cost (Kackar, 1985; Phadke, 1989; Taguchi 1986). The objective is to select the best combination of control parameters so that the product or process is most robust with respect to noise factors.

When parameter design is not sufficient for reducing the output variation, the last phase is tolerance design. Narrower tolerance ranges must be specified for those design factors whose variation imparts a large negative influence on the output variation. To meet these tighter specifications, better and more expensive components and processes are usually needed. Because of this, tolerance design increases production and operation costs (Phadke, 1989; Edwin 1991).

#### **2.8.4 Sequencing the work process**

According to Dr W. Edward Deming (Stasiowski et al., 1994) all work is a process that can be represented by a flow chart. This is particularly true of design projects, which have a natural sequence of activities that lead to the most efficiently produced product. Deviations from this natural sequence introduce rework and errors, which cost time and money to correct. This natural sequence can be determined by preparing a task precedence diagram for each project. After determining the natural sequence of activities, the project manager can evaluate the impact of design changes throughout

the project. Change can be made at relatively low cost during the early stages of a project; however, once the size of the project team begins to increase, every minor change has the potential for generating many costly errors.

The cost of changes can be greatly reduced by a concept called “Lead Discipline Management”; the objective of lead discipline management is to plan and execute the project so that virtually all the design changes are made during the early stages. The approach allows the lead discipline to direct the design process unimpeded by changes from other disciplines up to the 80% point. However, once the 80% point is reached and the other disciplines begin to work, non essential changes to process design can no longer be tolerated (Stasiowski et al., 1994, p63-67).

### **2.8.5 The principle of single statement**

The effective use of simple concept can prevent many design errors. This concept is known as “the principle of single statement”. Each dimension, coordinate, elevation, callout, and so on, must be shown only once in a set of drawings and specifications; it should be shown where it can be most easily found (Stasiowski et al., 1994).

There is a tendency for design professionals to want to show dimensions, material callouts, coordinates, and other information in several places in a set of drawings. All too often such information changes during the course of the design and is not corrected on all the drawings and specifications where it has been shown. This results in conflicts and potential contractor claims. If an item of information is called out only once and the contractor has to “dig” a little or read the plans and specifications more thoroughly to find it, even when a dimension is inadvertently left off completely, the contractor would probably ask at that point that the designer could either calculate the dimension or scale it from the drawings. It is far more difficult for the contractor to file a claim for a missing dimension than for a conflicting one.

In addition to creating potential construction problems, repeating dimensions and other information on the drawings takes extra design time. If a change becomes necessary and the designer is sufficiently thorough to catch it in every place, it takes even more time. If an error is not identified, it takes still more time during the construction phase to resolve.

It is not practical to achieve 100 percent compliance with the principle of single statement. However, this should be the goal that every project team member should strive for (Stasiowski et al., 1994, p67-70).

### **2.8.6 The REDICHECK method**

The REDICHECK system is a simple, comprehensive and effective method of conducting design reviews. Starting in 1982, it was put into place for all major military construction projects at the Trident Naval Submarine Base in Kings Bay, Georgia. Between 1982 and 1985, 29 projects with an estimated construction cost in excess of \$400 million were subjected to the REDICHECK system. The cost was approximately \$500,000, one-eighth of 1% of the estimated construction cost. As a result, from 1983 through to 1986, the change order rate at the Trident base dropped from 7% of construction cost to about 3%, the lowest rate of any major Navy command. During these four years at Kings Bay, REDICHECK appears to have saved 3 to 4% of all construction costs, a return on investment of approximately 30 to 1 (Stasiowski et al., 1994, p76).

### **2.8.7 Red-Green-Yellow checking technique**

The "Red, Green, Yellow" technique is for checking contract documents. The basis of the approach is twofold: first, get the benefit of the cooperation and collaboration of all disciplines and, second, complete the review and make corrections efficiently and effectively (Stasiowski et al., 1994, p81-82).

The procedure is as follows:

- A single set of complete documents is made for review. The review procedure is sequential. The lead discipline reviews the documents first, then passes the check set on to the next discipline. One reviewer should be a person who has not worked directly on the project. Each reviewer makes notations that differentiate between potential and definite change recommendations. "Potential change recommendations" are made when a reviewer is not certain that a change must be made, has a question, or wants to recommend a design enhancement in a discipline other than his or her own. "Potential" changes are

noted in green. "Definite" change recommendations are made when a reviewer is certain that a change must be made; these are noted in red.

- After the reviewers have completed their review, key design team members meet to walk through the check set. During the consolidated review meeting, each meeting, each question and change recommendation is reviewed and their impact discussed. This discussion includes impacts on design, cost, schedule, interdisciplinary coordination, constructability, and operability.
- Based on these impacts, the reviewer team leader either approves or rejects the change recommendation. The review team leader notes approved change recommendations. It is also helpful to put a distinguishing mark such as a check mark or an "OK" on the document. These approval notations are made in red. No marks need be made regarding change recommendations that are not approved.
- After this final review, the check set is given to project team members who will incorporate the approved changes.

### **2.8.8 Developing a corporate memory**

A powerful way of achieving long-term improvement in quality is through the use of feedback. The objective is to make a mistake only once, and then learn from that mistake and not make it again (Stasiowski et al., 1994). This "learning curve" concept works well for individuals who usually remember their mistakes, but it does not work well for organizations in which one person's mistake is rarely learned by others doing similar work.

Breaking this cycle of repetition errors requires the development of a "corporate memory" in which the mistake of one person is learned by others in the organization. The first step is to develop a formal feedback system from the "customers" of the design team – the contractors who must use the documents to build a facility and the operations / maintenance personnel who must make it perform its intended function. Such feedback can be solicited upon completion of each project. The result can then be fed back into the firm's design procedures, training programmes, design checklists, standard drawings and specifications (Stasiowski, 1994, p90).

### **2.8.9 Design review management**

Many problems related to time and cost growth result from errors of inadequacies in the contract documents. Technical design reviews and biddability, constructability, and operability reviews during the design phase can aid in detecting omissions, ambiguities, and inadequacies in the design, substantially reducing contract modifications or change orders during the construction phase (Construction Industry Institute, 1986; Kirby et al., 1988). Also the Architects / Engineers liability insurers are increasingly recognizing the impact of design reviews in reducing the risk of errors and omissions claims against the design professionals and the potential of subsequent litigation. The establishment of a formal design review programme conducted by qualified professionals is the most effective means of identifying deficiencies and incorporating improvements into the construction documents.

The process of reviewing construction documents for accuracy, completeness, and corrections is widely recognized as being integral to the proper execution of professional design services. Such reviews should be undertaken by the designer of the record of detecting and correcting errors, omissions, and technical deficiencies and are motivated by the desire to minimize the firm's exposure to liability. The maximum potential of design reviews occurs when they are conducted early in the conceptual design stage and diminishes as the design effort proceeds to completion (Kirby et al., 1988).

### **2.8.10 Constructability**

It has been suggested that the use of the constructability analysis could significantly reduce design and construction rework (Love et al. 1998; McGeorge et al., 1997). A publication prepared by the Construction Industry Institute (1986) suggests that savings on the order of 6-2% of original estimate are achievable through proper constructability review (Construction Industry Institute, 1986, pp6-12). Constructability is a strategy that can be used to achieve optimum integration of construction knowledge throughout the procurement process, as well as balance various project and environment constraints so as to maximize project goals and building performance. This is done by using the knowledge and experience of key design and construction personnel during the design process so as to improve teamwork, planning and scheduling of site operations, which in turn can translate into

ameliorated project performance in terms of time, cost, and quality. Projects where constructability has been specifically addressed have reported saving of 6%-10% of construction costs (CMC, 1991).

### **2.8.11 Value management**

Value management can be used to minimize design changes and errors (McGeorge et al., 1997). However, this technique can represent an additional cost, which many clients are often reluctant to pay (ibid).

### **2.8.12 Quality function deployment**

This can be used to develop the client requirements in a holistic and integrated manner so that requirements can be totally satisfied, and, as a result, minimize downstream changes (Mohamed, 1995).

### **2.8.13 Failure mode and effect analysis (FMEA)**

This can be used to identify all the possible failures that could occur in a product, component, process, or an organization as well as the most probable ones, the mode in which they occur, and their effect. Layzell and Ledbetter (1997) suggest that the use of FMEA as a technique to assess the impact of a failure can improve decision-making and thus reduce rework.

### **2.8.14 Activity-based costing**

This can be used to identify value-added and non-value-added activities in an organization. Together with activity-based management, it can be used to identify the activities that should be managed and controlled in order to reduce rework (Gunasekaran and Sarhadi, 1998).

Despite the fact that the above attempts/practice can lead to the development of a culture founded on quality which acts as the primary enabler for change (Love and Gunasekaran, 1997), the above brief descriptions reveal that the drawback of these methods is that they are not trying to identify the root cause of the error and they did not try to identify and understand the relationship between errors and causes. They are concerned mainly with detection of errors or proposing a change in the procurement,

so errors may still exist without anyone knowing why they are there and how to avoid them before they originate.

The current research attribute is to study more deeply the relationship between errors in the construction documents and their causes, in an attempt to prevent or at least reduce their occurrence.

## **2.9 Measuring the number of errors in construction documents**

The above review showed that errors in the construction documents might cause a rise in costs, delays, and deviation of quality in the construction projects, which are measurable objectives.

However, there have been some attempts in the past to measure the number of errors in the construction documents. The main objective was to find measurements that will tell how well the entire process is doing over the long term. The following are some techniques which have been identified by Stasiowski (Stasiowski et al., 1994).

### **2.9.1 Total quality project management**

Total Quality Project Management selects some parameters that are good indicators of how well the process is working (Stasiowski et al., 1994, p89). TQPM uses the following parameters:

- 1- Non-conformance, identified during final design reviews, expressed as the average number of design defects per sheet of drawings.
- 2- Efficiency of design, expressed as total man-hours required per sheet of drawings for each discipline.
- 3- Design Cycle time, expressed as the number of calendar days required to complete designs of various sizes.
- 4- Variability in construction bids, expressed in terms of statistical process control parameters.
- 5- Cost of construction change orders resulting from design defects, expressed as a percentage of construction cost.

### **2.9.2 Variability in construction bids**

If a set of plans and specification properly defines the project requirements, the spread in construction bids should be small; if there are many ambiguities; the spread will be large. While analyzing construction bids, it is also useful to compare them

with the designer's estimate to determine the quality of the firm's cost estimating process. A scatter chart can help management assess whether new estimated procedures are really producing more accurate cost estimates (Stasiowski et al., 1994, p98-99).

Periodical review of this chart will reveal trends in the uniformity of construction bids. Of course, there are many external factors that affect the spread of construction bids, so it will take a significant number of data points to establish real trends.

### **2.9.3 Costs of construction change orders**

This method can also be used to measure long-term improvement in the quality of designs performed by an organization (Stasiowski et. al., 1994, p99). This requires a system of determining

- 1- the cost of construction change orders for each project, and
- 2- how much of those costs was attributable to design defects.

### **2.9.4 Meeting the requirements**

Ferguson and Clayton (1988) proposed a model that tries to measure issues directly related to quality through measuring conformance to the requirements, as follows:

- 1- Meeting the requirements of the owner concerning function and appearance, completion on time and within budget, life cycle cost, operability and maintainability, environmental, health, safety, and human impact and features.
- 2- Meeting the requirements of the design professional concerning defined scope, adequate budget, reasonable schedules, timely decisions by owner, interesting work for the staff, realistic risk sharing, reasonable profit, a satisfied client, and a finished project which results in positive recognition and recommendation for future work.
- 3- Meeting the requirements of the constructor concerning a well-defined set of plans, specifications, and other contract documents, a reasonable schedule, timely decisions by the owner and design professionals, fair treatment, realistic risk sharing, reasonable profit, a satisfied owner, and positive recognition and recommendation for future work.



- 4- Meeting the requirements of regulatory agencies concerning public health and safety, environmental consideration, protection of public property, including utilities, and conformance with applicable laws, regulation, codes, standards, and policies.

### **2.9.5 Quality performance tracking system**

Davis et al. (1989) developed a system to evaluate the quality management activities in both the design and construction phases, and then tried to determine the cost of poor quality in design and construction. They developed a system (QPTS, Quality Performance Tracking System) that divides quality management activities into eleven activities in the design phase and fourteen activities in the construction phase. This system includes a cost-coding scheme compatible with the state-of-the-art cost and schedule coding system in design and construction, to record cost of deviations. Davis recommended that the QPTS developed in his study should be considered as a preliminary model and that a great deal of work remained to be accomplished (Davis et al., 1989).

However, none of these methods can be used to quantify the number of errors before the start of the design documentation. They are used to measure the improvement to the construction document process specifically and the construction industry in general. Such measurement is an important step toward the improvement, but another important step will be to find the number of flaws in the documents, based on the existing factors, and to try to prevent the occurrence of errors before the project starts.

### **2.10 Conclusion**

This chapter proposes a definition of construction documents for the purpose of investigation; these include drawings, schedules, bills of quantities, specifications, contract forms and conditions, and/or bidding requirements. It is clear that the purpose, content and complexity of documents produced and subsequently the number of errors created differ from one project to another, depending on the type of procurement used.

Minimizing errors require their identification first; as soon as an error has been identified, action can be taken to address it. The errors in the construction documents have been defined. The research found that the influence of errors in design documents is large and errors were the most significant factors for project delay and change order.

The chapter has concluded with some techniques that have been suggested to improve the quality in the construction documents. These techniques did not address the effects of factors that stimulate the occurrence of errors in the construction documents before the start-up of the project, compared with the current proposed research. The research is trying to address the relationship between factors that stimulate the occurrence of errors and the occurrence of errors, and also to understand/ find the most severe factors that should be managed properly to enhance the quality of the construction documents.

3.1	Introduction.....	49
3.2	Definition of the problem and scope of the research study .....	49
3.2.1	Problem definition .....	49
3.2.2	Scope of research .....	50
3.3	Debates about the research methodology in construction management .....	51
3.4	Selection of research methodology .....	54
3.4.1	Pure statistical analysis approach.....	63
3.4.2	Causal structure analysis approach .....	64
3.5	System dynamics .....	68
3.5.1	Background of system dynamics .....	68
3.5.2	Application of system dynamics in construction industry .....	70
3.5.3	Application of system dynamics in the current research .....	71
3.6	Key to understand system dynamics modelling.....	75
3.6.1	Modeling process .....	76
3.6.1.1	Qualitative system dynamics .....	76
3.6.1.2	Quantitative system dynamics .....	76
3.6.2	Creating causal loop diagrams .....	78
3.6.3	Pattern of behaviour .....	80
3.6.4	Delays .....	82
3.7	Approach of developing the thesis's model using System dynamics.....	83
3.7.1	The conceptualization stage.....	86
3.7.2	The formulation stage .....	87
3.7.3	The testing stage .....	88
3.7.4	The implementation stage .....	89
3.8	Data collection and sampling.....	91
3.8.1	Literature review .....	92
3.8.2	Case study projects .....	93
3.8.3	Questionnaire .....	94
3.8.4	Interview .....	96
3.8.5	Other source for data collections .....	98
3.9	Conclusion .....	101

### **3.1 Introduction**

Consideration of the research methodology will direct the road toward the research methods for collecting data and the modelling approach toward solving the research problem. The preceding chapters have observed the need to understand the relationship between errors and the factors that cause them. Modelling the relationship has been proposed as a potential solution. Development of a model should allow better understanding of the occurrence of errors that have previously exhibited puzzling or controversial behaviour. This chapter presents the approach to investigating the feasibility of this proposal. Given the objectives of this investigation, a methodology suitable for carrying out such a task will be sought. The aim of this chapter is to identify the most suitable approach for quantifying the crucial factors and relations that determine the quality of the documents with positive or negative consequences.

There has been some debate about the validity of approach to research in construction management. This will guide the strategy and methods used to identify the variables, collect and measure the data needed to develop the model.

### **3.2 Definition of the problem and scope of the research study**

The selection of appropriate research methods commenced with the identification of the problem to be investigated and a review of its potential consequences. By anticipating these consequences to be sufficiently determined, the case for an investigation of the potential means to address the problem will be established. It will then be necessary to define the scope of that investigation into a potential means of solving the identified problem.

#### **3.2.1 Problem definition**

The problem definition is the keystone of the entire activity. Although it might sound like the easiest part, it is not enough to have a vague notion about the problem's behaviour. Defining the problem is essentially defining the purpose of the model. The problem should therefore be defined as precisely as possible. This definition is the basis of all the future effort, and guides the decisions concerning the boundaries and validity of the model. The narrower the focus, the easier it will be to resist the temptation to overdo the structure.

The problem of the research, as stated in chapter one, is a lack of understanding of the causal relationship between errors and factors that induce their generation. Improving the understanding will help to reduce the number of errors generated in process of producing the construction documents.

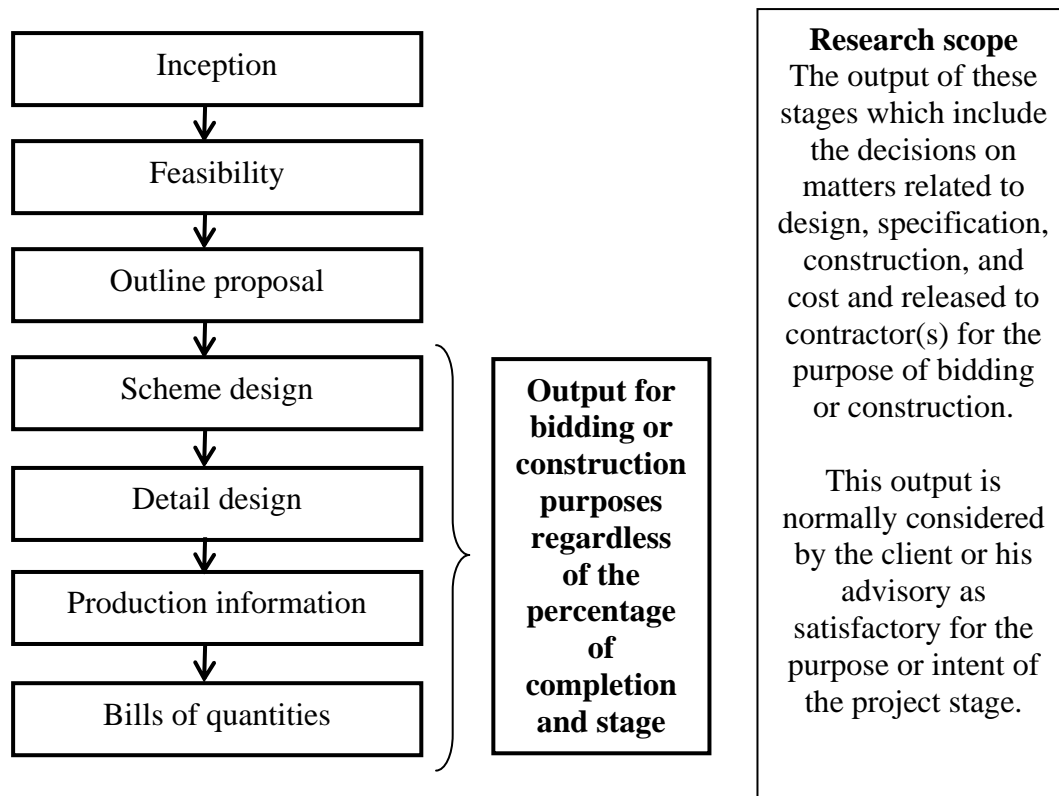
The purpose must be to avoid placing blame in favour of finding the true, long-term solution to a problem. Seeing the interrelationships can also help find leverage points within a system (places where a slight change will have a tremendous effect on the system's behaviour). Gaining awareness about how the system is built up and how it works can also help avoid solutions that only treat the symptoms of an underlying problem without curing the problem itself.

### **3.2.2 Scope of research**

Before selecting a research methodology, it was considered prudent first to clarify the focus and extent of the study. This is to ensure that research findings would be appropriate to the context in which they are applied.

The objectives of the research were stated in chapter one. The research scope has been limited to Saudi Arabia as the collection of data and case studies has been extracted from Saudi Arabia construction projects, though the findings can be adapted and applied in other construction industries. The definition of construction documents and errors has been discussed and identified in previous chapters.

Construction documents may cover the period from inception of the project up to and before signing the contract with the contractor, with the amount of detail and information being dependant on the selected construction procurement. For the purpose of this research, only documents which are handed to the contractor for the purpose of bidding or construction are considered (Figure 1).



**Figure 1 : Scope of Research**

### 3.3 Debates about the research methodology in construction management

Observations require explanation, but equally explanation must be tested against facts. De Vaus (1991, p11) believes that good explanation requires the related process of theory building and theory testing. He maintains that the basic question asked in theory building when having made a particular observation is "...is this observation a particular case of some more general factor?". In establishing meaning from observations he recommends a common sense approach, including locating common factors related to existing theories and concepts as source of ideas, working within the context of the subject area observed, asking survey respondents for insight into their answers to questions, and introspection, reflecting on why the observed has happened by trying to put oneself into the role of the respondent. In testing a theory one moves from the general to the particular to evaluate the variance. De Vause also states that the key to empirical testing of theory is to look for evidence that disproves the theory, as supporting examples can usually be found but are a weak form of evidence. He and many other authorities on research methodologies maintain that empirical research

provides strong evidence for explaining phenomena, whereas the use of logical deduction, anecdotal evidence, and personal "gut-feeling" provide only supporting evidence.

There has been considerable debate about "proper" research methodology in construction management. Seymour and Rooke (1995) suggested that much of the research that has been undertaken in the construction management and engineering field to date has been formulated on deductive theory-testing research methods. Such methods often are based upon the scientific process of deduction typified by the formulation of theories followed by the deduction of empirical consequences from large samples, and the observation of their validity. More recently, however, there has been a trend towards inductive research methods, which typically are used for relatively underdeveloped theoretical constructs or where complex observation is required. Such interpretative research methods have been advocated by numerous research studies in the field of the social sciences, such as those of Giddens (1976), Pettigew (1985), Romano (1989) and Parke (1993).

Authors who support the use of interpretative research, such as case studies, participant observation, and ethnography, argue that deductive reasoning and analysis have contributed to most theories not being studied by data (Perry and Coote, 1994). In other words, deductive theory testing research methods do not adequately capture the complexity and dynamism of the context of organizational settings (Coyle, 1977). However, a case study can take a deductive or inductive approach to a research problem. The research of Walker (1994) investigated the time performance of buildings based on predetermined hypothesis testing, and its external validity through the use of statistical measures demonstrates the use of deductive inquiry; however, Bresnen (1986), who researched the organization of projects and matrix management, placed emphasis on theory building and internally validating his research question through information richness, coherence and insight from triangulated sources. The approach taken by Bresnen demonstrates clearly the use of an interpretative inquiry. Such an approach can be used to provoke concepts and generalizations pertaining to the causes of errors, and therefore stimulate the development of a causal model of errors. Concepts, generalizations and interpretations that are derived from the case study can be used for assisting management in their practical decision making (Chentiz and Swanson, 1986).

In the case of the research presented in this thesis, that phenomenon is errors. If a purely inductive approach to the research problem were adopted, existing theory would not be taken into consideration. Under the inductive banner, knowledge gained through the process of specialization influences the formulation of hypotheses (Zikmund, 1988). In fact, Glasser and Strauss (1976, p253) state that it is difficult to ignore previous theory accrued in one's mind before commencing the research process. Research that relies solely on deduction would presumably not emerge with a new and useful theory. Parke (1993, p256) argues that "Both extremes are untenable and unnecessary and the process of on-going theory advancement requires continuous interplay between the two so as to lessen the gap between know and knowable". Furthermore, Miles and Huberman (1984, p134) state that "...induction and deduction are dialectical and not mutually exclusive research approaches". Thus, previous theory can provide guidance on the types of data to be collected so that the causal variables can be derived. Previous theory can also be used to interpret research findings. In fact, existing theory derived from the literature will form the basis for generalizations. For these reasons, the present research sought to obtain a balance between deductive (theory) and inductive (fact) reasoning, as will be discussed in the next chapter; even though the current research is primarily inductive in its nature.

Existing research method definitions were reviewed to select one suited to fulfilling the requirements of the study. Potential research methods were sourced from the literature and their compatibility with each of the objectives of the research study assessed using a weighted evaluation matrix. The research study objectives influencing method selection were adapted from Seymour et al. (1997):

- The main aim of the research is to find the relationship between the occurrence of errors and the factors that stimulate their occurrence. Based on this aim, the explication of inter-subjectivity established among all factors should be sought. This objective was actually considered as the aim of social research (ibid).
- As the research has different types of data, some qualitative and others quantitative, the test of the validity of an analysis is if it can be demonstrated so that such an analysis is the one which is used by the subject of the study.
- The findings of research should be useful to practitioners and at the same time fulfil the academic principles. The tension between the two can be managed



on the basis that all findings are produced in specific circumstances, for specific purposes.

- Previous knowledge should be taken into consideration; i.e. the research should be capable of communicating knowledge of how others in the construction process see that process in a way that is useful to practitioners.
- Previous experience should be taken into consideration; i.e. research should enable practitioners to reflect upon their own practices in such a way as to facilitate their attempts to improve these practices.

### **3.4 Selection of research methodology**

As discussed earlier in this chapter, the research seeks to investigate at the early design stage of the project while producing the construction documents the relationship between the major factors which induce the occurrence of errors in these documents and the rate of errors. The aim of the model is to show how a number of interrelated variables are mapped together showing their overall effect. The nature of this model is dependent upon the nature of the data, whether quantitative or qualitative.

If the data are measurable, the data analysis may involve quantitative analysis that will rely on measuring variables through experimental techniques resulting in structured, concise and explicit data. Quantitative methods have the advantage of higher internal validity, as the experiment may be repeated with similar results experienced. The data can be subjected to statistical analysis and clear statements may be made concerning causal and interdependent relationships between variables. The benefits gained from the quantitative approach are highly suited for testing of large populations where one can obtain a sample which represents the whole population. However, when the information required is of a non-quantifiable nature these benefits are reduced.

On the other hand, when the data are concerned with a qualitative phenomenon, the data analysis may involve qualitative analysis. Qualitative methods involve the analysis of complex descriptive data in which the researcher may increase his or her involvement and probe to obtain additional information. The research methods used are generally testing for the existence of variables rather than their frequency, and the methods normally yield large volumes of rich data obtained from a limited number of

individuals. Compared with quantitative techniques, the researchers collecting qualitative data exploit the context of data gathering to enhance the value of the data (Kidder and Judd, 1986). The qualitative approach to research is concerned with subjective assessment of attitude, opinions and behaviour. Research in such a situation is a function of the insights and impressions of the research. Such an approach to research generates results either in non-quantitative form or in forms which are not subjected to rigorous quantitative analysis. Generally, the techniques of focus group interviews, projective techniques and depth interviews are used (Kothari 1997, p 6).

With these in mind, for selection of the method the researchers need to understand the assumptions underlying various techniques, and they need to know the criteria by which they can decide that certain techniques and procedures will be applicable to certain problems and others will not.

Five approaches to research were considered at the outset of the fieldwork to identify the most appropriate to the research objectives. The research methods considered were:

1. Ethnographic research, which focuses on the manner in which people interact and collaborate in observable and regular ways. It generally places more emphasis on observation and semi-structured interviewing than on documentary data. This approach is mainly observational (Gill and Johnson, 1991; Fellows and Liu, 1997) as it observes human actions and established principles, and is founded in the social sciences as it studies the relationships between different people, or groups of people. Ethnographic decision models are qualitative in analyses oriented to understand why a person makes a decision in a determined circumstance (Bernard, 1999). It can be used to analyze one-time decisions such as adopting a particular technology, and also recurring decisions such as recycling behaviour or staffing policies (ibid). Grounded theory is an application of ethnographic research that is becoming more common. It is not possible to define ethnography as a single mode of collecting information since it usually entails the varying application of many techniques so as to elucidate the subjective basis of the behaviour of people. It attempts to understand the culture of the situation and so interpret it in such a way that its members do without conducting experiments or interviews in artificial environments (Mason, 1996). The problem of understanding social action lies in the fact that

it is a world of interpretation and meanings. There are always multiple perspectives and one must look beyond the official versions of the information given by the participants (Kidder et al., 1986).

2. Scientific research embodies the basic principles of scientific investigation, first exposed in Aristotle's philosophy of science (Losee, 1972). This research method is typically iterative, commencing with observation from which hypotheses are drawn and tested, facilitating conclusions and, potentially, justifying further investigation in another cycle of the process. Both inductive and deductive research modes are embodied within this cycle. A more developed method (comprising a greater number of and more precisely defined stages) of this approach is the hypothetico-deductive research method (Sekaran, 1992).
3. Experimental research (Fellows and Liu, 1997) derives conclusions regarding hypothesis validity by observing the outcome of experiments. To perform research of this type, the researcher must be able to plan and control experiments. Control is more readily achieved within a controlled environment, such as a laboratory, although experimental research is often used in less controllable contexts such as those found in the fields of psychology and the social sciences (Ferguson, 1959).
4. The simulation approach involves the construction of an artificial environment within relevant information, and data can be generated. This permits an observation of the dynamic behaviour of a system (or its sub-system) under controlled conditions. Simulation has been referred to in the context of business and social sciences (Kothary 1997) to the operation of a numerical model that represents the structure of a dynamic process. Given the values of initial conditions, parameters and exogenous variables, a simulation is run to represent the behaviour of the process over time. The simulation approach can also be useful in building models for understanding future conditions (ibid).
5. Action research is related to ethnographic research but, instead of observing activity only, the researcher participates in the activity itself and may influence the manner by which it is carried out. This allows hypotheses related to the way in which activities are performed to be tested. Generally, opportunities to practise action research are hard for researchers to find and often arise only when a researcher has been invited to participate in organisational activity (Gill

and Johnson, 1991). This limits the researcher's ability to choose the study context and topic. Action research has also been criticized for the following reasons (Winter, 1987):

- It dismisses the outside observer and independent experimenter.
- As it sits in between practical and theoretical practices it has also been dismissed as being idealistic.
- It is said to lack theoretical definition.
- The matter of ethics exists in terms of respondent protection awareness of personal and political motives.
- A conflict of goals may arise between demand for help by the client organization and the demands of the research.

To select the most suitable approach that will be adopted for the current research, the objectives of the research were weighted against the above approaches. A 5-point weighting scale was established for this purpose: 5 for very important objectives up to 1 for the least important objectives of the current research. Then each research approach was evaluated against the objectives.

As the main objective of the current research is to discover the relationship between errors and the factors stimulating their occurrence, the "explication of inter subjectivity" objective was considered as the most important objective for the research that should carry the highest important weight (i.e. 5). "Findings should be useful to practitioners and fulfil the academic principles" was the second important objective that was considered for selecting the appropriate research approach (i.e. 4). The remaining objectives carry equal importance weights (i.e. 3). The following table summarizes the objectives of the current research in relation to each approach discussed above:

Potential research method	Objectives of the research					Points
	Explication of inter-subjectivity	Ability to demonstrate the validity of the analysis	Findings should be useful to practitioners and fulfil the academic principles	Capable of communicating knowledge of how others in the construction process see that process	Research should enable practitioners to reflect upon their own practices	
Relative requirement importance 1=low, 5=high	5	3	4	3	3	
Ethnographic research	5	3	4	3	3	
	25	9	16	9	9	68
Scientific research	4	3	4	2	2	
	20	9	16	6	6	57
Experimental research	4	3	4	3	3	
	20	9	16	9	9	63
Simulation	5	3	4	3	3	
	25	9	16	9	9	68
Action research	5	2	3	3	2	
	25	6	12	9	6	58

**Table 1 : Research's objectives vs research methods**

Understanding the problem and objectives of the research, and from the above brief description of the different approaches, and as the comparison between the research approaches are close and none of the above approaches alone fits the description of the current research scope, a mixed mode of research approach will be used, but to fix / balance the criticism of any approach while performing the research. This was supported by Burns (2000, p11), in which he stated that "No one methodology can answer all questions and provide insights on all issues. There is more than one gate to the kingdom of knowledge. Each gate offers a different perspective, but no one perspective exhausts the realm of reality, whatever that may be". Furthermore; Hoshmand (2003) stated that the research approaches should be mixed in ways that offer the best opportunities for answering important research questions. Selection of such a mixed mode approach offers a practical and outcome-oriented method of

inquiry that is based on action, and leads, iteratively, to further action and the elimination of doubt; and it offers a method for selecting methodological mixes that can help researchers better answer many of their research questions (Johnson et al., 2004).

According to Johnson and Turner's (2003) fundamental principle of mixed research, researchers should collect multiple data using different strategies, approaches and methods in such a way that the resulting mixture or combination is likely to result in complementary strengths and non-overlapping weakness. Effective use of this principle is a major source of justification for mixed methods research, because the product will be superior to monomethod studies (Brewer and Hunter 1989). For example, adding qualitative interviews to experiments as a manipulation check and perhaps as a way to discuss directly the issues under investigation, and tapping into participants' perspectives and meaning, will help avoid some potential problems with the experimental method.

As the mix-mode research approach was selected, the dominant approach that will be adopted to establish the base and understanding of the current research will be ethnographic. Some researchers (Kidder et al., 1986) describe participant observation as the explanation of ethnography, while others (Gill et al., 1991) explain participant observation as the observer immersing completely into a social setting and adopting a role of full participant in the everyday lives of the subjects. This observation allows the ethnographer to feel the effects of what is happening, while observing them on one side; this may immerse the researcher into the culture thereby preventing him from taking a dispassionate view of events on the other side. On the other hand, they describe non-participant observation when the researcher takes the role as a spectator only observing events and processes, thereby avoiding becoming involved in interactions with the subjects. This non-participant observation may mean that the researcher experiences the effects by judging the events from within his own culture and it relies on the honesty of the subjects. They conclude that the only viable way of discovering what is actually happening is through participant observation.

The last statement was rejected as the investigation of variables influencing certain phenomenon with sufficient detail, cross validating methods of the variables under study and using the statistical method will give enough credibility of the non-participant observation.

The ethnographic method of research is generally suited to exploratory work to discover areas worth investigating further, or investigating relatively unknown social phenomena - in detail - in their natural setting to develop theories. This approach will be used, as stated above, while understanding the scope of work within the Saudi context. It will also be used to explore the content of the construction documents, to understand the nature of errors occurring within the Saudi construction industry, and to explain and discuss the factors influencing the occurrence of errors in the construction documents.

The scientific approach will also be used for the research, as was illustrated in proposing hypotheses that will be proved / disproved using the experimental / simulation approach to model the environment for producing construction documents, using computer simulation created to solve the problem of the current research. A major part of the research will be to discuss the creation of the model that describes the behaviour of factors that stimulate the occurrence of errors. Finally, the action research approach was used to create such a model through previous theoretical experience and knowledge that will be used to create the first version of the diagrams, and to describe what happens holistically in naturally occurring settings, whereas the traditional scientific paradigm reduces human phenomena to variables that can be used to predict future behaviour (Perry and Zuber-Skerritt, 1994). Furthermore, action research is more effective when participants engage in self-reflection while they are critically reflecting on the objective problem (Brown et al., 1982).

Mixed research has a long history in research practice, because practising researchers frequently ignore what is written by methodologists when they see that a mixed approach will best help them to answer their research questions (Johnson et al., 2004). This practice can be attributed, as noted by Greene et al. (1989), to the five major purposes or rationales for conducting mixed research:

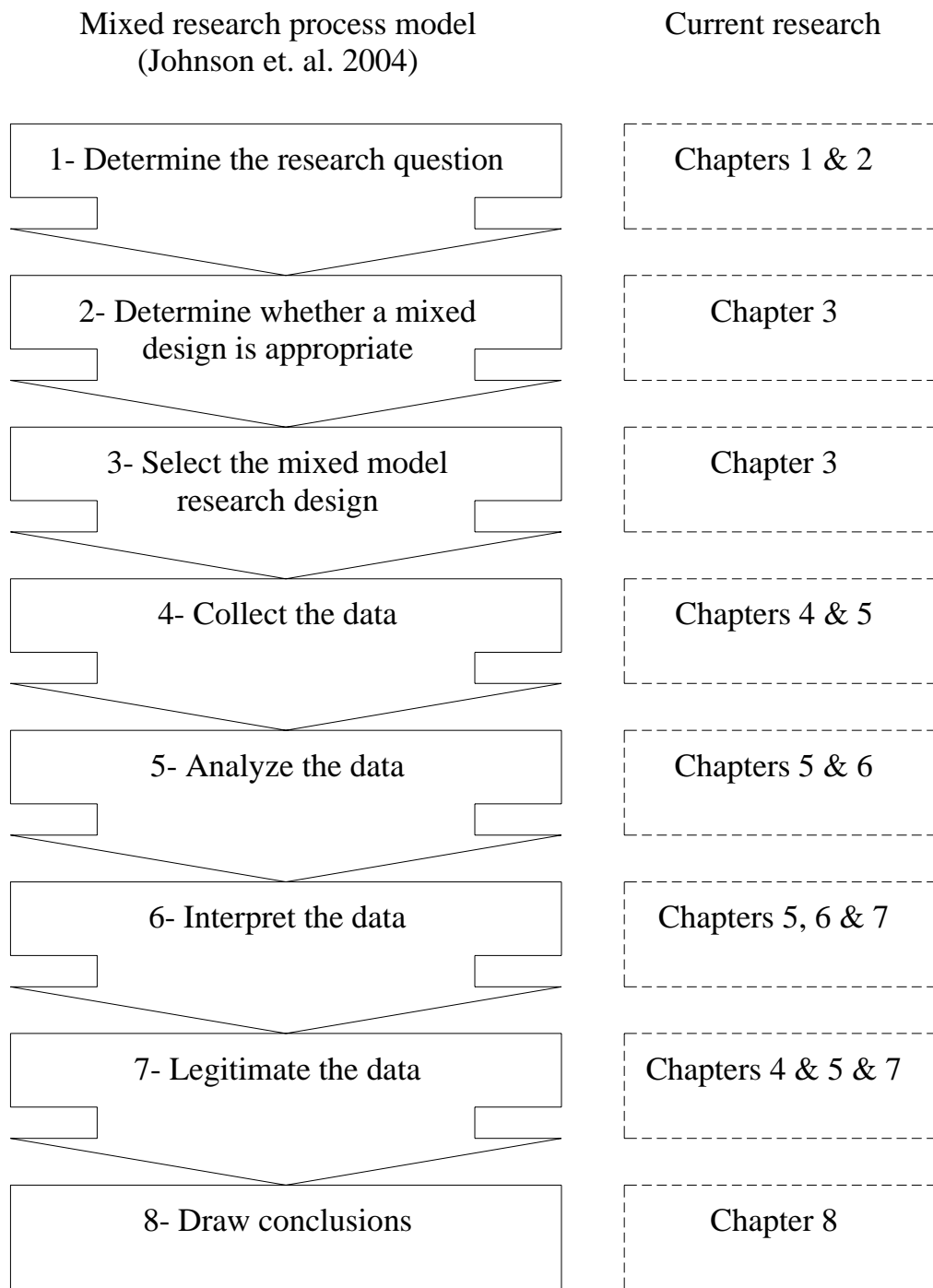
- (a) Triangulation (i.e. seeking convergence and corroboration of results from different methods and designs studying the same phenomenon);
- (b) Complementarity (i.e. seeking elaboration, enhancement, illustration, and clarification of the results from one method with results from the other method);
- (c) Initiation (i.e. discovering paradoxes and contradictions that lead to a re-framing of the research question);

- (d) Development (i.e. using the finding from one method to help inform the other method); and
- (e) Expansion (i.e. seeking to expand the breadth and range of research by using different methods for different inquiry components).

Furthermore; growth in the mixed research methods movement has the potential to reduce some of the problems associated with singular methods (Sechrest et al., 1995).

The mix mode of research method having been selected (Figure 2), potentially suitable research tools were reviewed to identify those that could be used in each of its stages. In measuring the relationship between variables, there are two analyses which will be explained, namely correlation analysis and causal analysis. Correlation analysis studies the joint variation of two or more variables for determining the amount of correlation between two or more variables. Causal analysis is concerned with the study of how one or more variables affect changes in another variable. It is thus a study of functional relationships existing between two or more variables. This analysis can be termed as regression analysis. Causal analysis is considered relatively more important in experimental research, whereas in most social and business research our interest lies in understanding and controlling relationships between variables, and then with determining causes per se; therefore correlation analysis was considered more important (Kothari, 1997).





**Figure 2 : Map of current research to mixed research process model**

### **3.4.1 Pure statistical analysis approach**

As the current research is mainly concerned with studying the relationship between more than two variables, all the methods which are used for the bivariate variables, such as Charles Spearman's, Karl Pearsons' coefficients of correlation, partial correlation, and simple regression, will be ruled out, since bivariate analysis carried out separately may lead to incorrect interpretation of the result. This is because bivariate analysis does not consider the correlation or inter-dependence among the variables (Kothari, 1997, p369).

As the result of the above limitations, multivariate techniques, which study the relationship between more than two variables, were considered. This analysis calculates the ratio of among groups variance to within groups variance. This technique is considered appropriate when several metric dependent variables are involved in a research study along with many non-metric explanatory variables. In other words, multivariate analysis of variance is specially applied whenever the researcher wants to test hypotheses concerning multivariate difference in group responses to experimental manipulations.

There are several methods of determining the relationship between variables and consider the simultaneous relationship, but no method can tell us for certain that a correlation is indicative of a causal relationship.

The limitations of this statistical approach are that (Kothari, 1997, p175-181):

- It assumes that the relationships between variables are linear.
- If there is a high degree of correlation between independent variables, there will be the problem of what is commonly described as the problem of multicollinearity.
- The total correlation between any two variables in a causal system cannot be decomposed.

However, this research requires a non-linear relationship between variables (it will be discussed in detail later) as it consists of multiple interacting feedback processes and nonlinear relationship, such as QA vs. Errors, Communication vs. Errors etc. Also, there are high correlations between factors of this research, such as coordination, communication, and quality control. For these reasons and based on the above

declared limitations of the pure statistical approach, the causal structure approach was investigated.

### **3.4.2 Causal structure analysis approach**

Seymour et al. (1997) outline some methodological principles which he attempts to follow in order to achieve what he called "verstehen", i.e. understanding in Dutch language. One of the principles requires the researcher to refrain from constructing theoretical explanations (including causal ones), since these impose the researcher's meanings at the expense of those of the subjects of the research.

This principle has been rejected by researchers (Runeson, 1997) because it rejects science as something that can be used for predictions or can be tested. Runeson's criticism was that science is about establishing causality, about formulating conditional statements that can be tested. He concluded that "this is how we differentiate between science and metaphysics".

Symour et al. (1995, p515) also argue that while it is perfectly appropriate, in the context of the rationalist paradigm, to look strictly causal relationships, it must be recognized when such analysis addresses only part of the problem. He added, "While we in the West pride ourselves on being able to distinguish cause and effect, we too ritualize ways of dealing with events and make sense of them in non-causal ways". Moreover, they reject the existence of covering laws, universal causal relationships, in any area where people are concerned. However, this argument is questionable as it begs the question: if scientific research is not about finding causal relationships, because there can be no such relationships, not about establishing general relationship, because there are no general relationship, not about verification, what is the purpose of scientific research? What is the nature of theories that will be developed instead, and how can they be used if test cannot be generalized or predicted?

Another problem with causal relationship is as noticed by Love et al. (1999) that "A fundamental problem with identifying cause and effect is that it does not examine the relationship between process activities". In fact, such an approach is frequently applied when a problem occurs and rarely applied as a means to determine the effect of process changes (Love et al., 1999).

The causal structure has been used by many researchers as a means to predict or formulate a conditional statement that can be tested. Moreover, in order to identify in

any great depth the factors which induce errors in the construction documents the causal structure should be used to understand such relations.

Causal models have been applied to a number of situations, for example determining the causal structure of rework influences in construction (Love et al., 1999), the influence of different management subsystems on productivity (Shaddad and Pilcher 1984), the application of expectancy theory of human motivation (Maloney and Fillen, 1985), and the factors influencing productivity levels (Borcherding et al., 1986).

Other researchers (Cnuddle, 1991, Hammarlund and Josephson, 1991, Burati et al., 1992, and Love et al., 1999) have used the causal structure to identify those major variables that stimulate rework occurrence in construction.

To identify in any great depth the influence of different factors on the stimulation of errors in the construction documents, its causal structure must be identified.

The most important methods which have been used by the researchers to construct the causal path are the following:

- Causal path analysis (CPA)
- System dynamics (SD)

Causal path analysis is a technique that allows for decomposing the total correlation between any two variables in a causal system. It provides robust analytical framework within which the strength of influences between variables can be measured and understood. It has been widely applied in the social sciences to investigate postulated cause and effect relationship (Kothari -1997).

Causal Path Analysis has been used by many researchers to find the relationship between variables (Shaddad and Plicher,1984, Shafiq et al., 1991, Brown, 1996).

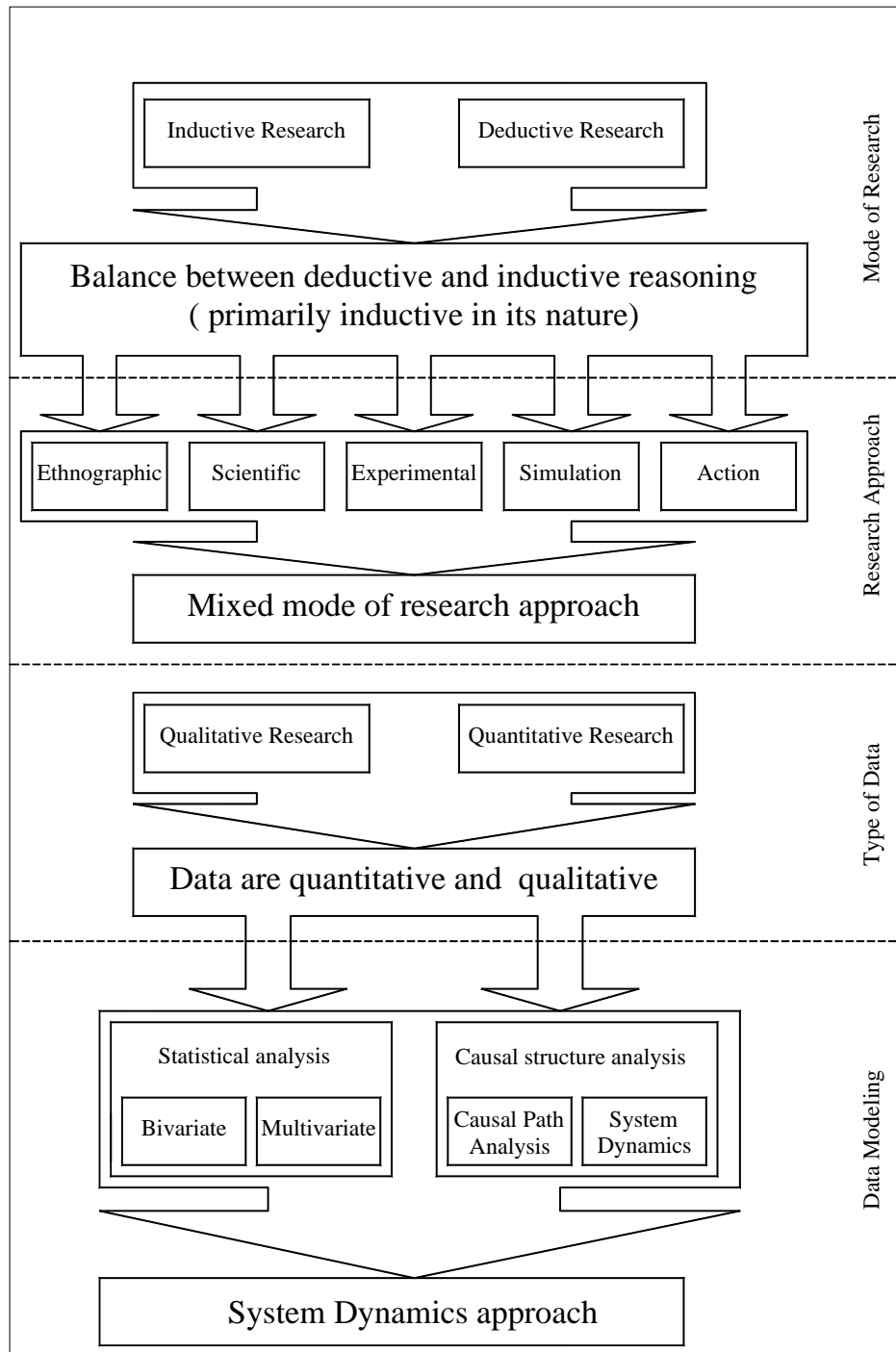
Based upon the discussion about the nature of variables which will be measured in the research and during the analysis of the method, it was found that the following assumption (Atkins, L.) will limit the use of this method:

- The causal path analysis explains the system of variables as they are observed; there is no guarantee that the causal relationships observed will continue to operate in future instances. This limitation will entail a major drawback, as the aim of the current research is to predict the occurrence of the errors in the construction documents based on the available information.

- The variables included in the analysis are additive i.e. there is no interaction between them, which is not the case in a complex system such as the design and production of construction documents.
- The possibility of circular causation between variables should be avoided, which again is not the case during preparation of the construction documents.

These limitations will present difficulties in the studies and therefore another approach was sought. The current research adapted the System Dynamics approach for the advantages that will be discussed later in this chapter.

The following diagram (Figure 3) depicts the above discussions:



**Figure 3 : Process of selecting the research methodology**

### **3.5 System dynamics**

System dynamics (SD) is a methodology for analyzing complex systems and problems with the aid of computer simulation software. It is an experimental approach to system thinking (Sterman, 2000; Richardson et al., 1991). Sterman (1992) suggests that it is a way of understanding complex systems and modifying or changing them in some way and also an approach for validating and assessing the consequences of implementing analytical (prescriptive) models or the recommendations of a case study report.

System dynamics is both a theory of structure in systems and an approach to policy design.

System Dynamics is comprised of two concepts:

- Feedback theory, which provides general guidelines for organizing system structure.
- Computer simulation, which provides a means to deduce the behaviour arising from a particular system structure.

System dynamics is concerned with the construction of graphical and mathematical computer-based models, with detailed descriptions, that tells how the conditions at one point in time lead to subsequent conditions at later points in time. The constructed model can then be simulated and its behaviour observed over time (Sterman, 1992).

In summary, system dynamics is about studying complex and dynamic systems which change over time, and about finding the ‘why’ (cause[s]) and ‘how’ (pattern) of system changes.

#### **3.5.1 Background of system dynamics**

System dynamics was formulated by Jay Forrester in the 1960s at M.I.T. (Forrester, 1961, 1968, 1969, 1971). Forrester, a professor in M.I.T.’s Sloan School of Management, became interested in the complexity of business management and the forces that caused businesses to succeed or fail. He concluded that people are not good at dealing with complex systems in which many factors influence outcomes, such as the success of a business depending on employees, consumers, middlemen, the economy, and the weather (in agricultural businesses), to name just a few.

Forrester observed that people usually identify one or two influences and assumed that those account for the observed outcomes or a problem. As a result, people

implement simple policies for solving a problem or reaching a goal, and quite often those policies have the opposite effect desired, the problem becomes worse, the business fails, and so on. For example, lowering the price of consumer goods does not necessarily increase consumer sales for a business, because competing businesses lower their own prices in response.

To help improve decision making and policy formation, Forrester created the system dynamics methodology, an approach for analyzing complex systems to include all the relevant cause-effect relationships, and more important, time delays and feedback loops in those systems which account for most of their unexpected behaviour. DYNAMO (Pugh, 1983), a mainframe computer program, was developed to facilitate creating simulation models of systems. DYNAMO permitted business managers to experiment in investigating potential solutions to problems and their likely outcomes. With system dynamics modelling, Forrester demonstrated how simple problem solutions often had unintended and undesirable effects, and how problems could be better solved with more sophisticated levels of analysis.

Originally, Forrester applied system dynamics to modelling and problem solving in industrial corporations (Forrester, 1961). Subsequently, he generalized the approach and applied it to social issues such as economics, crime and health (Forrester, 1969) and later to the physical and biological sciences, such as ecology (Forrester, 1971).

For years, system dynamics was the domain of university academics and researchers, requiring large mainframe computers to create and run complex DYNAMO models. But microcomputers became available in the late 1970s, and in the early 1980s Micro-DYNAMO (Pugh-Roberts, 1982a,b) made system dynamics modelling possible for everyone with an inexpensive microcomputer. Shortly thereafter, *Computer Simulation: A System Dynamics Modelling Approach* was published (Roberts et al., 1983), a textbook for secondary schools and colleges which taught the application of system dynamics modelling to a wide variety of academic subjects, including biology, psychology, physics, ecology, health science, economics, and mathematics. In fairly simple language it explained how successful problem solving in complex systems requires understanding the whole system, not just some small part of it, how such understanding could be attained through system dynamics modelling, and how problem solving could be improved through its use.

In the years since, far more powerful computer programs for system dynamics modelling have been created, including PowerSim (PowerSim, 1999), STELLA (High



Performance Systems, 2000b), itthink (High Performance Systems, 2000a), Extend (Imagine That, 2000), and Vensim (Ventana Systems, 1999).

### **3.5.2 Application of system dynamics in construction industry**

As explained in the previous sections, system dynamics modelling is useful for managing processes having two major characteristics (Richardson 1991): they involve changes over time and they allow feedback, the transmission and receipt of information.

System dynamics modelling is useful for managing complex processes that involve changes over time and are dependent on the feedback, transmission and receipt of information (Coyle, 1996). The design process relies upon construction project feedback for its effective management (Coles, 1992; Sawczuk 1992). The design process within the construction environment is extremely dynamic and complex; invariably it consists of multiple interacting feedback processes and nonlinear relationship (Sterman, 1992; Ogunlana et al., 1998). Moreover, it is a specialized and highly demanding form of problem solving (Pressman, 1993; Lawson ,1997). Some researchers and practitioners view it prescriptively and others take a less rule-driven approach and recognize the difficulty of placing boundaries on it by describing the activities that take place (Schon, 1993).

A recurring theme in the works by Sawczuk (1992) and Coles [1990] is the need to provide timely information to aid management. In addition, Chang et al. (1991) and Sterman (1992) have shown that construction design and management processes can be studied with advantage using system dynamics modelling. This is because the amount of work changes over time and the actors have access to output information that can be used to improve the process.

System dynamics has been applied in construction project management. It was first applied to general project management by Roberts (1964) who demonstrated that project management could be improved through dynamic simulation. Richardson and Pugh (1991) adopted Robert's model for teaching general principles of project management. However, their model was intended to be used as a general teaching model and is not specific to any industry. Jensen (1988) applied SD to client and project relationships in construction. He demonstrated that project team relationships could be improved with the aid of dynamic modelling. Pugh Roberts Associates (1993) applied SD to various large projects with emphasis on design and workscope

changes and dispute resolution. Sterman (1992) has written about the potential for improving construction project management through dynamic modelling. He found that the models have been used to manage projects more effectively, in the assessment of costs and benefits of various programmes, and to assess the magnitude and sources of cost and schedule overruns in the context of litigation. A summary of his thoughts will be discussed later in this chapter (section 3.6). Saeed (1994) has also demonstrated that civil contracting can be improved through dynamic reasoning. However, the two have not devised any formal models for project management. The management of site construction was modelled by Chang et al. (1991). Their work showed that a model of the site construction process could help to reduce project time and forecast the effect of materials supply disruptions on project performance.

The application of system dynamics modelling to design is limited to a specific application for a building construction project by Huot and Sylvestre (1985). Huot and Sylvestre's work was concerned with strategic project management, focusing specifically on fast tracked design-and-build projects. Their work showed that management performance could be improved through model simulation.

System dynamics modelling considers the project in a holistic way. Rodrigues and Bowers (1996) stated that the power of the system dynamics modelling approach lies in its ability to incorporate the more subjective factors which can have an important influence on the whole project.

### **3.5.3 Application of system dynamics in the current research**

The characteristics of the design process include its highly iterative nature, the use of primary generators (a relatively simple idea to test solutions), the sequence and content of the common design stages, the sequencing of the exchange of information, the impact of external agencies and the management of client changes to the brief (Chapman, 2001). Although the creative vision of the design may be separated from the practical imperative of converting it into a working model of a project, there is an intimate and continuing link between the creative and the documentation process. The documentation process (as distinct from the design process, as stated in chapter 2) is the focus of the research presented in this thesis.

The literature describes production of the construction documents as part of the project design stage as an incremental process of information gathering, problem solving and communication involving human interaction between different

stakeholder of the project as it moves through a series of steps from an initial statement of requirements to a three dimensional interpretation of those requirements. Growing technological advances, increased legislation and more diverse customer bases have resulted in the requirement for a project team to be composed of members with highly differentiated skills. Each discrete contribution is interdependent as frequently one task cannot be commenced until another is completed.

System dynamics has its own paradigm and has established itself as a powerful methodology (Mohaptra and Mandal, 1989). The modelling process is iterative, although the stages to be followed may appear to be sequential. Implicitly, Mohpartra et al. (1994) suggests that system dynamics can fulfil certain modelling requirements, especially in the context of errors. These include a holistic view of the errors phenomena, construction of causal relationships, identification of feedback mechanisms, and searching for explanations in behaviour (Rodrigues and Bowers, 1996; Williams et al., 1996). The primary focus in system dynamics is the examination of the effect that one element has on another. System dynamics as a modelling tool can be used to identify variables that need to be improved so that errors can be reduced or eliminated (Rodrigues and Bowers, 1996; Williams et al. 1996).

The application of system dynamics to the current research for the purpose of constructing the model has been justified through the following:

- Production of the construction documents is extremely complex and consists of multiple interdependent components.

Interdependencies complicate analysis beyond the capabilities of mental models because a change in one part of the system may have implications in other remote parts. For example, changing the location of a fitting in an engineering drawing may cause subsequent changes in other subsystems, necessitating rework far beyond the original change.

The research studies the occurrence of errors while producing the construction documents which may arise as a result of many interdependent components and in a complex relationship. System dynamics models are well suited to representing multiple interdependencies. Indeed, one of the chief uses of system dynamics is to capture such interdependencies so that the cause impact of changes may be traced throughout the system (Sterman, 1992). In addition, system dynamics has been

applied to understanding and improving the behaviour of complex projects (Lyneis et al., 2001).

- Occurrence of errors and production of construction documents are highly dynamic.

The process of producing the contract documents is intrinsically dynamic. Also, occurrence of some types of errors will lead to the occurrence of other errors, and some other errors may occur while trying to correct these errors and finishing the job. There are multiple time delays in carrying out programmes, in discovering and correcting errors, and in responding to unexpected changes in project scope or specifications. Such dynamic elements mean that the short-term response of a system to perturbation may differ from the long-term response. For example, hiring additional workers adds to the capability of an organization in the long term, but in the short term, experienced workers must divert time from their work to train the recruits, reducing productivity. System dynamics was developed to deal with dynamics. Sterman concludes that out of all the formal modelling techniques, system dynamics has the most highly evolved guidelines for the proper presentation, analysis, and explanation of the dynamics of complex technical and managerial systems (Ford, 1995; Sterman, 1992).

- Production of documents involves a multiple feedback process.

A complex system such as preparing the construction documents and occurrence of errors in a large-scale construction project contains a multiple interacting feedback process. Feedback refers to the self correcting or self reinforcing side effects of decisions.

Tightly coupled systems such as preparing the documents of a construction project contain large numbers of important feedback relationships. Feedback processes are fundamental to the dynamics of managerial, technical, and other systems.

System dynamics is the modelling method of choice whenever there are significant feedback processes (Sterman, 1992).

- Errors generation in the production of documents involves non-linear relationships. Design processes are nonlinear processes (Rodrigues et al. 1996; Walker, 1994) and nonlinear relationships are the norm rather than the exception

in a complex system such as error occurrence (Coyle, 1996). Nonlinearity means causes and effect do not have simple, proportional relationships. System dynamics models portray the rich range of nonlinear relationships found in real life with great fidelity. System dynamics, more than any other modelling technique, stresses the importance of non-linearities in model formulation (Ford, 1995, p33; Sterman, 1992).

- Errors occurrence / detection involve both “hard” and “soft” data.

A construction project is not merely a matter of engineering and materials. It is essentially a human enterprise, and cannot be understood solely in terms of technical relations among components. Some, perhaps most, of the important data needed to understand the evolution and dynamics of such a project will concern managerial decision making and other so-called "Soft" Variables. Forrester's argument for including soft information into models is straightforward: if relying only on hard numeric data, the model would inevitably exclude critical information and implicitly assume that those variables had no importance.

The overwhelming majority of all data are descriptive and qualitative. The numerical data contain only a tiny fraction of the information in the written database, which in turn is miniscule compared with the information available only in people's mental models (Forrester, 1980; Sterman, 2000). Mental data span all the information in people's mental models, including their impressions, stories they tell, their understanding of the system and how decisions are actually made, how exceptions are handled, etc. And the majority of these data have never been written down. Yet they are crucial for understanding and modelling complex systems. System dynamics use multiple sources of information, including numerical data, interview, direct observation, and other techniques to elicit the decision rules, organizational structures, goals, and other important managerial dimensions of the system. All these information sources are used to specify the relationships in the model (Sterman, 1992).

- Modelling the underlying influences

The power of the system dynamics approach lies in its ability to incorporate the more subjective factors which can have an important influence on the whole project. Factors such as changes in workscope, quality, productivity and

motivation may be included and represented explicitly within causal feedback loops. The system dynamics model offers a language, using symbols and the concepts of feedback loops, to express these factors in a rigorous though qualitative manner; it also offers the opportunity to incorporate simple, quantitative approximations of their effects.

The system dynamics approach is based on the premise that these underlying influences are the key to project management and deserve a much greater emphasis (Rodrigues, A. Bowers, J. 1996. p217).

- Graphical Output

The graphical output and analysis of system dynamics offer a distinctly different view of a project, with the main output being a better understanding of the important underlying influences; it also improves understanding and can provide a good estimate of the parameters of the subject of the study.

- The object of the system dynamics model is to reflect as closely the real and unbiased picture of reality, including best estimates of the project parameters. The picture might not be attractive but it is the truth, including the many imperfections of the real project (Rodrigues, A. Bowers, J. 1996. p217). Presumably a system dynamics model will organize, clarify, and unify knowledge (Forrester, 1991).

The above justifications indicate the suitability of system dynamics as a modelling technique that could help solving the problem of the current research.

### **3.6 Key to understand system dynamics modelling**

System dynamics is a tool intended to enable our thinking about how feedback, delay, loop dominance, and non-linearity contribute to systemic behaviour. System dynamics is a methodology embedded in the cybernetic or control paradigm, that is the 'branch of control theory which deals with socio-economic systems' (Coyle, 1977). Wolstenholme defines system dynamics as: "A rigorous method for qualitative description, exploration and analysis of complex systems in terms of their processes, information, organisational boundaries and strategies; which facilitates quantitative simulation modelling and analysis for the design of system structure and control (Wolstenholme, 1990: 3)".

### **3.6.1 Modeling process**

The modeling process has two distinctive phases that should be understood before proceeding:

#### **3.6.1.1 Qualitative system dynamics**

This phase of the method is based on creating cause and effect diagrams or system maps (known as causal loop or influence diagrams) according to precise and rigorous rules and using these to explore and analyse the system. These diagrams are developed with system actors (in this thesis people producing / using construction documents) to allow their mental models concerning system structure and strategies to be made explicit. The word structure refers to the process and information structure of the system and is referred to as the information feedback structure of the system. Hence System Dynamics models are often described as taking a feedback perspective of a situation. It is an underlying premise of the subject of System Dynamics that the feedback structure of a system is a direct determinant of its behaviour over time.

The diagrams create a forum for translating barely perceived thoughts and assumptions about the system by individual actors into useable ideas which can be communicated to others. The intention is to broaden the understanding of each person and, by sharing their perceptions to make them aware of the system as a whole and their role within it; that is, to provide a holistic appreciation.

Once created, the diagrams can be used to qualitatively explore alternative structure and strategies, both within the system and its environment, which might benefit the system. Although comprehensive simulation is not advocated by the method at this stage, it is possible from the study of the feedback loop structure of the diagrams, to estimate their likely general direction of behaviour (e.g. growth or decline). Further, by using some of the experiences from the results of quantitative simulation modelling in other systems it is possible to apply guidelines for the redesign of system structures and strategies to improve system behaviour (Wolstenholme, 1990: 4-5).

#### **3.6.1.2 Quantitative system dynamics**

The second phase of the subject is that of quantitative computer simulation modelling using purpose built software (discussed earlier in section 3.5.1). This is the more conventional and traditional phase of System Dynamics and involves deriving with system actors the shape of relationships between all variables within the diagrams, the calibration of parameters and the construction of simulation equations and

experiments. Although numbers are attached to variables during this phase, it should be stressed that the method is not aimed at accurate prediction or solutions. It is more concerned with the shape of change over time. Accurate prediction on the basis of past performance, assumes that the structure and strategies of the future will not be too dissimilar from the past. If the purpose of the model is to redesign structure and strategies, prediction must, by definition, be less accurate. Emphasis is on the process of modelling as a means of improving understanding. The idea being that such understanding will change perceptions and add to the ability of the system actors to react better to future problems, that is, to make them more self-sufficient as problem solvers.

The power of quantitative System Dynamics has been significantly enhanced in recent years by the development of the personal computer and associated software. The creation of computer simulations of dynamic models has always been a significant factor in improving systemic understanding. This is because there is a severe limit in the cognitive ability of the human brain to process multi-variate problems without such help (Wolstenholme, 1990).

Comprehensive testing (it will be discussed in detail in chapter 7) is needed to build confidence in model behaviour over the full range of parametric values (Balas and Carpenter, 1990; Coyle and Exelby, 2000; Forrester, 1961; Forrester and Senge, 1980). Sterman (2000: 846-853) notes that it is not possible to validate models in order to establish truth in an absolute way. Despite this, the extensive system dynamics body of knowledge is considered and robust. It is assumed to be sufficiently robust for the purposes of the investigation of its integration with qualitative modelling.

The goal of a modelling effort is to improve understandings of the relationships between feedback structure and dynamic behaviour of a system, so that policies for improving problematic behaviour may be developed (Richardson and Pugh, 1981: 38-39).

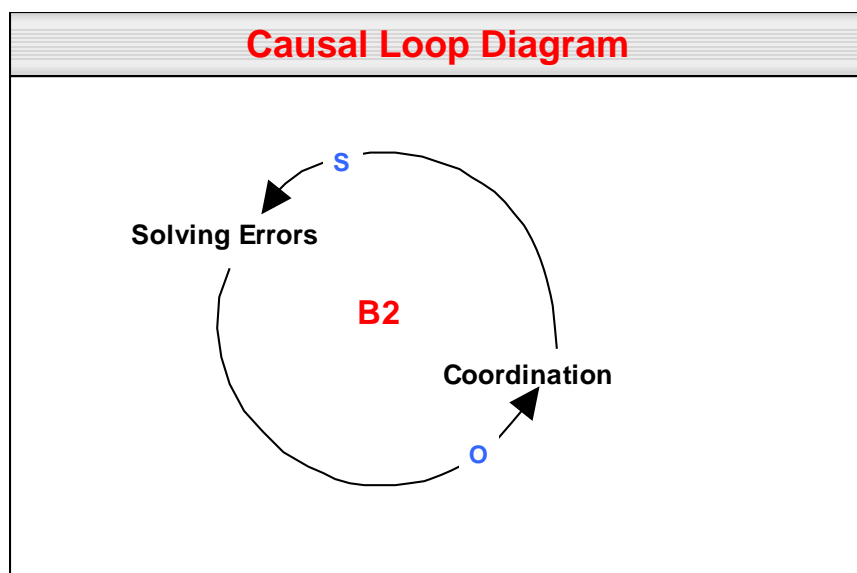
System dynamics modelling allows us to analyse systemic structure, feedback and delay mechanisms that produce counter-intuitive behaviour that often defies our strategic decision-making efforts. Modelling is a never-ending process. We build, revise, compare and change, and with each cycle our understanding improves. Simulation provides a graphic vehicle for demonstrating dynamic behaviour of systems that would otherwise be far beyond our ability to visualise; thus modelling



and simulation can be powerful tools to aid learning. System dynamics modelling also provides a vehicle for simulating the effects of changing policy. It facilitates evaluation of alternate strategies in a benign environment before foisting them upon a world where consequences might be both dire and irreversible.

### 3.6.2 Creating causal loop diagrams

As stated above, the modelling process starts with building up the causal loop diagrams. The technique and guidelines of causal loop diagramming (Richardson and Pugh, 1999 and Kim, 1992) will be used to provide a platform for linking the major causal variables that stimulate the occurrence of errors. A causal loop diagram can show explicitly the direction and type of causality among the major factors, which is fundamental in understanding errors in a project system. It can be used to model the influences of input on outputs and vice versa. For example, if the variable "Coordination" is causing a change in the variable "Solving Errors", the direction of causality is from "Coordination" to "Solving Errors" and vice versa. If an increase (decrease) in the variable "Coordination" leads to increase (decrease) in the variable "Solving Errors" then the type of causality is positive (S), otherwise it is negative (O). The polarity of the loop is either Balancing (B) or Reinforcing (R). If the feedback effect reinforces the original change, it is a reinforcing loop that is denoted (R); if it opposes the original change, it is a balancing loop that is denoted (B).



**Figure 4 : Causal loop diagram**

Senge (1990) has undertaken interesting work in the area of causal relations. He used the concept of the causal loop to show why certain process patterns develop over

time, and theorizes that there are patterns of causal behaviour (or archetypes) that can explain why events happen in certain ways. For example, one archetype defined by Senge is the 'vicious circle'. This is interpreted thus: "Coordination" implies an increase in "Communication", which implies an increase in "Coordination" which implies an increase in "Communication" and so on. In order to understand the inner mechanism and behaviour of error events there is a need for a degree of experimentation. Such experimentation is not considered to be easy to implement owing to the complex and dynamic nature of the research.

The following guidelines for drawing causal loop diagrams are used for this research (Chapter 5) and are based on the guidelines by Richardson and Pugh (1981) and Kim (1992):

- 1- The diagram is kept as simple as possible. The purpose of the diagram is not to describe every detail of the production of the construction documents process, but to show these aspects of the feedback structure which lead to observed patterns of behaviour, i.e. occurrence of errors in the construction documents. At the start, each factor will be studied separately to understand the mechanism that the factor works to stimulate occurrence of errors, then during building the model, all interactions will be taken into consideration.
- 2- The factors shown in the causal loop diagram are variables which can go up or down, with measuring scales which are compatible with each other.
- 3- The nouns or noun phrases have been used to represent the factors, rather than verbs. That is, the actions in a causal loop diagram are represented by the links (arrow), and not by the elements. Some phrases have been abbreviated.
- 4- The used definition of an element makes clear which direction is "up" for the variable with the use of positive sense to make clear direction.
- 5- Casual links imply a direction of causation, and not simply a time sequence. That is, a positive link from element A to element B does not mean "first A occurs and then B occurs". Rather it means "when A increases then B increases".
- 6- As the links are constructed in the diagram, the possible unexpected side effects which might occur in addition to the influences were added.
- 7- For negative feedback loops, there is a goal. For clarity reasons the goal is explicitly shown along with the "gap" that is driving the loop toward the goal.

- 8- A difference between the actual and perceived states of a process can often be important in explaining patterns of behaviour. Thus, it was considered important to include causal loop elements for both the actual value of a variable and the perceived value. As there is a lag "delay" before the actual state is perceived.
- 9- There are often differences between the short-term and long-term consequences of actions and these were distinguished with different loops.
- 10- If a link between two elements needed a lot of explaining, intermediate elements were added between the two existing elements that would more clearly specify what is happening.

In light of the above guidelines the causal loop diagrams were drawn. To start drawing a causal loop diagram, the events of interest in developing a better understanding of system structure should be decided. These events, as stated earlier, are the variables, which will be discussed in Chapter 5, which stimulate the occurrence of error in the construction documents. From these events, the pattern of behaviour will be shown over time for the quantities of interest. Finally, once the pattern of behaviour (will be discussed in section 3.6.2.2) is determined, the concepts of positive and negative feedback loops with their associated generic patterns of behaviour can be used, to begin constructing a causal loop diagram which will explain the observed pattern of behaviour.

There are many ways to justify the causal links, such as direct observation, reliance on accepted theory, hypothesis or assumption, and statistical evidence (Coyle, 1977). The selection of the variables and justification and validation of the causal link will be discussed in Chapter 5

### **3.6.3 Pattern of behaviour**

Recognising symptoms is a crucial part of diagnosing complex systems, and the human brain is particularly strong in pattern recognition. However, recognition is strongly context dependent. When appropriate contexts are created, recognition of patterns is greatly enhanced, and creative ideas are likely to be generated. Creative ideas lead to alternate strategies requiring evaluation. System dynamics, qualitative and/or quantitative, is used to discriminate among alternate strategies by exploring model sensitivity, dominant feedback mechanisms, and pressure points.

To start to consider system structure, it is necessary to generalize from the specific events associated with the problem to considering the pattern of behaviour that characterize the situation. Usually this requires investigation into how one or more variables of interest change over time. That is, what pattern of behaviour do these variables display? The system approach gains much of its power as a problem-solving method from the fact that similar patterns of behaviour show up in a variety of different situations, and the underlying system structure that is known to cause that pattern. By finding and modifying this system structure, there is possibility of permanently eliminating the problem pattern of behaviour (Craig -1998).

The pattern of behaviour of the factor will be shown while discussing the behaviour of the model in Chapter 7.

The following are the recognized patterns of behaviour (Richardson and Pugh, 1981; Kim, 1992):

1- Exponential growth

An initial quantity of something starts to grow, and the rate of growth increases. The term exponential growth comes from a mathematical model for this increasing growth process where the growth follows a particular functional form called the exponential. It is worth mentioning that the growth may not follow this form exactly, but the basic idea of accelerating growth holds. An example of this includes the total number of problems that have been solved in the construction documents.

2- Goal seeking

With goal-seeking behaviour, the quantities of interest start either above or below a goal level and over time move toward the goals. Examples of this can be found in the number of errors occurring and to be solved and the number of errors that might be fixed as a result of experience, education, review etc.

3- Oscillation

With oscillation, the quantity of interest fluctuates around some level. It should be noted that oscillation initially appears to be exponential growth, and then it appears to be an s-shaped growth before reversing direction. An example of this can be found in the accumulation of the assumed number of errors that will be proved correct or not through quality assurance process and so on at each phase, where the process will start over again.

The three patterns of behaviour often show up individually or in combinations, such as S-Shaped growth, overshoot and collapse.

A group meeting (11 experts) was used to draw the required reference mode for different factors and expected behaviour. If the problem concerns the interactions of variables, such as the effect of the size of project on the level of error, it is necessary to map the relevant variables against each other. This way an understanding can be build of how each of the various variables affects each other. It is necessary always to keep in mind that system dynamics models are not concerned with the behaviour of individual variables. The main focus is on how each variable interacts with the other variables to produce the system's behaviour.

As a result of the interaction of many different variables, these predictions cannot be simplified to "if x and y occur, the behaviour z is the result". On the contrary, the goal is to predict "action intervals" of given events based on the observation of different behavioural data (Frankenberger et al., 1998)

#### **3.6.4 Delays**

Not all cause and effect relationships occur instantaneously. Sometimes the consequences of an action or decision are not apparent until several days, months, or even years after an event has taken place.

Often the relationship between cause and effect is obscured by separation in time. It is difficult to understand a system when the consequences cannot be seen in close proximity to the behaviour. Many decisions have outcomes that cannot be known for years and may never be linked to early mistakes.

Delays occur everywhere in the real world. A project may, for example, have cascading side effects when critical-path tasks are delayed. New investments can have limited "windows of opportunity" for making a return on investment. Introducing new products or services sometimes has first mover advantages.

Delays can produce interesting and complex behaviour in systems, even when those systems have no feedback and limited cause and effect complexity.

For example, when errors occur in the documents, the correction of errors will not happen immediately till the error has been analysed, the cause of the errors has been identified and enough sources (time, manpower) have been sourced to correct such errors. Cooper (1993) estimates the delay in the discovery of errors to be

approximately 1/4 to 3/4 of the time required to design the work the original time, and concludes that this delay is one of the most important determinates of cycle time performance.

The delay factor will be discussed while description the formulation of the model in Chapter 6.

### **3.7 Approach of developing the thesis's model using System dynamics**

The central idea involved in the study of the dynamics of real systems is the idea of a model of the system (Forrester, 1961). Models of systems are simplified, abstracted constructs used to predict their behaviour. The characteristic feature of these models is that some, but not all, of the features of the real system are reflected in the model. The assumption is that some aspects of the real system are unimportant in determining the influences of the input on the output, and thus the model contains only those aspects of the real system that are supposed to be important to the characteristics under study (Deans et al., 1990, p4).

Because a model must be a simplification of reality, there is a great deal of art in the construction of models. An overly complex and detailed model may contain parameters which are virtually impossible to estimate, may be practically impossible to analyze, and may cloud important results in a welter of irrelevant detail if it can be analyzed. An overly simplified model will not be capable of exhibiting important effects. It is important, then, to realize that no system can be modelled exactly (Deans et al., 1990, p4).

It must be acknowledged that construction projects are also essentially human enterprises, and cannot be understood solely in terms of technical relations among components (Love et al., 1999). Most of the data required to understand the evolution and dynamics needed to determine the variables that cause errors primarily are concerned with what are called “soft” variables, which contribute to the complex nature of the problem at hand (Stermann, 1992; Coyle, 1996). According to Hogarth (1980), people generally have difficulty inferring accurately the behaviour of complex dynamics systems. Also, the capacity of the human mind for formulating and solving complex problems is very small compared with the size of the problem whose solution is required for objectively rational behaviour in the real world, or even for a reasonable approximation to such subjectively rationality (Simon, 1957). The bounded rationality of humans means that the best intentioned mental analysis of a

complex problem, such as errors, cannot be accounted for accurately because of the myriad of interactions that jointly determine its outcome (Richardson, 1991; Sterman, 1992). Fundamentally, no mental model can adequately assess the impact of externally imposed changes or allocate responsibility for the delay and disruption caused by errors in construction documents. According to Richardson (1991), Sterman (1992), and Ford (1995), computer models based on system dynamics can be used to overcome the limitation of mental models for the following reasons:

- The many and various project parameters and relationships can be modelled more comprehensively with the flexible representation available than with mental modelling methods.
- They are explicit and their assumptions are explicit and unambiguous by their representation as formal equations, and they are open to review;
- They are able to interrelate many factors simultaneously,
- They can be simulated under controlled conditions, allowing analysts to conduct experiments which are not feasible or ethical in the real system.
- The model's reflection of actual project structure provides an effective means of communicating research work and results.
- Consequences of assumptions and policies over time can be revealed through the simulation under safe experimental conditions.

Using these concepts represents a new way of viewing the world around us. By using software, these concepts and views of the world can be formalized into a computer simulation model. The important point is to develop a model that is capable or represents the system's characteristics needs, to enable practitioners to manage effectively the complexity associated with errors in a project system (Love et al., 2000) as it was asserted in the objective of the research.

When describing the modelling process, experts have organized the main modeller activities using different arrangements, varying from three to seven different stages (Table 2). At one extreme, Wolstenholme (1990) visualizes the process in three stages. At the other extreme, Richardson and Pugh (1999) conceptualize the modelling process as involving seven different steps. Randers (1980), Sterman (2000)

and Robert et al. (1983) have grouped the activities in four, five and six stages respectively.

Although the ways of grouping the activities vary among the different authors, the activities considered along the different stages remain fairly constant across them, allowing the building of a comparison like the one depicted in the following table (Table 2).

Randers's (1980) conceptualisation stage or Wolstenholme's (1990) diagram construction and analysis consider activities that can be mapped onto the problem definition and system conceptualization stages from Richardson and Pugh (1981) and Roberts et al. (1983). Sterman's (2000) dynamic hypothesis stage involves the same activities described in the system conceptualization stage of Richardson and Pugh (1981) and Roberts et al. (1983). Similarly, model behaviour analysis and model evaluation (Richardson and Pugh 1999; Roberts et al. 1983) include the same activities considered in the testing stage (Randers 1980; Sterman, 2000).

Regardless of the differences in the way of grouping the activities, all authors conceptualize them as parts of an iterative process in which the modeller will test a dynamic series of behaviours over time, allowing the problem actors to learn about the situation, and to design or redesign their guidance policies.

Randers (1980)	Richardson and Pugh (1999)	Roberts et al. (1983)	Wolstenholme (1990)	Sterman (2000)
Conceptualization	Problem Identification and Definition	Problem Definition	Diagram Construction and analysis	Problem articulation
	System Conceptualization	System Conceptualization		Dynamic Hypothesis
Formulation	Model formulation	Model Representation		Formulation
Testing	Analysis of model behaviour	Model behaviour	Simulation phase (stage 1)	Testing
	Model evaluation			
Implementation	Policy Analysis	Model evaluation	Simulation Phase (stage 2)	Policy formulation and evaluation
	Model Use or implementation	Policy analysis and model use		

**Table 2 : The system dynamics modelling process across the classic literature (Luis, et al. 2004)**



Within the structure of the current research, a four stages view of modelling behaviour will be used to see how the influence of the identified factors induces errors in the construction documents, as will be discussed (see figure 3):

### **3.7.1 The conceptualization stage**

This stage does not require, as some might expect, that the modeller has access to explicit numerical data. While data are very helpful, one is often focused with a dynamic problem in which a key variable is not traditionally quantified or tabulated. It is even more likely, however, that the modeller knows the dynamic behaviour of interest without referring to data (Richardson and Pugh 1981, p19). In addition, Sterman (2000, p90) stated that modellers usually develop the initial characterization of the problem through discussions, supplemented by archival research, data collection, interviews, and direct observation or participation. However, Coyle (2000) emphasizes that qualitative modelling can be useful in its own right and that quantification may be unwise if it is pushed beyond reasonable limits.

So, to conceptualise the model it was necessary to understand the procedures and identify the types of errors in construction documents within Saudi Construction industry. The data required for this stage were collected and analyzed using the following procedure:

- the literature review to gather the initial insights into issues related to construction documents and errors,
- 5 case study projects to investigate and understand the characteristics of the construction document procedures in Saudi Arabia and identify initial list of errors occurring in Saudi industry,
- 36 questionnaires to understand procedures followed in Saudi construction industry and to obtain information on the actual errors that occur in practice in the construction documents of the Saudi industry.
- 10 interviews to understand the construction documents procedures of the Saudi industry.

A major part of this stage has been discussed in earlier chapters and at the beginning of this chapter while defining the problem and scope of the current research. However, the remaining part of this stage will be discussed in more depth in chapters four and five, while discussing the nature of errors occurring and the factor inducing the occurrence of errors in the construction documents.

### 3.7.2 The formulation stage

This stage, positing a detailed structure and selecting the parameter values, can also contain elements of quantitative data. With regard to the formulation of qualitative concepts, Richardson and Pugh (1981, p 160) suggest that "the modeller may wish to represent such a concept explicitly. To do so requires the invention of units and a measurement scale, and consistent treatment throughout the model". The importance of the inclusion of these qualitative constructs in the models is stressed by Sterman (2000, p854). "Omitting structures or variables known to be important because numerical data are unavailable is actually less scientific and less accurate than using your best judgment to estimate their values". Nonetheless, this is an area in which system dynamics practitioners have questioned the use of qualitative variables. Nuthmann (1994), for one, stated that there is a basic problem with modelling social judgment. He asked, "Can psychological variables be treated with the same mathematics as physical variables?".

Richardson (1996. pp148-150), in fact, devotes a section of his article on future problems in the field to the issue of qualitative mapping and formal modelling. His questions reach the heart of the matter for system dynamics, but the methods of answering these qualitative questions are not easily apparent. It is appropriate to use qualitative data for some aspects of the modelling process, but the formalization stage seems to be the area where there is greatest concern about the applicability.

The starting point for formulating the initial relationships in the model was based upon theoretical and empirical evidence published in literature to identify the factors causing errors in construction documents, and to develop a priori causal diagrams.

The formulation was refined using:

- observable evidence gained from 9 case study projects, and
- experience elicited from 16 interviews.

When there was an initial first glance identified contradiction between early diagrams derived from literature and evidence of case study projects and interviews, further analysis were undertaken to understand the relationships. This process created necessity to add more interpreting factors to the diagrams. However, in no cases, the analysis identified a contradiction to literature in any of the causal diagrams presented in chapter 5.

While the sample of nine projects and 16 interviews are not significant statistically, the literature, in conjunction with the case study projects and interviews, provided theoretical saturation for all the factors that cause the occurrence of errors in the construction documents, and informed a wide database for deriving the relationship between different variables that lead to the occurrence of errors, since each case describes its unique characteristics, as will be explained later in the brief of the project. The selection of limited unique case study projects was supported by many researchers (Eisenhardt, 1989; Yin, 1984; and Romano, 1989).

These refined and proposed causal diagrams and relationships were validated using an expert panel of 11 experienced and senior practitioners in Saudi construction industry. Understanding causal relationships among variables within a system and its consequent behaviour has for long been one of the key issues in system dynamics (Santanu et al., 2000). Even in some cases, a model can be entirely qualitative, consisting only of an influence diagram (Coyle, 1998; Wolstenholme, 1999).

The process of formulation was culminated through operationalising the model by converting the initial validated causal diagrams into a system dynamics model (full detail of elicitation process is addressed in section 6.5). This required 12 further interviews to gain qualitative information on the nature of the relationships and so to form the equations between different variables causing errors in the construction documents.

Again, while the number of experts involved in the validation of causal diagrams and elicitation of equations for the model was limited (not significant statistically), their professional education, the cumulative years of experience (205 years) and deep involvement in the production of construction documents represent an appropriate base for their engagement in the validation process of causal diagrams. The experts' group participation to elicit information was supported by many researchers in the field of system dynamics (Forrester, 1961; Vennix et al., 1992; Sterman, 2000).

Part of this stage will be discussed in chapter five while explaining the causal diagrams that depict the impact of factor on occurrence of errors, while the full formulation process of the current research model will be discussed in chapter six.

### **3.7.3 The testing stage**

The third stage in building system dynamics is the testing stage. Forrester and Senge (1980) go into great detail in describing 17 tests at this stage of model development.

For example, in the structure-verification test (p. 416): "the model must not contradict knowledge about the structure of the real system. Structure verification may include a review of model assumptions by persons highly knowledgeable about corresponding parts of the real system. Structure verification may also involve comparing model assumptions to descriptions of decision making and organizational relationships found in relevant literature. In most instances, the structure verification test is first conducted on the basis of the model builder's personal knowledge and is then extended to include criticisms by others with direct experience from the real system". Similarly, Randers (1980) stated that "in judging how well a model meets the listed criteria, the modeller should not restrict himself to the small fraction of knowledge available in numerical form fit for statistical analysis. Most human knowledge takes a descriptive non-quantative form, and is contained in the experience of those familiar with the system, in documentation of current conditions, in descriptions of historical performance, and in artefacts of the system. Model testing should draw upon all sources of available knowledge".

Beside the traditional testing techniques of a model, Sterman (2000, p851) points out the practical and political issues of modelling. "There are no value-free theories and no value-free models" As a part of the testing process, "model users must ask about the modeller's biases (and their own). How do these biases, especially those we were not aware of, colour the assumptions, methods and results?".

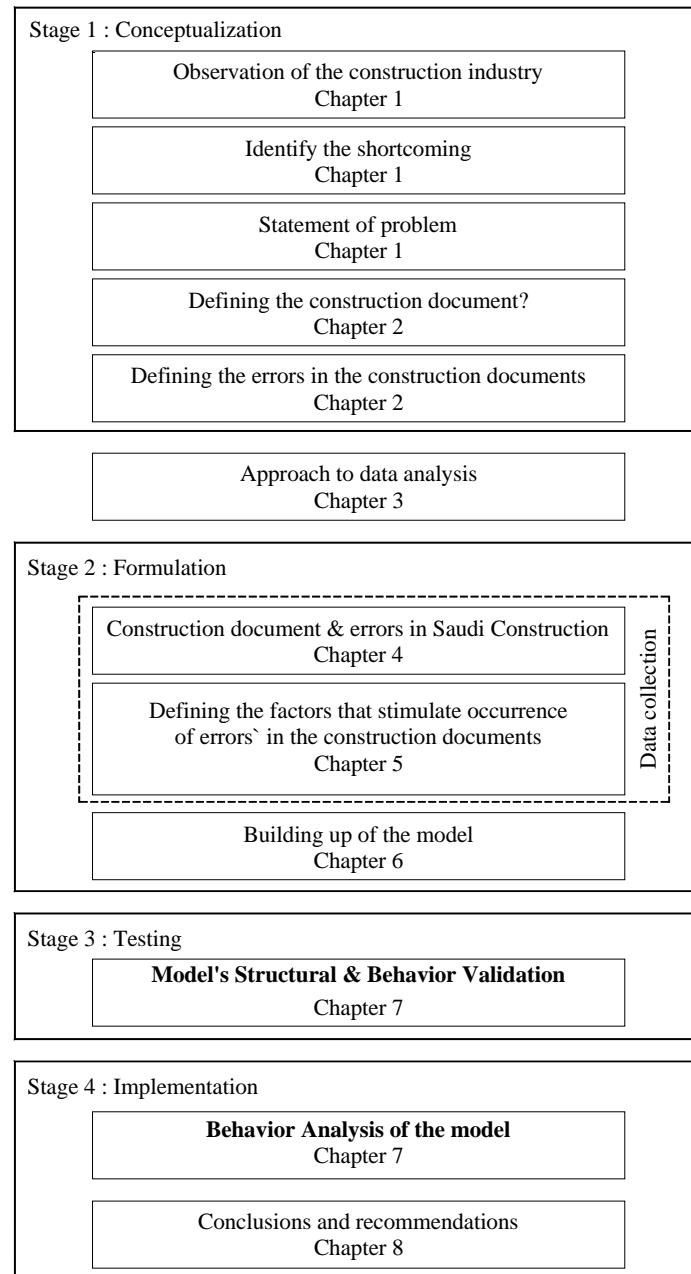
After validating the structure and behaviour of the model using suggested tests and procedures (Barlas 1996), its findings were tested against 4 further case studies. The full testing of the proposed model will be discussed in chapter seven while discussing the validating and verification of the model.

#### **3.7.4 The implementation stage**

Finally, the last step of the modelling process is implementation, where the study will be transferred to the user of the model. This is a qualitative process that requires discussion more than examination of parameter values and equation formulation. Furthermore, the interpretation and use of simulation results by policy makers pose several important challenges associated with understanding the many types of judgments needed during the model-building process, and the judgments needed to assess and use the output of the model (Andersen and Rohrbaugh, 1992).

The full explanation on the implementation stage will be discussed in chapter seven, while discussion the most serious factors that stimulate the occurrence of errors in the construction documents and also in last chapter while discussion the research conclusion and recommendation.

The following diagram (Figure 4) maps the above modelling process with the structure of the thesis. To conceptualize the model, 5 case studies, 36 questionnaires and 10 interviews were needed to understand the procedures and identify the types of errors. Then, to formulate the relationships in the model, the process was initiated by developing a priori causal diagrams based upon theoretical and empirical evidence published in literature. These causal diagrams were refined using a further 9 case studies and a further 16 interviews. Once causal diagrams based on theory, refined by observable evidence gained from case studies and refined by experience elicited from interviews were in place, an expert panel was formed to validate the proposed relationships. Following that process was operationalising the model, i.e. converting the initial validated causal diagrams into system dynamics model. This required 12 further interviews to gain qualitative information on the nature of the relationships and so to form the equations. Finally, once the model was operationalised, its findings were tested against 4 further case studies.



**Figure 5 : Relationship of Research Method to Thesis Structure**

### 3.8 Data collection and sampling

As discussed during the selection of the appropriate approach to conducting the research, a mix mode of approach was selected as the most appropriate approach to fulfil the objective of the research.

The system dynamics model requires moving between qualitative and quantitative techniques, constantly testing to ascertain if the data indeed mirror the reality of the system under study (Luis et al., 2004).

Most of data selected for the model developed in this research will be qualitative. Qualitative data collection and analysis are ways of bringing formality and rigour into the modelling process. They add richness and details that numbers cannot provide. They also allow for insight about the mental models of experts in the field and the variety of individuals' understanding about meaning and connections, and uncover the complexity of real world system through detailed stories and descriptions (Luis et al., 2004). Such an approach is supported by many gurus of system dynamics. Forrester identified qualitative data as a main source of information in the modelling process of the system dynamics in several papers (Forrester, 1975). Moreover, this perception is shared among mainstream authors in the field (Randers 1980, Richardson and Pugh 1999, Roberts et al., 1983; Wolstenholme, 1990, Sterman, 2000) beside the general agreement about the importance of qualitative data during the development of a system dynamics model (Luis et al., 2004).

In order to increase the validity of the research data, it was decided to combine a number of data collection techniques. Sterman (2000, p158) suggests that to develop good model of the problem situation, "we should supplement the links suggested by the interview with other data sources such as our own experience and observations, archival data, and so on". He added that "we may add additional causal links not mentioned in the interviews or other data sources". While some of these will represent basic physical relationships and be obvious to all, others require justification or explanation. He concluded that "we should draw on all the knowledge we have from our experience with the system to complete the diagram".

Following a similar approach, the data from a variety of sources will be collected and investigated to build up the accuracy and viability of the proposed model.

### **3.8.1 Literature review**

The literature review gathered initial insights into issues related to construction documents, errors, and factors stimulating occurrence of errors in the construction documents. This research tool was used in the process of collecting data about the research problem, gathering the information and observation requirements of the chosen mixed-mode research methodology, errors in the construction documents and different factors inducing the occurrence of errors in the construction documents (Figure 5). In a number of instances, further information to that which could be

elicited from the literature was required, necessitating the use of further research tools, as it will be discussed later in this chapter.

### **3.8.2 Case study projects**

The second method to be used to collect data will be from the case study projects. A case study project can provide analytical rather than purely statistical generalizations and may lead to a more informed basis for theory development (Fellows and Liu, *op. cit.*; Yin, 1994). Also, according to Kothari (1997, p140-141), the "case study method is a form of qualitative analysis where in careful and complete observation of an individual or a situation or an institution is done, efforts are made to study each and every aspect of the concerning unit in minute details and then from case data generalizations and inferences are drawn". The case study is a method of studying in depth rather than breadth. The case study places more emphasis on the full analysis of a limited number of events or conditions and their interrelations. Thus, the case study is essentially an intensive investigation of the particular unit under consideration. The object of the case study method is to locate factors that account for the behaviour patterns of the given unit as an integrated totality.

Each project case describes its unique characteristics. Eisenhardt (1989, p537) supports the use of cases that are polar or of a unique nature. Furthermore, Eisenhardt contends that cases that are selected randomly are considered to be neither necessary, nor even preferable. In this instance, however, the projects were selected on pragmatic considerations, namely their availability and the willingness of the designer(s) to share information with the researcher. There is no ideal number of cases that should be undertaken (Yin, 1984). Similarly Romano (1989) suggests that the number used should be left up to the individual researcher. By contrast, however, Lincoln and Guba (1986) and Eisenhardt (1989) suggest that cases should be used up to theoretical saturation or to the point of redundancy which, as Perry and Coote (1994) highlight, neglects time and money constraints.

In spite of the pragmatic selection of the project, the scale of detail required to obtain the information necessary from the case study projects imposed limits on the number of projects that could be included in the study. Limitations have to be considered with any research project; with the benefit of experience gained from the pilot study it was decided to limit the case studies projects to:



- qualified companies / design offices as per MOMRA (will be discussed in section 3.8.4).
- those companies which implement design time management,
- there are records of quality control set, bidder queries, and/or final project variations list,
- availability of some senior members of the design team.

Further to the use of literature, case study projects were used and analyzed in this research for the following purposes (Figure 6):

- 5 case study projects to investigate and understand the characteristics of the construction document procedures in Saudi Arabia and identify initial list of errors occurring in Saudi industry,
- 9 case study projects to draw initial causal diagrams of the occurrence of errors in construction documents.
- 4 case study projects to validate the finding of the system dynamics model.

The insightful data of these 18 projects were very important to derive and structure the initial model of the research. The number of case study projects and background information collected for this research will be discussed in detail in the relevant chapter.

### **3.8.3 Questionnaire**

The third method of data collection will be the questionnaire. The questionnaire survey is one of the most cost effective ways to involve a large number of people in the process in order to achieve better results, whereas the above face-to-face interviews serve as crosscheck and, sometimes, unexpected information may be given during the interviews (Kothari, 1988).

The questionnaire was constructed using a variety of question forms (Wilson and McClean, 1994) to ensure that data of the type and in the format required for analysis (McCormack and Hill, 1997) was elicited from respondents. However; the approach adopted in this research is the investigation of a sufficiently large sample size of projects to enable statistical analysis of data groups to be undertaken. A minimum

sample size for this type of data collection was decided upon after consulting the literature of statistics. The minimum sample size that allows normal distribution assumptions to be used rather than using a *t* distribution is thirty cases (Hinkle et al., 1988). A normal distribution forms a more reliable sample than heavily skewed distributions for the type of study proposed (Levin 1987, p394).

The questionnaires were distributed to offices that were selected from the qualified design offices, as listed by the Ministry of Municipal Affairs and Rural Area (MOMRA), where they have pre-qualification procedures for the consultant office to carry out any municipal projects (Table 3). A direct contact with those involved in the production and use of construction documents was established, as this allowed better selection of the sampling population and a higher rate of responses.

In addition to the use of literature and case study projects, questionnaire was used. The questionnaire used in this research was in two parts:

- Part one of the questionnaire was designed to understand procedures in Saudi construction industry
- Part two of the questionnaire was designed to see the spread of errors in the construction documents of the Saudi industry.

Out of 40 forms distributed, 36 completed forms were returned (percentage of return 90%).

The result of the questionnaires and the background information collected for this research will be discussed in detail in Chapter four.

Criteria	Notes
Office type of work	These criteria are given points and weighted for each office. Offices who achieve certain points are qualified
Size of the office	
Current Projects	
Experience	
Qualification of the technical staff	
Registration in official organization	
Yearly turn over	

**Table 3 : MOMRA Criteria for qualifying consultants**

### **3.8.4 Interview**

Further to the above techniques, it was important to use the interview technique to collect data as it gives inside of the practitioners and obtains all the mental data available in people's mental models. Mental data span all the information in people's mental models, including their impressions, stories they tell, their understanding of the system and how decisions are actually made. Mental data cannot be accessed directly but must be elicited through interview. Undertaken concurrently to the literature survey and case study project analysis, a series of unstructured exploratory interviews was held with senior project managers, designers and engineers to complement and corroborate initial observations with the findings of the literature review as they arose. Face-to-face interviews will allow the researcher to probe fully the meaning of questions and to add supporting contextual evidence. This approach was adopted by Walker (1994), Ireland (1983), and Sidwell (1982). The unstructured format of these interviews provided an opportunity to make further observations qualitatively that would influence the subsequent deployment of the research. One such observation noted the extent of the understanding the role of the construction documents and types of errors occurring in the construction documents. Hence this additional observation necessitated the investigation of the role and definition of construction documents and defining the meaning of errors within such a context. Therefore the interview data collection technique could be used for such purposes to elaborate the understanding of the role of the construction documents in the Saudi construction industry, and to draw causal diagrams and formulate the relationship between factors stimulating the occurrence of errors in the construction documents. In addition, interviews with the design team members will be used primarily to determine those variables that influence the occurrence of errors in the construction documents. Coyle (1977) supports such an approach for establishing causal relationships. This method relies on self-reports; despite their problems, they seem to be common in research on human error, where it is usually difficult to undertake direct observation, not least because errors are typically infrequent, and people tend not to make the most serious errors when under observation (Busby 2001, p236).

The interviews will be conducted on a one-to-one basis and will be open so as to stimulate conversation and break down any barriers that may have existed between the interviewer and interviewee. The interview, either in person or over the telephone,

allows for interaction between the researcher and the respondent (Luis et al., 2003). This interaction can be structured, driven by a carefully worded interview script that channels the topics of the interview. It can also be highly unstructured, allowing the respondent to tell stories, give examples, and often unearth issues that the interviewer finds novel or counterintuitive. Interviews allow for clarification of definitions, elaboration on topics and collection of the respondent's own words or usage in a way not supported by questionnaires or surveys (ibid). This will be used to obtain the opinion of practitioners on the causal links between different factors which induce errors in the construction documents.

The interviews carried out in this research will be unstructured to ensure the best outcome. The unstructured interview allows the researcher much greater freedom to ask, in case of need, supplementary questions. He may even change the sequences of questions Khothari (1997, p140-141).

However as asserted in the previous section regarding the conditions set for this research and regarding the availability of member from the team who carried out the production of construction documents, at least one senior member of the design team of the case study was interviewed.

A total of 39 interviews (Figure 6) were conducted for the current research in the following order:

- Further to literature, 5 case study projects and 36 questionnaires, 10 interviews were conducted to understand the construction documents procedures of the Saudi industry,
- Further to literature and 9 case study projects, 16 interviews were carried out to identify the factors causing errors in construction documents and draw causal relationships between factors and occurrence of errors in these documents,
- After forming the causal diagrams an expert panel of 11 experts in field of producing construction documents were interviewed in 1 "group interview" for validating the drawn diagrams and finally
- After validating the causal diagrams, 12 interviews were conducted (workshop for 2-3 people) for elicitation of equations between factors for the system dynamic models.

These insightful data also were very important to derive and structure the initial model of the research.

The result from this data collection and the background information collected for this research will be discussed further in the relevant chapter.

### **3.8.5 Other source for data collections**

In addition to the above stated approach, direct observations and documentary sources provided by the consultants, designers and project managers will be used to derive data. Sterman (2000) suggested using the modeller's own experience and observation(s) to suggest links when some of the links are missing or the feedback system is not close. Numerous other sources, such as variation lists, tender queries, quality control and assurance lists, time logs, design project management documents, will also be used to identify error events and the cause of their occurrence. Such an approach to data collection is commonly referred to as "triangulation" (Todd, 1979).

The following diagram maps (Figures 6 and 7) the data collection with the adopted system dynamics modeling approach and the structure of the thesis.

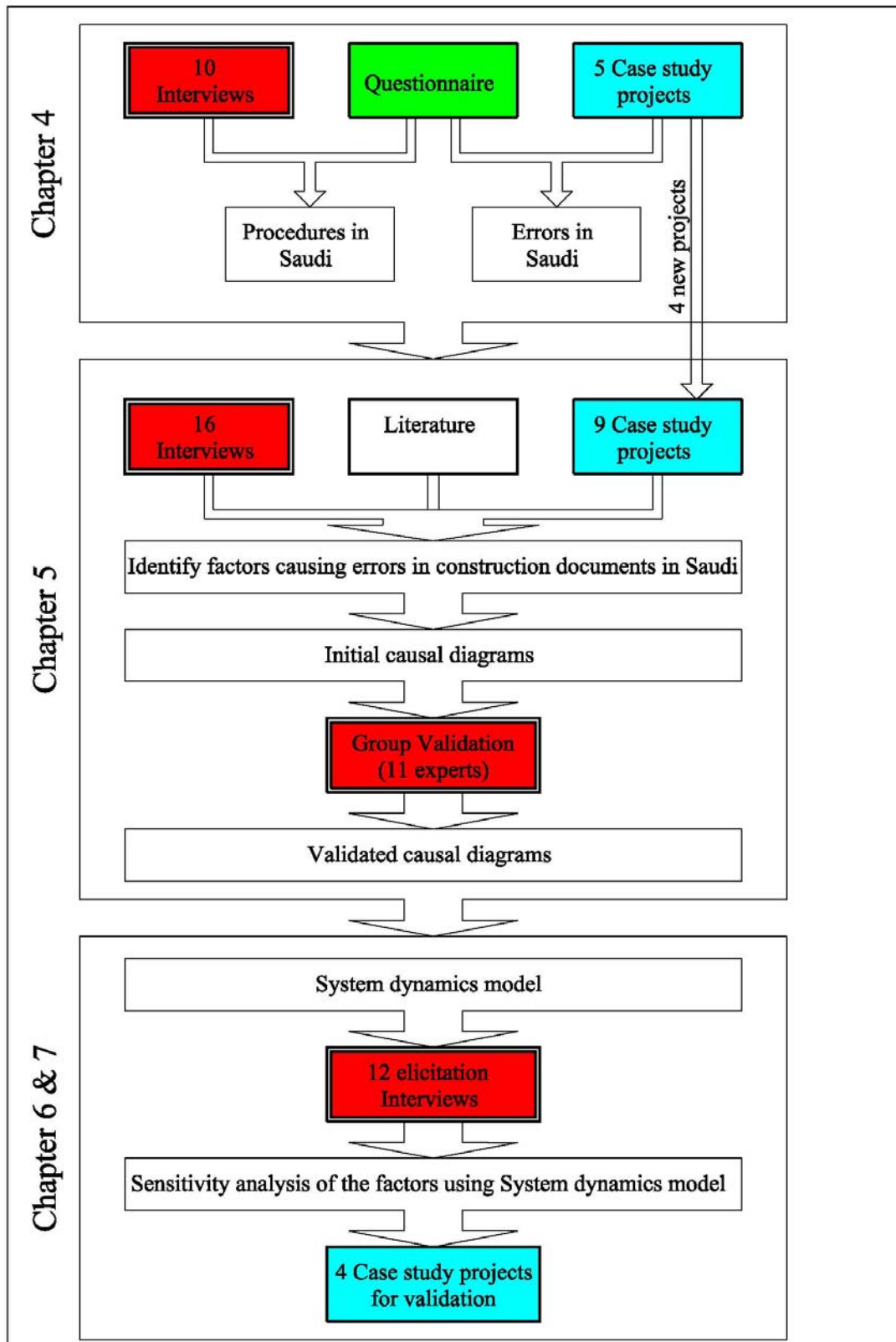
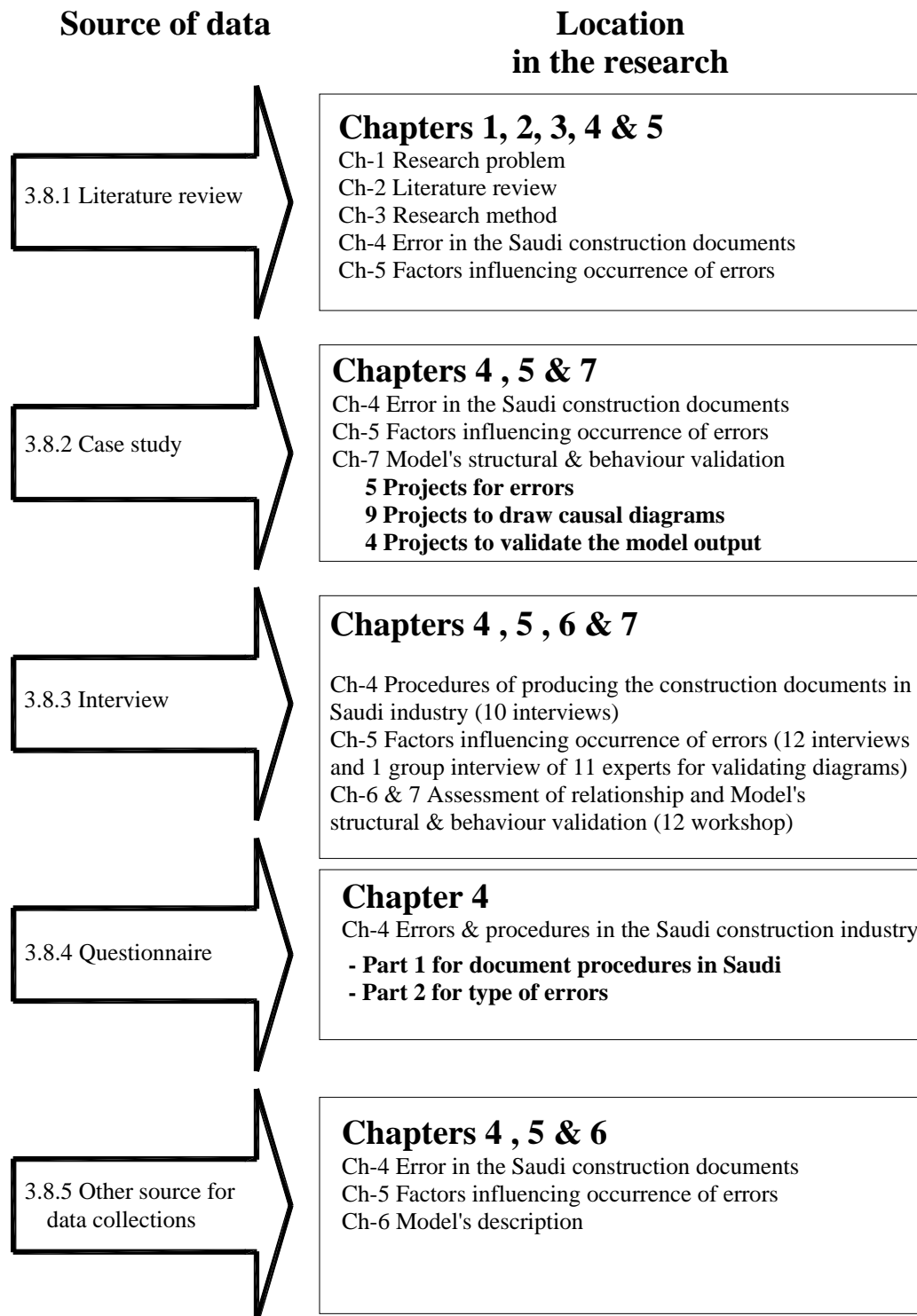
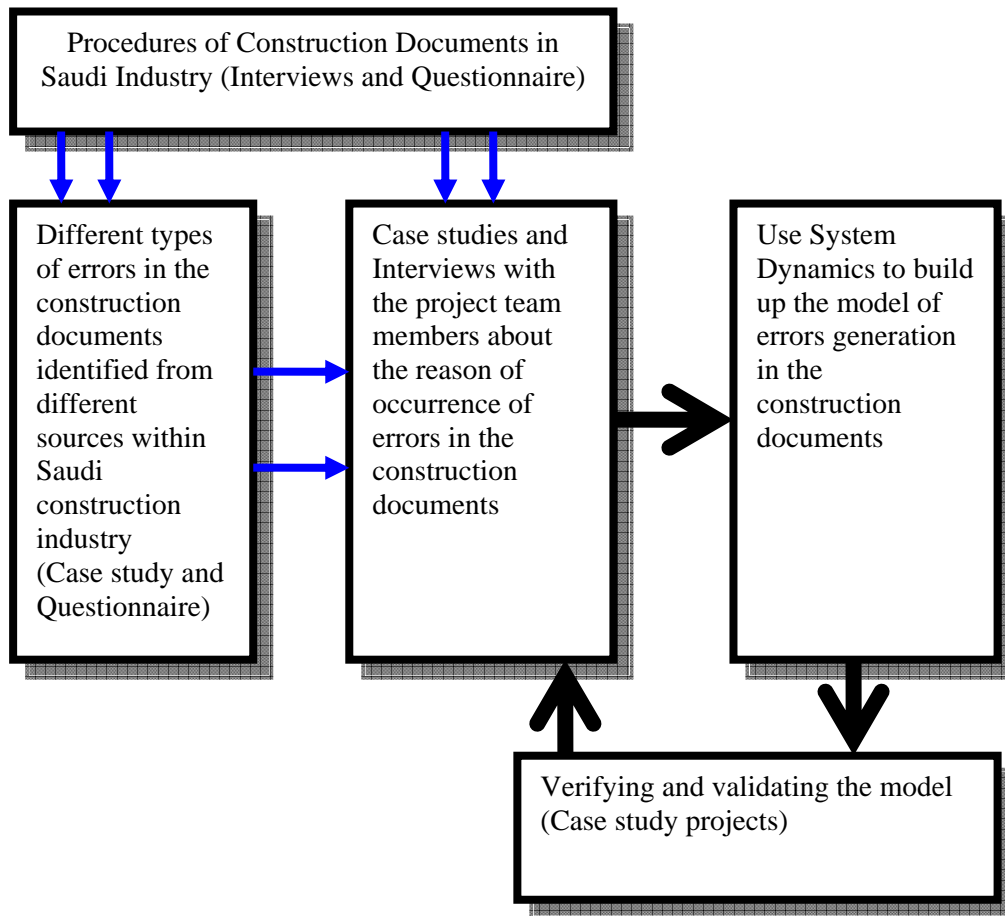


Figure 6 : Data collection used for the thesis



**Figure 7 : Map of data collection to thesis structure**

Therefore, based on the findings of this chapter, the following diagram summarizes the methodology that will be used to carry out the research:



**Figure 8 : Research methodology diagram**

### 3.9 Conclusion

In light of ongoing debate on research in construction management, and based on the definition of the problem and the current research scope of the work, this chapter has discussed the most appropriate approach to conduct the research and method of collecting data. It was decided to choose a mixed mode research approach as it is more practical for the current research within the constraints of time and effort. The data will be collected mainly from case studies projects, interviews and questionnaires when there are not sufficient data.

As in most cases it is prohibitively costly to run the necessary experiments in actual organizations. Thus the development of models to capture the dynamics of such processes is critical to understanding which policies are robust to changes in the environment and the limitations of the decision maker. Therefore the research selected



and justified the use of system dynamics as most suitable method of describing the relationship between different factors influencing the stimulation of errors in the construction documents, through producing a simplified and abstracted model of the error's occurrence system to predict the number of errors. The core idea of a robust design is applicable to the design of processes and organizations and has been a focus in the field of system dynamics since its inception. The focus of the model and its boundary will be on understanding the internal mechanism of the errors' occurrence (endogenous explanation) to avoid placing blame in favour of finding the true, long-term solution to a problem. System dynamics provides an important means to generate useful models of organizations and processes, and can contribute substantially to understand the events that lead to the occurrence of errors in the construction documents.

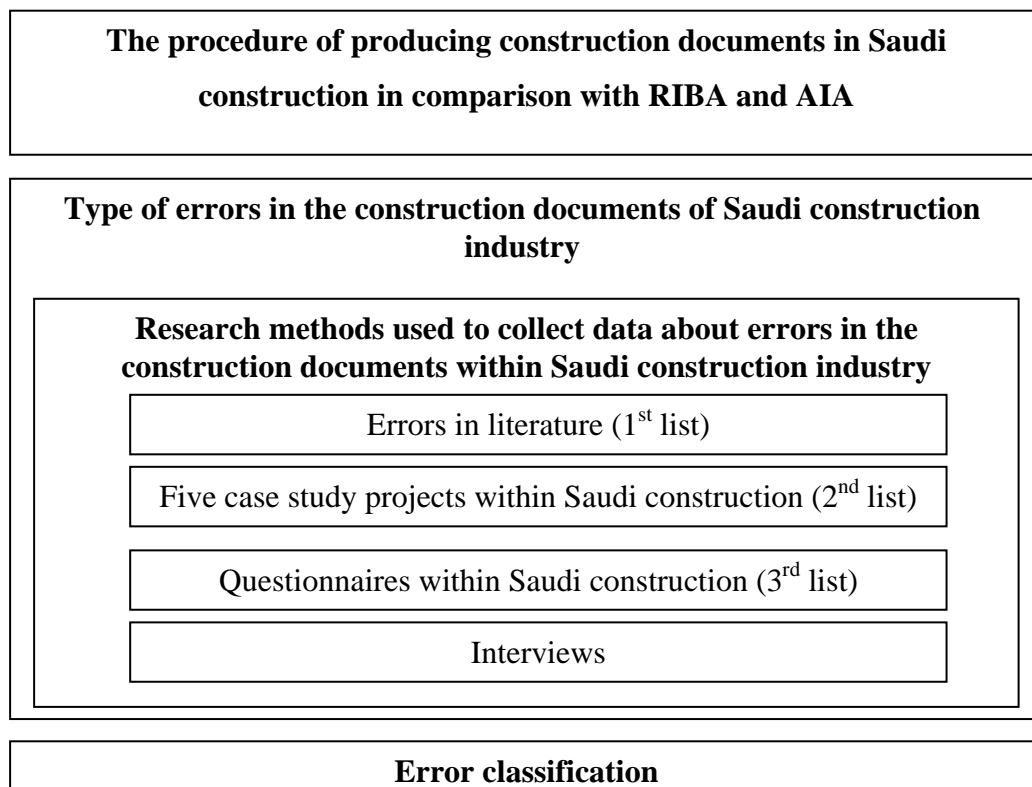
This chapter has therefore provided the premise for the subsequent analysis and modelling activities using the data gathered by means explained in this chapter.

4.1	Introduction.....	104
4.2	Procedures for producing construction documents.....	104
4.3	Research methodology used to collect data about errors.....	114
4.4	Types of errors in construction documents of the Saudi construction industry .....	117
4.4.1	Document does not conform to client’s design criteria .....	118
4.4.2	Document does not conform to code .....	118
4.4.3	Document does not conform to calculations.....	119
4.4.4	Document does not conform to vendor data.....	120
4.4.5	Document does not conform to the law .....	120
4.4.6	Document does not conform with building regulations.....	120
4.4.7	Discipline coordination problems .....	121
4.4.8	Interdisciplinary coordination problem.....	122
4.4.9	Operability problem .....	122
4.4.10	Constructability problem .....	123
4.4.11	Document does not conform to drafting standards .....	123
4.4.12	CADD –related problem .....	124
4.4.13	Dimensional error .....	124
4.4.14	Symbol and abbreviation errors .....	125
4.4.15	Callouts incorrect or missing .....	125
4.4.16	Incorrect or missing notes .....	126
4.4.17	Additional views / details needed .....	126
4.4.18	Errors in capital cost estimating.....	127
4.4.19	Designer errors .....	127
4.4.20	Error in project contextual factors .....	128
4.4.21	Errors and omission in the bills of quantities.....	128
4.4.22	Errors in Specification .....	129
4.4.23	Biddability.....	129
4.5	Error classification .....	130
4.6	Conclusions:.....	134

#### 4.1 Introduction

The main objective of this research is to investigate the relationship between errors and factors influencing their occurrence in the construction documents. In the previous chapters we placed the research in context by defining the construction documents and errors for the purpose of the research. This chapter identifies typical procedures used for producing the construction documents in Saudi and the types of errors generated in these documents, based on a review of literature, questionnaire, interviews and analysis of case study projects.

Identifying typical errors that occur in construction documents of the Saudi construction industry is an important step toward developing the thesis model as the chapter lays the foundations for understanding the local practice and removes any ambiguity regarding the types of errors discussed within the scope of the current research.



**Figure 1 : Road map of the chapter: Studying errors in the Saudi construction documents.**

#### 4.2 Procedures for producing construction documents

As we have seen in previous chapters, the early control of the development of construction documents has considerable influence on the achievement of a project's

objectives. After recognition and identification of the client's program - either the owner brings the programme to the start of design or the designer provides the services as part of the professional services – the consequent design deliverables are produced to meet contractual obligations against a planned release schedule.

To facilitate that, procedures have been established which divide the construction documents into stages. This segmentation establishes deliverables and a contractual framework. They impose an order on the process. When there are stages, the designer brings the documents to an interim level of development, the client reviews and approve it, and the project moves forward based on mutual understanding. However, in reality, the different phases have large overlapping areas during implementation (Ryd, 2004, p233). In addition, the shortcomings of this simplistic approach are widely recognized because the crucial events are the transfer of key items of information between disciplines and organizations, not the completion of sets of information outputs contained on contractual documents (Andrew et al., 1998, p149). Andrew et al. concluded that traditional planning techniques have proved unsatisfactory for this more complex approach because of the iterative nature of design and the complex interdependencies between design disciplines, particularly in complex buildings where large multidisciplinary design teams are required in addition to any factors that combine to make each project different.

Notwithstanding the above, individual designers approach design documentation in different ways and with different values and attitudes. However, there are very well widely established and standard procedures for developing the design documents. Abolnour (1994) stated that, in Saudi Arabia, each design office selects an international system that is compatible with their employees, the nature of the project and their clients.

The two most well-known procedures in Saudi construction for producing the contract documents are AIA and RIBA. This is owing to the lack of any comparable organization in Saudi Arabia providing a model of the project life cycle and design development, (at the beginning of 2004 there was a royal decree to establish the Saudi Council for Engineers). Instead, design offices adapt a recognized existing system, which is typically either the AIA or RIBA, depending on the background and experience of the management of design (based on unpublished data from newly established SCE, 70 - 95% of consultant office staff are foreigners or have graduated from international universities).

Sector	Saudi (Eng. / Arch)		Non-Saudi (Eng. / Arch)		Total No
	No	%	No	%	
Public sector	5,777	76%	1,856	24%	<b>7,633</b>
Private Sector	16,028	16%	83,052	84%	<b>99,080</b>
<b>Total</b>	<b>21805</b>	<b>20.4%</b>	<b>84908</b>	<b>79.6%</b>	<b>106,713</b>

**Table 1 : Percentage of Saudi and Non-Saudi engineers/architects**

The second factor influencing the adoption of the existing procedure emerged when the Saudi construction boom started in the late 1970s: most designs of mega projects were carried out by overseas offices because of the limited knowledge and experience of local offices in the newer types of construction (the first college of engineering opened in 1962). These led to the adaptation of the system used by these overseas offices. The third factor was that non-Saudis employed by governmental, semi-governmental Saudi agencies and leading design offices adopted the system of their country (mostly American and British) in the new initiated work procedures and these have been followed since then.

In order to understand the phases that are implemented in Saudi construction it is appropriate to conduct an exploratory research through a questionnaire (see the appendix). An initial telephone contact was established with each of the qualified design offices as listed by the Ministry of Municipal Affairs and Rural Area (MOMRA), and discussed earlier in Chapter Three (Section 3.8.4), and the purpose of the research was explained to the person in charge. Then 40 questionnaire forms were distributed by hand/post to those offices that agreed to participate. The response of the questionnaires was 90% (36 forms) owing to the procedure followed (direct contact with respondents). The properly filled forms presented information about 33 unique projects. These projects give a good picture owing to the varieties they are representing. Table 2 indicates the range from private client (57%) and governmental client (36%) and developer (7%), as the first two represent the majority within the Saudi construction industry. Table 3 indicates that the projects are procured in a traditional method (55%) where all document are completed before going to tendering, while 30% of the project represent the construction management procurement where documents are ready for packages only.

Type of Client	Number	%
Private	18	57%
Government	12	36%
Developer	3	7%
<b>Total</b>	<b>33</b>	<b>100%</b>

**Table 2 : Classification of type of clients in the questionnaire**

Procurement Type	Number	%
Construction Management	10	
Design and Build	5	
Traditional	18	
	<b>33</b>	

**Table 3 : Classification of type of procurements in the questionnaire**

The questionnaire was complemented with semi-structured interviews with a senior project manager / designer from 10 different offices which participated in the above questionnaire, following also the procedure set in the research method chapter. With this type of knowledge, we can compare the normal practice of developing the design documents in Saudi Arabia with those of the established one. This comparison will give an insight view for understanding the process, to see if the practice of Saudi construction imposes certain variables on the generation of errors while producing the construction documents.

Comparison of the AIA documents and RIBA plan of work (AIA, 1994, p9, document B163, part 2; Kelly et al., 1998), and the practice of Saudi consultant offices which has been elicited through questionnaires and semi-interviews reveal the following:

- **Pre-design phase**

This stage establishes the financial and time requirements, and the scope of the project for the benefit of the client. Inefficient preparation of the brief of the project greatly affects the building design as well as the risk of increased total cost (Ryd, 2004, p231). The RIBA plan of work inception and feasibility stages relates to this phase.

Whilst Saudi practice covers this work in the programming, it was found in the questionnaire that this does not become a feature as a separate identifiable phase in most contracts. This may be attributed to the fact that it is not included in the scope of

work of the designers. Most clients, because of auditing and financial requirements, do not request the proposal without a clear idea about real needs and the approximate budget of the project. However, experience shows that sometimes this stage is featured in by experienced clients to clarify and fine-tune their requirements.

However, even though this phase determines the nature and scope of the project in the early design stage, it is beyond the scope of the research since it is concerned mainly with collecting the requirements of the client in terms of quality, viability, space, and function (Kelly et al., 1998).

- **Site analysis phase**

This stage establishes the site-related limitations and requirements for the project, and the output includes the conceptual master plan

The RIBA plan of work considers this within the outline proposals phase. While Saudi practice cover this phase by the concept master plan phase, this phase enables the client to have a clear view of the layouts and dimensions of the project and the interrelationship between different elements of the project.

- **Schematic design phase**

This stage establishes the conceptual design, and scale and relationship among the elements of the project. The primary objective is to arrive at a clearly defined, feasible concept and to present it in a form that achieves client understanding and acceptance. The secondary objectives are to clarify the project programme, explore the most promising alternative design solutions, and provide a reasonable basis for analyzing the cost of the project.

Typical documentation at the end of this phase can include:

- a site plan, plans for each level, all elevations, key sections,
- an outline specification
- The design area and other characteristics in comparison to the program
- a preliminary construction cost estimate,
- other services, e.g. illustrative materials, renderings, models, economic studies, life cycle cost analysis....

The scheme design phase of RIBA has a similar output. Saudi practice covers this phase with the preliminary conceptual plan stage.

- **Design development phase**

During design development, the design team works out a clear, coordinated description of all aspects of the design. This typically includes fully developed floor plans, sections, exterior elevations, and, for particular areas or aspects of the building, interior elevations, reflected ceiling plans, wall sections, and key details. Often these become the basis for the construction documents to follow. The basic mechanical, electrical, plumbing, and fire protection systems are accurately defined if not fully drawn. No major issues that could cause significant restudy during the construction contract documents phase should be left unresolved. The design development phase usually ends with formal presentation to, and approval by, the client.

The design development, as stated by the AIA document, may be a substantial undertaking, or it may be a much briefer transition from schematic design to construction documents. Some owners require extensive schematic design services, with much of the project developed by the time this phase ends.

The design development for some clients may be used to secure construction cost commitments before the design is fully developed – thus reducing or even eliminating the design development phase. In the RIBA plan of work, the detailed design phase covers the same output, while Saudi practice uses the same terminology to cover the output of this phase.

- **Contract documents phase**

The previous stages deal mainly with design development and approval, but this stage sets forth the requirements for the construction of the project and assists the owner in preparing the necessary bidding and contractual information for construction. Decisions on design details, materials, products, finishes, and the many fine points of bidding and construction contracts all serve to reinforce the design and begin the process of translating it into reality.

While in the RIBA plan of work, production information and bills of quantities cover the same output of the last two stages with variable types of detail, Saudi practice covers this phase with the contract documents phase as outlined in AIA practice. The preliminary investigation found that, in some situations, Saudi consultants used two



stages to get the output of this phase. These two stages were the final design stage (which includes all types of drawings) and the construction documents stage (which includes contract, specifications, bills of quantities and any other required documents).

The early phases are aimed at connecting a customer with a project, giving the work the character of a sale. The customer is buying a complex service that first defines an object to match his needs and then provide the action needed to create this object via a production process (Ryd 2004, p233). During the elaborating progress stages, the design itself achieves the refinement and coordination necessary for polished documents. The decisions made in the early stages of design are worked out on a scale that minimizes the possibility of major modifications during the later phases. Construction documents are complex and intricately interrelated; changes in those documents are costly and more likely to lead to coordination problems during construction.

While AIA and RIBA documents call for the sequential performance of these phases as it has listed above for normal work, it does not object to the overlapping for the fast track project; "...the architect shall provide the services designated in an overlapping manner rather than in the normal chronological sequence in order to expedite the owner's early occupancy of all or a portion of the project" (AIA, 1994, p9).

However, the above plan of work is used in fairly large, complex to mega projects only. In other types of projects (less than SR 100 million), it was noted by the respondents that the content and level of contract documents of the above projects that the call is for three phases only: preliminary, design development, and final design phase respectively. The designer will suggest all issues related to finishes and selection of material in the design development stage, and the client will approve it before commencing the final design documents.

The practice for small projects may differ from the above description. The contract stage is normally divided into two stages only: preliminary design and final design. The client has to take all decisions in the preliminary design before developing the final design documents. This division can be attributed to the system adapted by the municipality (the official body issuing building permits in Saudi) which requests that the document be submitted in two stages, i.e. preliminary and final design.

The response of the questionnaires and the semi-structured interviews with the person in charge in the selected offices indicate the awareness of the designer regarding the responsibility of error clauses in the contract.

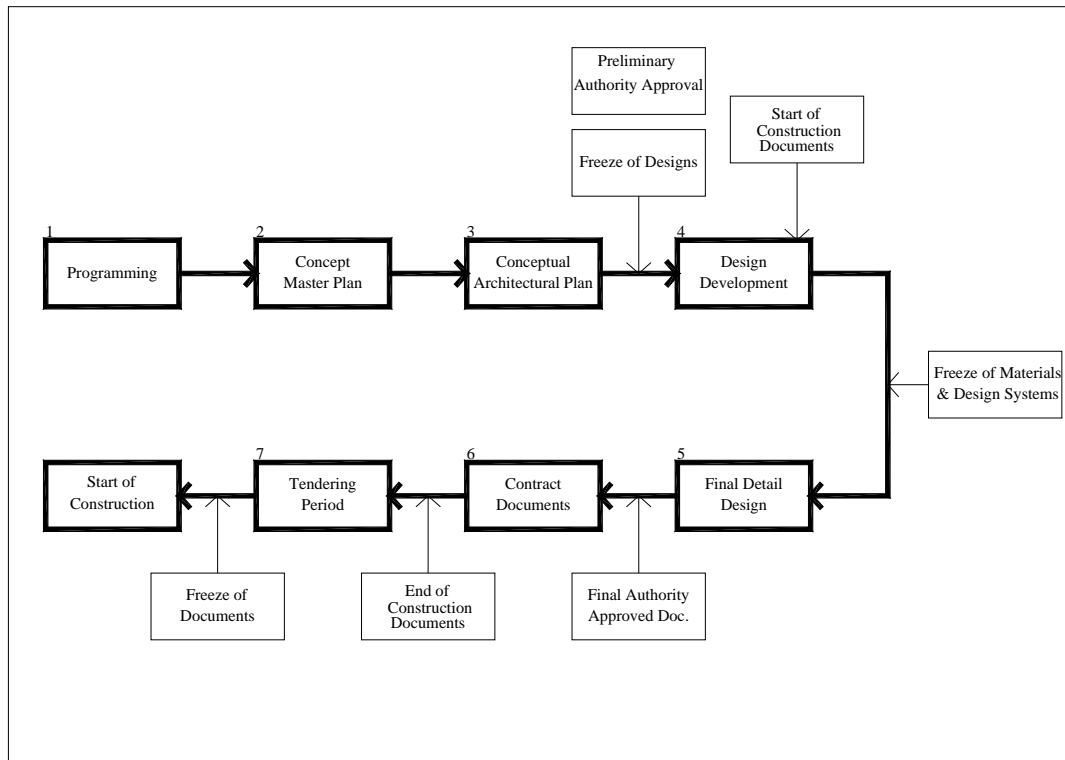
The above was also noted while reviewing the case study projects (which will be discussed later) that the consultancy services contract includes clauses, " ....that the approvals of any documents in any stages do not release the designers from the responsibility of errors". He has to fulfil all the requirements of the authorities and regulations in the construction documents. It states clearly that "...it is the designer's responsibility to correct all deficiencies in the construction documents related to such deficiencies". The last payment – which is about 10% of the value of the contract -, is not released to the designer until the tendering period is over and the contractor takes over the site.

The interviewees emphasized the role of procedures in the construction documents. They claimed that failure to follow a systematic procedure to produce the construction documents and obtain the necessary approval before commencing to the next stage will create problems between the client and designer. However, one senior project manager raised the argument that waiting for such official approval from the client side will delay contract completion and lead to failure in meeting the deadline of the next stage. Therefore, the practice of his office is to take the risk and start the next stage of work without obtaining such approval, in the hope that the client will approve the documents as they are or with minimal change.

The following table (Table-1) and Figure (Figure 2) summarise all stages of producing the construction documents relating to AIA, RIBA and Saudi practice. However, these comparisons raise the concern that the existence of well-developed procedures in the production of construction documents alone will not reduce the number of errors. Other factors will affect the quality of the documents as will be explored.

Common terminology (Saudi)	AIA	RIBA Plan of work	Task to be done	Notes
Briefing (Programming)	Pre Design Phase	<b>Inception</b>	Set up client organisation for briefing. Consider requirements, appoint architect	This stage is beyond the scope of the research as it deals with collecting and confirming data about the requirements of the client
		<b>Feasibility</b>	Carry out studies of user requirements, site conditions, planning, design, cost, etc, as necessary to reach decisions.	
Sketch plans (master plan, preliminary stage))	Site analysis	<b>Outline Proposals</b>	Develop the brief further. Carry out studies on user requirements, technical problems, planning, design and costs, as necessary to reach decisions.	
	Concept Schematic design phase	<b>Scheme design</b>	Final development of the brief, full design of the project by the architect, preliminary design by the engineers, preparation of cost plan and full explanatory report. Submission of proposals for all approvals.	
Working drawings (design development phase)	Design development phase	<b>Detail design</b>	Full design for every part and components of the building by collaboration of all concerned. Complete cost checking of design.	
(Contract Document Phase) In some cases Saudi practice uses two stages: final design and construction documents	Contract Document Phase	<b>Production information</b>	Preparation of final production information, i.e. drawings, schedules and specifications.	
		<b>Bills of quantities</b>	Preparation of bills of quantities and tender documentation	
		<b>Tender action</b>	Action as recommended in NJCC code of Procedure for Single Stage Selective Tendering	

Table 4 – Comparison of RIBA Plan of Work, AIA Phases and Saudi Practice



**Figure 2 : Process of producing the construction documents**

### **4.3 Research methodology used to collect data about errors**

The investigation of the literature concerning types of errors in the construction documents revealed a lack of data; Koskela (1992) stated that "...there is lack of data on internal wastes in design". Even when errors were mentioned, these were identified only as a list of items within the QA books (e.g. Stasiowski et al., 1994) and journals (Andi et al., 2003) without any further explanation of the nature of the errors or their cause.

In order to understand the spread of the errors in the Saudi construction it was appropriate to conduct exploratory research through a number of case studies, questionnaire and interviews. Such exploratory research helps to understand the nature of a problem in depth and produces fruitful results. Case studies encourage in-depth investigation within the research subject (Fellows and Liu, 1997). The questionnaire survey is one of the most cost-effective ways to involve a large number of people in the process in order to achieve better results, whereas face-to-face interviews serve as a crosscheck and, sometimes, unexpected information may be given during the interviews (Kothari, 1988). From the literature review, a list of errors has been identified based on the definition stated earlier in the previous chapter. This was followed by a pilot study of case study projects. Five projects were selected to study the type of errors occurring in the construction documents of Saudi construction projects. The projects were basically selected for practical reasons i.e. their availability (Tables 5 and 6), but within the parameters set in the research method section 3.8.2. The purpose of the pilot study was to understand the type and frequency of errors occurring in the Saudi construction industry. The quality assurance (QA) set of those selected projects were reviewed, as stated in the research method chapter, i.e. the availability of QA document for any selected case studies project. The reason was that the standard procedure to carry out the QA process (Stasiowski et al., 1994) is to mark the documents with comments of the reviewers, indicating their opinion about any item(s) represented on the document. These documents were then checked with the originator's designer and were marked in coordination with the QA manager, either to implement the changes or that they have been rejected. The accepted comments were marked clearly on the document to be changed. Those accepted comments on every document in the QA documents were listed and classified as per their types, occurrence and numbers.

Case Study No	Type of project reviewed	Time allowed for project (consultant view)	Availability of QA	Client experience (consultant view)	Clear client requirements (consultant view)	Availability of procedures	No of phases
1	Mosque / Resident	Good	Yes	Good	Good	Yes	4
2	Monumental	Good	Yes	Fair	Not clear	No	2
3	Site Work	Short	Yes	Good	Fair	Yes	3
4	Private Palace	Good	Yes	Fair	Fair	Yes	5
5	Office Building	Good	Yes	Fair	Good	Yes	5

**Table 5 : Background of the case study projects (general)**

Case Study No	Type of project reviewed	No of drawings (Size)	No of errors	Design fees (SR)	Construction cost (SR)	Stage of drawings
1	Mosque / Resident	91 (A1)	217	760,000	9,000,000	Final
2	Monumental	60(A0)	167	600,000	20,000,000	Final
3	Site Work	140 (A1)	146	1,500,000	33,000,000	Design development
4	Private Palace	210(A1)	192	2,000,000	45,000,000	Design development
5	Office Building	100 (A0)	183	375,000	16,000,000	Final

**Table 6: Case study projects (type, drawings, errors, fees)**

Then the compiled list of errors was distributed to 40 professionals in the questionnaires described above (Section 4.2) to investigate the occurrence of these types or to add to the list more of the types of errors which they are facing. In addition to the above information about the properly completed and returned forms, the following information indicates the representation of the sample of the projects in the Saudi construction industry.

The cost of these projects ranges from SR5,000,000 (US\$1,500,000) to SR1000,000,000 (US\$250,000,000). All these offices were multi disciplinary, where construction documents are done for all disciplines under one roof. Most of the construction documents referred to in this questionnaire were prepared for all disciplines (31 out of 33), while one project was for preparation of architecture construction documents only and the other one was for structure only. However, these projects represent diverse types of project, as shown in tables 2, 3 and 7. Then the final list was checked with supplementary interviews (10 interviews).

<b>Type of Project</b>	<b>Number</b>	<b>%</b>
Interior design project	2	6%
Monumental work	1	3%
Military	1	3%
Residential	7	21%
Site work	1	3%
Religious project	3	9%
Shopping	4	12%
Office building	7	21%
Multi use building (office/residential apartment)	3	9%
Multi use building(office/retail)	4	12%
<b>Total No. Of projects</b>	<b>33</b>	<b>100%</b>

**Table 7 : Types of projects in the questionnaire**

#### 4.4 Types of errors in construction documents of the Saudi construction industry

It was indicated in the previous section that defining errors should be the starting point for the investigation. For these reasons, it was necessary to identify types of errors in the construction documents as an important element to complete the process. Once an error has been identified it is possible to take action to address it.

The literature, in conjunction with the pilot case study projects and questionnaires, has identified the following types of errors which typically occur in the construction documents:

Type of errors in the construction documents	Literature	Pilot Case Study	Questionnaire
Document does not conform to client's design criteria	✓		✓
Document does not conform to code	✓	✓	✓
Document does not conform to design calculations		✓	✓
Document does not conform to vendor data	✓		✓
Document does not confirm with building regulations	✓	✓	✓
Document does not conform with the law (such as documents must specify Saudi products)			✓
Discipline coordination problems (within the same discipline)		✓	✓
Coordination problem (between disciplines)	✓	✓	✓
Operability problem	✓	✓	✓
Constructability problem	✓	✓	✓
Document does not conform to drafting standards	✓	✓	✓
CADD (Computer ) related problem	✓	✓	✓
Dimensional error	✓	✓	✓
Errors in symbols and abbreviations		✓	✓
Callouts of the details are incorrect or missing	✓	✓	✓
Missing or incorrect notes on the drawings	✓	✓	✓
Additional views / details needed	✓	✓	✓
Errors in capital cost estimating errors			✓
Designer error	✓	✓	✓
Error in project contextual factors, (not compatible with survey or roads)	✓	✓	✓
Errors and omission in the bills of quantities	✓	✓	✓
Errors in specifications	✓	✓	✓
Biddability	✓		✓

**Table 8 : Comparison between types of error found in literature, pilot study projects and questionnaire**



#### **4.4.1 Document does not conform to client's design criteria**

The projects inevitably begin with a statement of what the project needs to do, i.e. the project goals, the activities to be accommodated, and any special requirements or considerations that will guide the design and development of the construction documents. The client normally sets the scope, quality, and budget. The prospective project is defined at least sufficiently well to understand what it is being undertaken, what facilities and amenities are required, when the project is needed, and how much it is likely to cost (AIA, 1994, p377). By research definition, if the construction documents fail to address such requirements or constraints set up by the client in the brief, this will be considered as an error and we have to seek the reasons of such error. As some studies (Kirby, 1983; Morgren, 1986) have identified, the user requested changes as a major cause of contract modifications. Similarly Love (Love, et al.,, 1999) found that errors in the design stages of the project are the result of the lack of understanding and incorrect interpretation of customer requirements. The questionnaire results indicated that this error represents 3% of the total number of errors in the projects surveyed in Saudi construction.

As defined in the construction documents in chapter 2, this is a violation of the purpose of the construction documents. Contractually, the designer has to develop a design solution based on the approved project requirements and constraints. The client has the right to pursue the designer to correct the error if it has been proved that the construction documents failed to address the requirement of the client brief.

Failure to address the requirement(s) of the client at the early stages of the documents' development process will raise the cost of change at a later stage, as discussed in chapter 1.

The impact of this type of errors is enormous to the client, as the project does not satisfy his full requirements and this might raise the cost of the project owing to variation change and delay of the delivery of the project on time for the designer, as it might raise a legal case against him and he must bear the cost of revising the construction documents.

#### **4.4.2 Document does not conform to code**

The primary regulatory instrument for the design of buildings and structures is the building code, as it provides fundamental design parameters for a large number of design and construction details (AIA, 1994-p663). Compliance with the building code generally is a duty that cannot be delegated, and code violations in construction

documents may be considered evidence of negligence on the designer's part. Often, it is not sufficient that the designer has complied with the local custom or practice if such conformity starts. Failure to conform with the code at the beginning of the project will result in design change later and will delay the project. The questionnaire results indicated that this error represents 3% of the total errors occurring in the surveyed projects in Saudi construction.

This type of error might be discovered during the authority approval of the document; if it is not, then the final check up of the project after construction will discover it. If it is not discovered until the occupation of the project, violation of building codes can cause injury to building users and expose the designer to legal liability and possible revocation of their licences (AIA, 1994, p377).

If it is discovered during the construction stage then the delay and cost of change could be enormous for the client, who may pursue the designer to pay the damages.

The seriousness of this type of errors is that neither an owner's requirement to disobey the code nor the unknowing or unreasonable approval by a building official of a non-compliant project relieves the designer of this duty.

#### **4.4.3 Document does not conform to calculations**

Every discipline is based on some standards which are used to calculate different needs and requirements. Failure to conform to these calculations will result in violation of the codes, and failure of the system used for that discipline.

Many clients in Saudi construction request the calculation to be part of the construction documents, so they can check the assumption of the designer for the proposed system. The main cause of this type of error is usually a lack of experience from the designer, or carelessness or pressure of time. The questionnaire results indicated that this error occurred in 3% of the projects in Saudi construction.

This type of error is not easy to discover during the process of producing the construction documents. It might be discovered if it is an obvious error, or the designs do not make sense. If the error is discovered during the construction stage it will raise the contractor's change variation orders and he will claim for an extension of time and compensation for the extra costs. The client will pursue the designer at his / her own expense to correct the error.

#### **4.4.4 Document does not conform to vendor data**

This type of error was a factor in the development of many strategies in the construction industry, such as Partnering, Concurrent engineering, etc., as discussed in chapter 2, where supplier(s) participate in the process of developing the construction documents. Dissanayaka and Kumaraswamy (Dissanayaka et al., 1997, p157-167) found the lack of involvement of key subcontractors in the partnering process had a negative impact on project performance. In Saudi, the questionnaire results indicated that this error represents 4% of the total number of errors.

Every vendor has his own equipment, specification, material and requirements for his product to work properly or to get the best performance. The errors may lie in the incompatibility of equipment, out-of-date specification, and inappropriate materials.

This type of errors could delay the project and increase its cost as a result of the raising of change variation orders.

The client has to approve vendors at the early stages of the design. The early involvement of the vendors in the process of the construction documents can help the designer to minimize such errors.

#### **4.4.5 Document does not conform to the law**

This type of error was discovered as a result of the questionnaire indicated earlier, and represents about 2% of the total number of errors occurring in projects. They are those which do not conform to the law used for certain types of project and clients. E.g. the law has stated in Saudi Arabia (and many other countries) that any government project should specify local materials and supplier (if available). Such errors, when discovered during the construction stages, will cause a delay in the project and may raise costs to the client as a result of the increase in price of the local materials..

#### **4.4.6 Document does not conform with building regulations**

All projects are governed by many regulations and design parameters. Communities establish rules for development to protect public welfare and conserve environmental resources. Building regulations create important disciplines for the designer. It is imperative that designers comply with regulations unless they obtain variances or specific ruling allowing alternative solutions (AIA, 1994, p653). Regulations include: Zoning requirements, Planning regulations, and Environmental regulations.

In Australia, Walker (Walker, 1994) found that the most pernicious cases of lost time and cost resulted from amendments to design documents arising from design errors

and incompatibilities in design details with building regulations. NEDO (NEDO, 1988, p76-77) has identified incompatibilities in design and design details with building regulations as a source of errors in construction documents, while Saudi construction indicated that about 2% out of the total errors are under this category.

The occurrence of this class of error could lead to delays in project, until the requested approvals are obtained, and may raise the cost following the change order raised during the construction stage.

#### **4.4.7 Discipline coordination problems**

NEDO (1987, p3) states that “ The design process is difficult enough to control when there are several disciplines to bring together, each of which can affect the performance of others. Nigro (1984) reported that more than half of the errors and omissions in construction drawings and specifications are caused by poor coordination between design disciplines, while Saudi construction indicated 6% of the errors in the construction documents fall into this category. This low percentage may be caused by many types of errors that have been identified in this research, compared with the Nigro study, in addition to the fact that coordination errors have been divided into two types of errors: discipline coordination problems and interdisciplinary coordination problems.

Poor design coordination may result from inadequate attention being given to detailed design or it may follow from a general atmosphere of haste surrounding fast-tracked projects. While overlap of design and construction can save time for the client, it may cause delays during the construction phase from problems associated with design coordination and design detailing.

This type of error is discovered mostly during the review process of the quality assurance of the documents. Under the traditional procurements, if errors are discovered during the construction stage, this will give the contractor rights for claiming extension of time and/or compensation for extra cost for correction of the drawings.

During the tendering stage, if the number of this type of error is high in the documents, it will raise many queries during the tender stage and create a bad impression of the designer.

#### **4.4.8 Interdisciplinary coordination problem**

These types of errors were not discussed in the literature but they were revealed in the pilot study as well in the questionnaire. 8% of the errors in Saudi construction documents referred to this type of error which occur within one discipline e.g. the coordination problem between plans, elevations, sections and the detail drawings, between the calculations and the drawings, or between the drawings and the specifications. This finding was supported to some degree by the implementation of a general interdisciplinary coordination review system which has reduced construction costs on projects by as much as 7%, by reducing the number of change orders (Nigro, 1987).

As the number of errors increases in the documents, many queries will be raised during the tender stage and create a bad impression of the designer.

If this type of error is not discovered during the construction documents process then it will raise problems later in the construction stage and raise claims for extension of time and sometimes compensation of extra costs.

#### **4.4.9 Operability problem**

Operability refers to the ease with which a facility can be operated and maintained (Kirby et al., 1988). This is considered an error since it defeats the purpose of the construction document as stated in the construction documents definition, where the decisions taken and shown in the construction documents affect the client satisfaction (quality) and increase the maintenance cost during the occupancy of the project. The seriousness of this error lies in the difficulty of seeing the errors in the construction document, as these will only be discovered by experienced personnel. This type of error can be attributed to the error of the designer, owing to a lack of knowledge or experience. The questionnaire results indicated that 5% of the errors fall into this category. The occurrence of this type of error is serious because it is normally discovered during the utilization of the project and not during the process of producing the construction documents. Also, this error often plagues the project for many years after the design team has completed its work. The long-term effect can be devastating to a design firm reputation. The user(s) of the project either has / have to live with the error or pay for the expensive cost of replacement.

#### **4.4.10 Constructability problem**

This is considered an error since it defeats the purpose of the construction document as stated in the construction documents definition.

Constructability is a concept similar to buildability, and both terms were used interchangeably (Patrick et al., 2006; Hon et al., 1988/89). However, constructability is defined (Kirby et al., 1988) as the compatibility of the design with the site, materials, methods, techniques, schedules, and construction. Moreover; constructability is commonly known as the optimum use of construction knowledge and experience in different project stages to achieve overall project objectives (CII, 1986; CII Australia, 1996a; Arditi et al., 2002)

The seriousness of this error lies – as operability - in the difficulty of seeing the errors in the construction document and as they will only be discovered by experienced personal. This type of error can be attributed to the error of the designer, owing to the lack of knowledge or experience. Andi (Andi et al., 2003) found that the designers acknowledged that ‘lack of construction knowledge’ had been a major problem for them, bringing impractical design.

This type of error was a factor in the development of many strategies in the construction industry, such as partnering, concurrent engineering, etc., as discussed in chapter 2, where contractor(s) participate in the process of developing the construction documents. This problem includes those designs which are difficult for the contractor to bid for or construct, specification for equipment which has not been manufactured for years, and construction sequencing that cannot be done without disrupting ongoing operations. These problems are often caused by insufficient time allowed for in design. Together with a lack of understanding of building construction on the part of designers (Fox et al., 2002), constructability has not received adequate attention, leading to wastage and reworks (Patrick et al., 2006).

The questionnaire results indicated that 5% of errors in Saudi construction documents fall into this category.

If this type of error is discovered during the construction stage it will often turn into costly change orders. This may influence the budget of the project or cause delay in the project completion date.

#### **4.4.11 Document does not conform to drafting standards**

To facilitate the production of construction documents, to build consistency between drawings and from project to project, and to make it easy for other people to read and

understand the drawings, most offices probably employ documentation standards (AIA, 1994). These standards may address the subject as:

- Drawing sheet sizes, layout, scale, sequence, numbering
- Line thickness, and lettering sizes
- References within the documents
- Notes, abbreviations
- Dimensioning

The questionnaire results indicated that this error occurred in 4% out of the total number of errors in the construction documents of the projects in Saudi construction. Errors in these standards will confuse contractors and lead to misunderstanding while pricing the project, as Andi (Andi et al., 2003) defined clarity as one of the attributes of documentation quality.

This type of error creates a bad impression of the designer. Client or contractors may avoid working with such designers.

#### **4.4.12 CADD –related problem**

This type of error represents 5% of the total numbers of errors in Saudi construction documents and relates to the capability of Computer Aided Design and Drafting (CADD) software used, and setup of the CADD standards and procedures. They are related mainly to coordination problems between files, un-updated background files of other disciplines, which will create errors in the construction documents.

The CADD problem increases as the project complexity increases with the reality that more people and even firms will work simultaneously on the same project.

Organisations such as AIA (AIA-1994) have recognized the importance of CADD in the process of producing the construction documents, and have set up procedures for CADD implementation and usage. Following such procedures will have an influence on the productivity of the designer and minimize this type of error.

This type of error may influence the duration of the project and raise claims from the contractor(s) as more time might be needed to resolve problems and update drawings or preparations of the shop drawings.

#### **4.4.13 Dimensional error**

Dimensioning requires an understanding of the sequence of construction, for new assemblies can only be located relative to assemblies already in place. The

questionnaire results indicated that this error occurred in 4% out of the total number of errors in the projects of Saudi construction.

Necessary dimensioning should be numerically indicated on the drawings. The contractor is not entitled to rely on scaling the drawings for dimensioning; the drawings should contain the minimum dimensioning consistent with this concept.

Most dimensional errors found in the case studies refer to errors which could be easily prevented if the proper guidelines for dimensioning are followed; these errors include the following: the dimensions do not add up, conflict of dimension between drawings, details, and schedules.

There have been reorganization and attempts to minimize this type of error in the procedures adapted for documents production. One should refer for example to AIA dimensioning guidelines (AIA, 1994, p713) for the set of standards for dimensioning drawings:

This type of error might affect the duration of the project as the contractor has to wait for clarification from the designer about conflicting or missing dimensions.

#### **4.4.14 Symbol and abbreviation errors**

These errors were not discussed in the literature but they were found in the pilot study and the questionnaires, which represent 3% of the total number of errors occurring in Saudi construction documents. The need to communicate a great deal of information in a limited space commonly dictates the use of many symbols and abbreviations. Good practice suggests that these be defined early in the documents and used consistently (AIA, 1994). Designations on the drawings should be consistent and be coordinated with those used in the other parts of the construction documents, such as schedule, specifications etc.

This type of error will lead to misunderstanding and confusion about the documents which might lead to requests for extension of time resulting from time wasted while waiting for a response from the designer.

#### **4.4.15 Callouts incorrect or missing**

The callouts describe different aspects in the drawings or details, either wrong or missed or do not describe clearly what is meant by the callout.

The common error within this category is the "vague statement"; for example, Thermal insulation, Natural stone; such statements do not describe the type, size, or method of fixing. These errors represent 8% of the total number of errors in Saudi



construction. They have an impact on the understanding of the project and interpretation of the documents for the purpose of pricing and construction. It might lead to a change in variation orders as the contractor might price for item as per his understanding, not per what is meant by the designer or required for the project.

#### **4.4.16 Incorrect or missing notes**

The notes are the text on the drawings which convey the intent clearly, describe the contents or set up the conditions for the applicability of the design in the drawings (AIA, 1994).

The construction project information committee (CPIC 2003) recognized that written information on drawings is often the cause of poor coordination because when making revisions it can be difficult to ensure that all affected drawings are changed. Annotation should therefore be put on drawings only for good reason, and if there is not a good reason it should not be given. The questionnaire results indicated that this error represents 6% of the total number of errors in the projects of Saudi construction. This category of error includes the following: the note is not applicable to the drawings or details, describes wrongly what it is meant to be, or an additional note is needed to make the drawings clear and understandable.

This type of error might raise claims for extension of time if notes are missing or the content is vague. It might also raise requests for time extension and cost compensation in the case when the note is incorrect.

#### **4.4.17 Additional views / details needed**

has Additional views / details needed have been identified by Stasiowski (Stasiowski et al., 1994) as the third category of non-conformance in the shop drawings. The documents as they are do not transfer the information clearly to the contractors for construction purposes. The documents need more detail to be clear and understandable because of the ambiguities in the current situation of the documents. The questionnaire indicated that this error represents 9% of the total number of errors in the projects in Saudi construction.

This type of errors might raise many queries during the tender stage or claims for extension of time during the construction stage if detail(s) are missing or the design is not clear.

#### **4.4.18 Errors in capital cost estimating**

The consultants are providing cost estimates as part of some contracts to the client, based on the available documentation. Therefore, if this service provided and found to be wrong after the bidding process, it will be considered an error as per the definition stated at the beginning of the chapter. Most important decisions of the client are based on this estimate. Therefore, it will be considered a serious error that defeats the purpose of the construction documents.

This error was discovered during the questionnaire, as indicated earlier, and it represents 4% of the total number of errors in the Saudi construction documents. Many companies realize that budget overruns are not necessarily the result of bad project control/cost control work, but are rather the result of bad capital cost estimating and budgeting work. Evidently many unfortunate budget and control estimates could have been drastically improved if some simple and well-known facts had been implemented (Sigurdson, 1996).

This type of error will normally be discovered during the tendering stage, when the bidders submit their offer to execute the work. The designer may have to do the exercise of reducing the cost of the project or revise the documents to stay within the client budget if he had signed a contract of guaranteed maximum cost. In this case the error will delay the start up of the execution of the project.

The error is serious in some situations as it might lead to the cancellation of the project, if the estimate is beyond the capacity of the client.

#### **4.4.19 Designer errors**

Nikkie (Nikkie Construction, 2001) reported some examples of designer errors. However, some studies (Kirby, 1983; Morgren, 1986) found that 56% of all contract modifications are made to correct design deficiencies. The questionnaire results indicated that this error represents 6% of the total number of errors in the projects of Saudi construction. This low percentage of Saudi construction could be attributed again to the spread and varieties of types of errors identified in this research.

These types of errors are the most serious as they are related to the pure mistakes of the designer owing to the lack of education, knowledge or experience. They include missing item(s) and missing consideration of some important item(s) in the design. These errors may cause the failure of the documents to deliver the purpose of the project.

In one case study project, the failure of the designer to consider the appropriate height of the mezzanine floor resulted in discarding the use of that floor as rentable space, and it was used as a storage area only.

This type of error leads to a rise of claims for time extension and compensation of costs as a result of the extra time required to correct the errors and revise the documents accordingly.

#### **4.4.20 Error in project contextual factors**

Some studies (Kirby, 1983; Morgren, 1986) have identified unknown site conditions as one of the major causes of contract modifications. The questionnaire results indicated that this error represents 3% of the total number of errors in the projects of Saudi construction.

As standard procedure, there is always a geotechnical survey and site visit before starting the design of the project, but it has been found that some errors occur in the construction documents which ignore some important factors which are critical in the design of the project, such as soil characteristics, site contours, and the access to the site.

Arics (Arics, 1987) found that contextual differences, such as limited working areas or weather have been found to influence construction costs significantly.

This type of error is mainly the result of missing or misleading information regarding the project site. It will lead to delay of the start up of the project and compensation for the contractor to correct the documents as per the site condition(s) and requirements.

#### **4.4.21 Errors and omission in the bills of quantities**

Researchers identified errors and omissions in the bills of quantities as a main source of variations in the construction projects (Choy and Sidwell,1991).

The practice of pricing the project in most contract procurements is dependant on the bills of quantities. However, the influence of this type of errors on the project depends on the procurement of the contract selected for the execution of the project. The questionnaire results indicated that this error represents 5% of the total number of errors in the projects of Saudi construction.

When the contract is based on a lump sum price, this type of error may raise many queries during the tendering stage and will create a poor impression of the designer. During the construction stage, when an item in the bills contradicts other documents, it might lead to a claim for cost compensation and a request for time extension.

The main types of errors found under this heading were:

- descriptions of items are wrong
- the item is missing in the bills of quantities
- the measurement is wrong
- the item is included in the bills but not shown in the drawings
- the unit of measurement is wrong

#### **4.4.22 Errors in Specification**

The specifications present written requirements for materials, equipment, and construction system as well as standards for products, workmanship, and the construction services required to produce the work (AIA, 1994). The questionnaire results indicated that this error represents 4% of the total number of errors in the projects in Saudi construction.

Errors include missing items in the specification, items included in the drawings but not in the specification or vice versa, items do not conform to client / discipline criteria, the list of applicable applications incorrect, or inconsistency with industry practice.

These types of errors when discovered during the construction stage will raise claims for either cost or time extension or both.

#### **4.4.23 Biddability**

Biddability pertains to the ease with which the contract documents can be understood, bid, administered, and enforced (Kirby, et al., 1988).

Errors in this type include insufficient and inaccuracy of details, design errors, omissions and ambiguities, ambiguity, complexity, and incompleteness of contract documents.

The questionnaire results indicated that this error represents 1% of the total number of errors in the projects in Saudi construction. This type of error leads to requests for extension of time during the bidding time as well as an increase in the value of the contract owing to the fear of contractor about the hidden risks in the construction documents.

#### 4.5 Error classification

It will be beneficial to classify all these errors under a smaller number of categories to understand which category has the greatest proportion in Saudi construction documents.

The benefit of these classifications can be summarized in the following reasons (McMahon et al., 1997):

- The classification can be used to record the incidence of observed causes of error and consequently to identify where there is most scope for improvement in the process.
- By prompting for further investigation, knowledge of where an error has taken place leads to exploration of why it has taken place, and subsequent resolution of underlying constraints in the process.
- The classification can indicate the likelihood of error occurrence and provide some professional guidance in the avoidance of errors (Brown C. B. et al., 1988).

By reviewing all the above identified types of errors we can classify them into the following categories:

Another group of errors can be combined under erroneous actions

- Errors in capital cost estimating errors
- Designer error
- Errors in project contextual factors, (not compatible with survey or roads)
- Errors and omissions in the bills of quantities
- Errors in specifications

The sum of percentage of these errors will build up 23% of the total number of errors occurring in the construction documents in Saudi Arabia. This category is ranked as number one, and most types of errors in Saudi construction fall into this category.

The errors which can be grouped under the omissions category are:

- Callouts of the details are incorrect or missing
- Missing or incorrect notes on the drawings
- Additional views / details needed

The sum of these errors will add up to 22.4% of the total number of errors occurring in the construction documents and will form the second highest category.

The failure to conform to design parameters, which consist of the following errors:

- Construction documents do not conform to the client's design criteria
- Construction documents do not conform to code
- Construction documents do not conform to design calculations
- Construction documents do not conform to vendor data (elevators, equipment,...)
- Construction documents do not conform to the municipal regulations
- Construction documents do not conform with the law (for example, documents must specify Saudi products)

By summing the percentage of these errors we found that 17% of errors will fall into this category.

The errors which can be grouped under failure to follow procedures are:

- Do not conform to drafting standards
- CADD (computer ) related problem
- Dimensional errors
- Errors in symbols and abbreviations

The sum of these errors will account for 15.2% of the total number of errors occurring in the construction documents.

The other category is related to coordination problems

- Discipline coordination problems (within the same discipline)
- Coordination problems (between disciplines)

The summing of both coordination types of errors will give 13.3% of errors that fall into this category.

Difficulty of bidding (1.2%), failure to address operability (4.7%) and constructability issues (4.3%) are the remaining categories.

The above classification was an improvement from those suggested by Reason (Reason, 1990). He classified errors into three types: skill-based errors (slips and laps), rule-based errors and knowledge-based errors; later (Reason (1998) he added a fourth class of errors: violation. The main reason for preference was that some types of errors can be classified under more than one category; for example, coordination problems which can be categorized under skill-based errors and rule-based errors.

The following table summarises the errors / classification occurring in the Saudi construction documents and their relative ranking:

Classification	Type of errors in the construction documents	Influence on project	% Error	% Error classification
Erroneous	Designer error	Time, cost	6	23
	Errors and omission in the bills of quantities	Time	5.4	
	Errors in capital cost estimating errors	Time, cost	4.4	
	Errors in specifications	Time, cost	4.3	
	Error in project contextual factors, (not compatible with survey or roads)	Time, cost	2.9	
Omission	Additional views / details needed	Time	8.8	22.4
	Callouts of the details are incorrect or missing	Time, cost	7.7	
	Missing or Incorrect notes on the drawings	Time, cost	5.9	
Conformance	Does not conform to vendor data (elevators, equipments,...)	Time, cost	3.8	17
	Does not conform to design calculations	Time, cost	3	
	Does not conform to client's design criteria	Time, cost	2.9	
	Does not conform to code	Time, cost	2.5	
	Does not conform to the municipal regulations	Time, cost	2	
	Does not conform with the law (such as documents must specify Saudi products)	Time, cost	1.8	
Process	CADD (Computer ) related problems	Time	5	15.2
	Does not conform to drafting standards	Time	3.8	
	Dimensional errors	Time	3.7	
	Errors in symbols and abbreviations	Time	2.7	
Coordination	Coordination problem (between discipline)	Time	7.6	13.3
	Discipline coordination problems (within the same discipline)	Time, cost	5.7	
	Operability problem	Time, cost	4.7	4.7
	Constructability problem	Time, cost	4.3	4.3
	Biddability	Time, cost	1.2	1.2

Table 9 : Types of errors and classification in Saudi construction documents



#### **4.6 Conclusions:**

We have seen that the procedures for producing the construction documents in the Saudi construction industry are similar to those detailed in AIA and RIBA, with some adaptation owing to the nature of the office personnel and approval procedures.

To minimize errors, one first has to identify them, since once an error has been identified it is possible to take action to address it. In this chapter we have characterised the type and number of errors generated in project documentation in the Saudi construction industry. The errors in construction documents can be classified as follows: most serious first, the erroneous action as the highest followed by omissions, failure to conform to design parameters, failure to follow procedures, coordination problems, failure to address operability and constructability issues and at the bottom is the difficulty of biddability. We have seen that the effects of these errors on the construction documents, and later during the construction stage, differ depending on the severity of the error and the stage of work when the error(s) was discovered. The sources of errors differ from project to project.

Up to now we have determined the types of errors occurring in the construction documents – the effect; the next stage is to explore the factors – cause - that influence the generation of errors in the construction documents.

5.1	Introduction.....	136
5.2	Causes of errors.....	136
5.3	The approach to identify factors and develop the causality relationship...	137
5.4	Classification of factors influencing occurrence of errors in construction documents .....	148
5.5	Factors influencing the occurrence of errors in the pre-contract-stage.....	151
5.5.1	Management.....	151
5.5.1.1	Management organizational structure.....	153
5.5.1.2	Project manager experience .....	156
5.5.1.3	Project brief.....	157
5.5.1.4	Changes to key project personnel .....	161
5.5.1.5	Group organization .....	162
5.5.2	Designer .....	165
5.5.2.1	Design process .....	165
5.5.2.2	Design Management Experience .....	167
5.5.2.3	Designer professional education .....	168
5.5.2.4	Designer experience.....	169
5.5.2.5	Design fees.....	169
5.5.2.6	Design team efficiencies.....	171
5.5.2.7	Design time .....	172
5.5.2.8	Procedure for producing documents .....	174
5.5.2.9	Designer salary.....	175
5.5.2.10	Number of Designers .....	176
5.5.2.11	Concurrent design activities.....	177
5.5.2.12	Amount of work with the Designer .....	178
5.5.2.13	Reputation of designer .....	179
5.5.2.14	Availability of quality management.....	180
5.5.2.15	Effective design team.....	182
5.5.2.16	Communication.....	184
5.5.2.17	Availability of information .....	186
5.5.2.18	Transfer of knowledge and experience between designers.....	188
5.5.3	Client.....	191
5.5.3.1	Type of client (private, government, developer) .....	192
5.5.3.2	Client experience .....	194
5.5.3.3	Construction constraint time (start or finish).....	196
5.5.3.4	Client Point of contact .....	198
5.5.3.5	Planning of the project.....	200
5.5.3.6	Identification of project risks;.....	203
5.5.3.7	Attitude of Client .....	205
5.5.4	Project Characters .....	208
5.5.4.1	Uniqueness of the project.....	208
5.5.4.2	Time schedule pressure.....	209
5.5.4.3	Project Budgeted cost .....	210
5.5.4.4	Procurement .....	211
5.5.4.5	Size.....	212
5.5.4.6	Quality.....	213
5.5.4.7	Compatibility with designer goals .....	214
5.5.4.8	Services provided.....	215
5.5.4.9	Authority Approval.....	217
5.6	Interaction between factors .....	221
5.7	Assessing the fitness of the causal diagrams .....	223
5.8	Conclusions:.....	224

## 5.1 Introduction

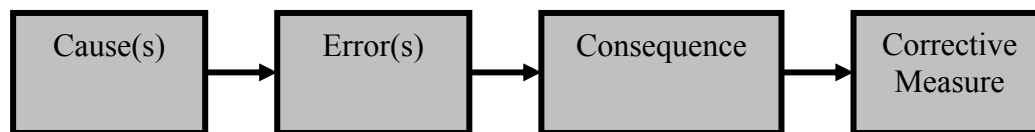
The previous chapter identified, classified and ranked the types of errors which are arising in the construction documents of the Saudi industry. This knowledge laid the foundations for understanding the local practice, and removed any ambiguity regarding the types of errors discussed within the scope of the current research. This process was an important part of the conceptualization and formulation stages of system dynamic modelling (Figure 4 in Chapter 3).

To understand why errors occur in the first place, the factors which cause and stimulate their occurrence have to be identified, as quality improvement methodology warns against taking shortcuts from symptom to solution without finding and removing the cause. To reduce errors effectively, it is important to understand the inherent factors and the mechanisms whereby errors occur. These factors are an important step toward completing the process of finding the relationships between errors and causes. The literature review, interviews and the case study projects will be examined to identify factors influencing the generation of errors in the construction documents. Each factor will be followed by a proposed causal diagram to describe how each factor is linked to the generation of errors in the construction documents. The diagrams identify the feedback structures of the system as a roadmap to solve the problem of the research. These diagrams are very important as they form the base for developing system dynamics model.

## 5.2 Causes of errors

Errors are likely to be repeated again in the future because little information and knowledge have been articulated to learn reasons that have led to the actual defects. To reduce errors in the construction documents effectively, it is important to understand the inherent factors and the mechanisms whereby errors occur (Andi et al., 2003a). Juran's quality improvement methodology warns against taking shortcuts from symptom to solution without finding and removing the cause (Stasiowski et al., 1994, p39). By this influencing, contributing factors can be identified and proactive actions can be taken. All defects, including causes, errors, consequence and corrective measures, can be considered as a chain of events, as per the following model (Figure 1). Cause is defined in this research as a proven reason for the existence of errors. Often there are several causes of the same erroneous action. There may be either combined causes or a chain of causes. For that reason, the term "root cause" is

sometimes used to describe the most basic reason for undesirable conditions. If the root cause is eliminated or corrected, this will prevent the re-occurrence of the errors (Dew, 1991, Wilson, et al., 1993). The direct causes of errors can primarily be attributed to individuals. However, every action by an individual is influenced by conditions, as will be discussed later in this chapter. Whittington et al. (1992) recorded that, for the accidents they studied, there were between 3 and 15 causes and an average of 7 per accident.



**Figure 1 : Error(s) and Cause(s) relationship**

Furthermore, Wood (Wood et al., 1994, p22) found: that errors are not some mysterious product of the fallibility or unpredictability of people; rather errors are a regular and predictable consequence of a variety of factors (Wood et al., 1994, p22). In some cases a great deal is understood about the factors involved, while in others very little is currently known. This premise is not only useful in improving a particular system, but also assists in defining general patterns that cut across particular circumstances. Finding these regularities requires examination of the contextual factors surrounding the specific behaviour that is judged faulty or erroneous. Wood (Wood et al., 1994, p22) concludes that erroneous actions and assessments are context conditioned.

### **5.3 The approach to identify factors and develop the causality relationship**

The system dynamics modeling approach adopted for this research was discussed in section (3.7.1). As part of the modelling formulation process, it is necessary to identify factors that will be used for the model. Therefore system dynamics principles will be used to map and identify the major variables that influence the incidence of error. This chapter is very important foundation works for developing the system dynamics model. It represent the hypotheses of the model, where the type of relationship that might exists were proposed – for further verification using system dynamic model - between different factors and the generation of errors in the construction documents. The formulation of causality relationship will be based on

drawing causal diagrams that explain how the factor is influencing the occurrence of errors in construction documents directly or through other intermediate factors.

Much of the literature (Walker, 1994; Burbridge, 1987, p16; NEDO, 1987, p3) has discussed the factors that stimulate the occurrence of errors in brief while discussing the quality of design work and documents in the construction industry without explaining the nature of relationship between these factors and the existence of errors in the documents. Based on these, the factors listed in this section have been extracted from the literature review, the review and the examination of the five case study projects discussed in chapter 4, and the detailed analysis of another new four case study projects, and interviews with 16 professionals working with these case study projects (Figure 2).

While the sample of nine projects and 16 interviews are not significant statistically, the literature, in conjunction with the case study projects and interviews, provided theoretical saturation for all the factors that cause the occurrence of errors in the construction documents, and informed a wide database for deriving the relationship between different variables that lead to the occurrence of errors, since each case describes its unique characteristics, as will be explained later in the brief of the project. The selection of limited unique case study projects was supported by many researchers (Eisenhardt, 1989; Yin, 1984; and Romano, 1989).

The following form a brief description of the additional case study projects:

**1- Case Study project 1 (Office tower):**

The project is a 16-storey office tower, with podium and parking building. The total area of the project is around 65,000m<sup>2</sup>. The client has a direct contract with the UK-based firm A to carry out the full construction documentation of the project. Because of its speciality, firm A has a separate contract with firm B. Firm A will do the architectural, landscape and interior design while firm B will carry out all the structural, mechanical, electrical and public health engineering documentations. The client has already an agreement with an international company to lease 50% of the tower for their headquarters in Saudi Arabia. This agreement imposes pressure on the design schedule and the quality of work required. Because of lack of knowledge in the local Saudi market and practice, firm A and firm B have sub-consultancy services

agreement with a reputable local Saudi company (the information about the case study was provided by this local company) to carry out the development of the documentation beyond the schematic stage. The client appointed a construction manager to supervise the work, as he was lacking knowledge in construction. The local firm has to coordinate all the work through the international firms (A and B). The local firm appointed a professional team of architects and engineers to finish the work. The first stage of work (design development stage) went ahead smoothly. The local firm contacted the local municipality to gain approval of the project. The approval of the first stage of work took a long time (4 months) as the municipality was reviewing/revising its regulation and zoning requirement. Because of this long period of stoppage, firms A and B and the local firm moved its staff to another project. When the approval was gained the firms were under pressure to finish the work but the teams had already lost enthusiasm in the project and new people had to work together to finish the remaining work. However, they managed to finish the work through many changes and crisis (see table of the details of the project).

Project area	17,000 m <sup>2</sup>
Project built up area	65,000 m <sup>2</sup>
No of firms involved	2 international firms (UK based) 1 Local Saudi firm
Project estimate cost	SR 180,000,000 (1US\$=SR3.75)
No of design team (Local firm)	Project Manager 1 Head of department - 7 Senior Architects/Engineers: Architect/ Engineers CADD operator
No of phases	3 stages (Schematic, detail design and production information) Schematic done by firms A+B while the remaining 2 stages were done by local firms and overviewed by the international firm / construction manager
No of disciplines provided	6 (Architectural / Structural / HVAC / Public Health / Electrical / Landscape ) Firm A was doing interior design
Total hours of work	17,790 hour
Duration of design	6 months (original)

	18 months (revised)
Persons interviewed	Project manager Senior architect Senior structural engineer Senior mechanical engineer

**Table 1 : Summary of case study project 1**

## 2- Case Study project 2

The project comprised designing four TV studios with associated spaces of control rooms, editing suits, workshops and broadcasting facilities, rentable office spaces, multipurpose hall, media training centre and business centre in Riyadh, Saudi Arabia. The total built-up area of the project is 32,600m<sup>2</sup>. The client approached the firm through recommendation of the client's representative, as he was admiring the work of the office. The project was priced with low fees as the firm was going through recession. The project was scheduled for an aggressive completion date. However, the client requested placing studios in the basement, which violated the current regulation of prohibiting building any habitant space under the ground, except for the parking space. The firm, through its reputation, has convinced the municipality to give special permission for the project. However, this process took a long time (three months) and the firm moved some of its staff to other projects. The consultant continued working on the project for the design development stage where he developed the documentation in full coordination and review with the client and his advisory team. The advisory team of the client comprised three professors from the university, one for project management and structural review, one for architectural design aspects and one for electro-mechanical. While the architectural and electrical designs were moving smoothly, the structural and mechanical designs were struggling to get approval. The structural system was debatable between the design and review team for layout and location of columns because of the long span and headroom height required for the design of studios. The interface of the interior designers in the late stages of the design work necessitates some changes in the architectural layouts which affect the remaining disciplines. While the electrical and public health designs were done smoothly because of the experience of the engineers working on the job, HVAC was struggling to get the approval from the review team, due to duct sizes and layout, and the selection of air handling units. What made the situation worse was the appointment of a studio specialist by the client to review the design. The specialist

highlighted serious errors in the HVAC design, as will be discussed later in Chapter 7.

Project area	6,750m <sup>2</sup>
Project built up area	32,000 m <sup>2</sup>
Project estimate cost	SR 87,000,000
No of design team	Project manager Senior architects/engineers: 19 Architects/ engineers : 22 CADD operator : 16
No of phases	3
Total hours of work	12,144 hours
Duration of design	8 months (excluding review and approval period)
Persons interviewed	Project manager Senior architect Senior structural engineer Senior mechanical engineer Senior public health Senior electrical engineer

**Table 2 : Summary of case study project 2**

### **3- Case Study project 3**

The design firm was approached by a governmental client, because of the reputation of the designer, to design a unique and landmark project that will be used as a community and culture centre in 15 neighbourhoods of the city. While the main components of the project will be typical, the site work will be changed to suit the available lot area and layout. The design firm initiated a scheme design based on a vague programme and budget set by the client. The designer created a unique and big tent structure that created a landmark for the project. The client was under the impression that the designer was working within the budget that he had agreed earlier. As a first stage, the client allocated two sites on which to build the project. Based on the approval of the scheme design, the designer developed the construction documents. Then 5 contractors were invited to submit their competitive bids for the project. The prices quoted were double the budget estimated by the designer. The client, after several attempts to secure funding from the government, requested some



radical changes in the design to reduce the construction cost of the project. The designer has to bear all the consequence costs of redesigning the project.

Project area	12,000m <sup>2</sup>
Project built up area	4,000 m <sup>2</sup>
Project estimate cost	SR 15,000,000 (original) SR 8,800,000 (revised)
Client	Governmental
Design team	Project manager Senior architects/engineers: 12 Architect/ engineers:17 CADD operator 12
No of phases	2
Total hours of work	4,565 hours
Duration of design	There was no time frame agreed with the client. However, it finished in 6 months as it was considered as a time filler by the design firm
Persons interviewed	Client representative Project manager Senior architect Senior structural engineer

**Table 3 : Summary of case study project 3**

#### **4- Case Study project 4**

The office was approached by a potentially important client to design a private villa that was designed for him by a famous architect. The office, as part of its marketing strategy, agreed a low fee with the client for developing the construction documents. There was no time frame or construction budget agreed with the client. As the workload was low in the office, the firm started working on the project, while the contact person with the client was on annual vacation. The project team started working on developing the documents based on the available information. Because of the low fees, the assigned team was less experienced personnel. The errors generated from this policy in the project will be discussed later in chapter 7.

The construction documents were almost complete when the contact person returned from his vacation; he requested a copy for a quality control review; he remembered that the client requested some functions that should be included in the construction documents. Included in this request was a major redesign in the architectural drawings which impacted on the remaining disciplines. The time and cost allocated for the project were overrun by almost double.

Project area	1,200 m <sup>2</sup>
Project built up area	Ground & first floor = 960 m <sup>2</sup> Basement 480m
Project estimate cost	SR 7,000,000
Client	Private
Design team	Project manager Senior architects/engineers: 3 Architect/ engineers: 8 CADD operator 14
No of phases	2 phases Design development and construction documents
Total hour of work	3,311 hours
Duration of design	There was no time frame agreed with the client.
Person interviewed	Project manager Senior architect

**Table 4 : Summary of case study project 4**

The analysis of the above projects and interviews with personnel listed under each case study project were important for understanding the occurrence of errors in the construction documents. Before commencing with any interview, the purpose of the research was explained to the individual interviewed. The unstructured interviews were held with senior project managers, designers and engineers to complement and corroborate initial observations with the findings of the literature review as they arose. Face-to-face interviews allowed the research to probe fully the meaning of questions and to add supporting contextual evidence. The unstructured format of these interviews provided an opportunity to make further observations qualitatively that would influence the subsequent deployment of the research (Figure 2).

The purposes of the above analysis were to:

- I. List the variables that are directly relevant to the errors occurrence in construction documents system.
- II. Link the variables listed above by using the casual diagramming convention discussed in Chapter 3. For each connection, the relationships were noted between the variable pair - either positive (same direction) or negative (opposite direction). Within the diagramming process and following the interview, some variables and links were added or dropped as revealed but within the problem statement.
- III. As the diagram evolves, each diagram was studied to locate the feedback "loop" structures that form. Identify and label each feedback loops as a reinforcing (R) or balancing (B) loop.

The concept of system dynamics modelling has been used to examine the effect that one variable has on another. To acknowledge, propose and capture all sources of the problems, causal diagrams have to be drawn (Andi et al., 2003). The causal diagrams simply depict a succession of causations so that all variables are both causal and affected variables. Essentially, this means that cause and effect relationships can be traced by following the direction of arrows, starting from any one variable, traversing the loop and coming back to the same variable.

To validate these causal diagrams (Figure 2), each diagram was demonstrated to a group of experts (Table 5) via a combined meeting, to do the following:

- Verify the existence of the link (EL). 0 there is no link, 1 there is link.
- Indicate the strength of the link (SL) weak, reasonable and strong link.  
1 for weak link, 2 for reasonable link and 3 for strong link.
- Verify the direction of the link (DL) + agree the direction and – disagree the direction.
- Indicate any missing link(s), using the above value.

The eleven individuals (Table 5) who attended the meeting were invited through a direct contact (28 experts with a minimum of a bachelor's degree and 10 years of experience in MOMRA's accredited design offices were approached, but because of their commitment only 11 agreed to participate in the meeting). **Again, while the number of experts involved in the validation was limited (not significant statistically),**

their professional education, the cumulative years of experience (205 years) and deep involvement in the production of construction documents represent an appropriate base for their engagement in the validation process of causal diagrams. The experts' group participation to elicit information was supported by many researchers in the field of system dynamics (Forrester, 1961; Vennix et al., 1992; Sterman, 2000).

The meeting began with a brief description about the research goal, the methodology adopted and the expected outcome of the meeting. Every participant was given all the diagrams prepared so far based on the literature, interviews and the case study projects. After explaining each diagram, the participants were asked to review the above factors for every link shown on the diagrams and suggest further factor(s) if deemed necessary to describe the causality relationship.

Then the Importance Factor (IF) was calculated for each link using the following formula:

$$IF = EL * SL$$

$$\sum IF = (IF_1 + IF_2 + IF_3 + \dots + IF_n)$$

Where n is the number of individual experts (11). The maximum value of the sum for IF is  $3 * 11 = 33$ , the minimum is 0 and the median is 16.5.

So, if  $\sum IF > 16.5$  the link was accepted as it is, otherwise the link was deleted.

Similarly, when a participant indicated there was a missing link, IF was calculated for the added links and the link was added to the diagram when  $\sum IF > 16.5$ .

Then the direction of the links was inspected by counting the number of + and – to see which one is more, so the direction was changed accordingly.

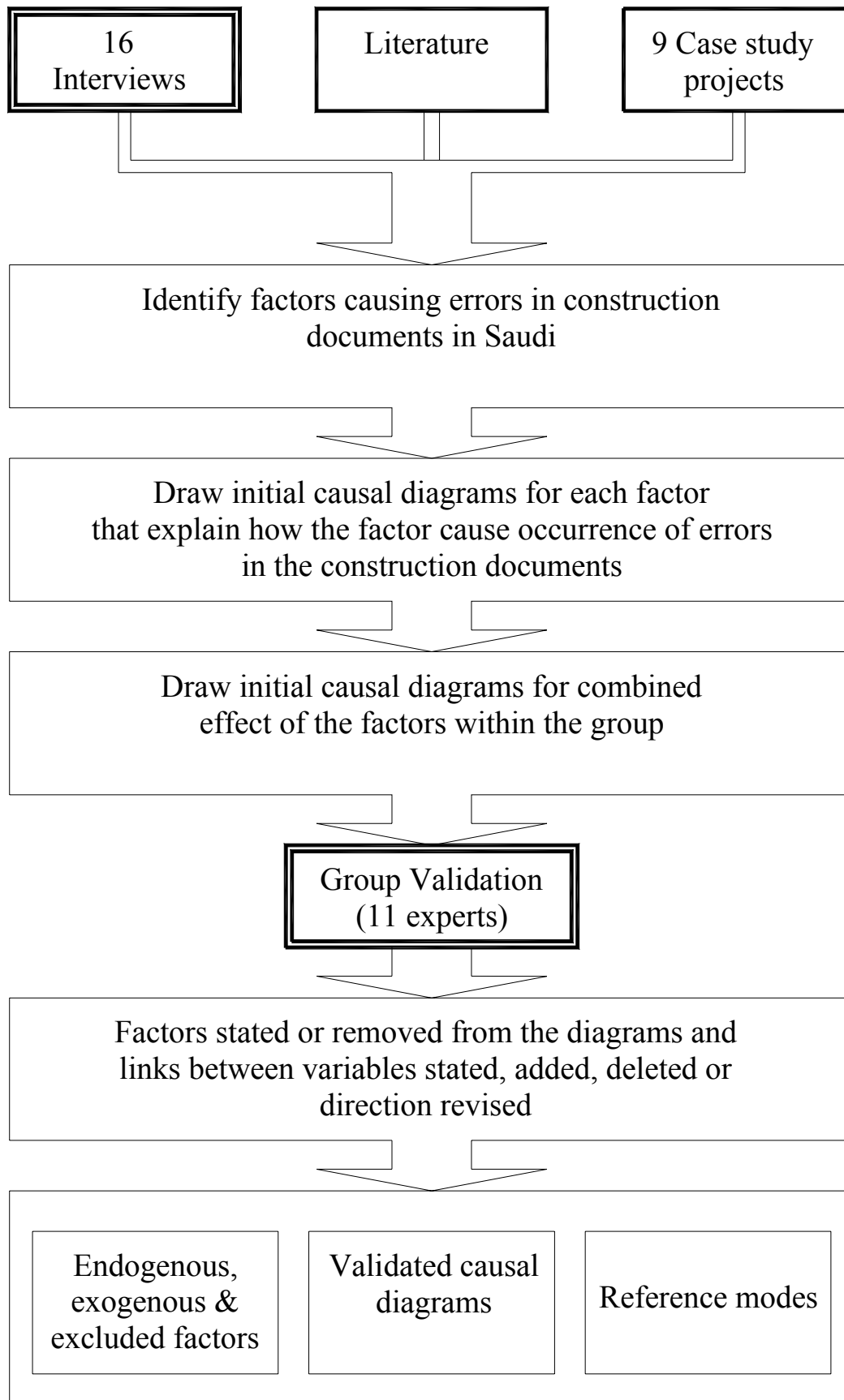
This validation process was necessary to ensure that the point of view of Saudi construction industry experts in the field is reflected in these diagrams.

After finishing the above validation process, the participants were asked to classify factors endogenously, exogenously and excluded so the model's boundary can be set accordingly (Chapter 6). The participants were also asked to draw basic reference mode diagrams of how errors are solved over time to be used later during model building activities (Chapter 6).

The advantage of such diagrams is that errors are likely to be repeated again in the future because little information and knowledge have been articulated to learn what led to the actual defects.

<b>Name Code</b>	<b>Title</b>	<b>Years of experience</b>	<b>Education</b>
1	Head of Architectural Department	20	MSc Project Management
2	Chief Mechanical Engineer	30	Bach. Mechanical
3	Head of Structural Department	15	PhD in Structural engineering
4	Project Manager	19	MSc Project Management
5	Project Manager	16	MSc project management
6	Head of CADD department	14	MSc project management
7	Project Manager	8	Bach of Architecture
8	Head of Interior Design	12	Bach of Architecture
9	Project Manager	10	Bach of Architecture
10	Chief Electrical engineer	25	Bach of Electrical Engineering
11	Chief Architect	35	BSc Architectural

**Table 5 : Experts Participated In Validation Of Causal Diagrams**



**Figure 2 : Identifying and validating factors causing errors in the construction documents in Saudi industry**

#### **5.4 Classification of factors influencing occurrence of errors in construction documents**

To understand the internal mechanisms of errors in a project, one should generally look at the project activities from a systems perspective (Rodrigues and Bowers, 1996; Williams et al., 1996). Such a perspective provides a fundamental shift in thinking and encourages error problems to be visualized in a holistic manner (Rodrigues and Bowers, 1996). By adopting a systems perspective, the interdependence and links amongst different components of a system can be explored. A system is assumed to be an entity separable from the rest of the universe by means of a physical or conceptual boundary, and is composed of interacting parts (Dean et al., 1990). Similarly, Shearer defined system (Shearer et al., 1971) as a collection of matter, parts, or components which are included inside a specified, often arbitrary boundary.

In spite of the fact that the term "system" is being used in different fields in a variety of meanings (Klir 1991, p 4) the following general characteristics of systems can be stated within the context of the current research:

- Systems consist of (definable) elements - just as a mathematical set consists of certain distinguishable elements. The elements of our system are all factors stimulating the occurrence of error(s) in the construction documents.
- Between these elements there exist (mostly functional) interrelations. A system is more than a mere accumulation of elements; there must also be a certain structure of relations among these elements. The interrelations will be driven from understanding the factors, and the research methodology adapted for the research and data collection using different data collection techniques described later in the chapter.
- Every system has a boundary to the surrounding "environment", which is more or less permeable. System borders are important for several reasons:
  - Borders ensure (and may even determine) the identity of the system.
  - The relations between a system and its environment take place mainly at the borders. It is at the borders where the system is determined, and what can enter or leave a system (input and output).

However, the boundary of the research has been defined in the scope of research, as discussed earlier in the thesis.

- On a closer perspective, individual system elements might be considered as whole sub-systems, or a system might be a single element of a larger system. A motor might

be a sub-system of a car, which is again an element of a more complex transport system. Thus whole hierarchies of systems may emerge.

Moreover; Rapoport (1988, p 30ff) named the following characteristics as fundamental features of the system:

- Identity or stability within change,
- Organization or the design and the handling of complexity and
- Goal-orientation or the destiny of a system

Within the context of construction industry, Love et al. (1999), Evans and Lindsay (1996) and Mandal et al. (1998) categorized a project system as being comprised of the following sub-systems:

- Technical and operational,
- Human resources, and
- Quality management.

Similarly, Ford (1995) has divided each phase of the project system during development to the following sub systems which interact and impact upon the performance of the project:

- Process structure, which includes development activities, and phase dependencies.
- Resources which include quantities, allocation among development activities, and effectiveness.
- Scope which includes project scope and rework
- Targets which include deadline, quality control and budget.

The problem of this categorization is the difficulty and complexity of the model generated based on this classification and which may become an obstacle to pinpoint the source of the problem and define the endogenous factors as stated in the hypotheses of the research.

Furthermore, since it is people who decide what to do, how it should be done, and who has to do it, it is assumed that all errors in design are originated from humans (Andi et al., 2003). Moreover, studies in construction failures (Sowers, 1993; Petroski, 1994; Nishigaki et al., 1994) have similarly reported that human and



organizational factors were the major causes of the failures and only a few cases were caused by the absence of contemporary technology or the state of the art.

Frankenberger (Frankenberger et al., 1998) classifies the factors influencing the design process in practice thus: "Individual prerequisites", "Prerequisites of the group", "External conditions", and the "Task". A similar classification was also adapted by other researchers (Nowak, 1992; CIB, 1993; Reason, 1990) where they consider classification depending on individuals. This is because the project team consists of individuals who cooperate with a specific aim. Therefore, it is natural for the errors to be ascribed to individuals (Nowak, 1992; CIB, 1993). Similarly, Reason (1990) stated that "any systems are always made up of people in various roles and relationships and when we begin to investigate the factors that lead to a behaviour we quickly progress to studying people embedded in a larger organizational context".

Therefore, the classification of factors will be explained in this research according to the origination that could influence the occurrence of errors in the construction documents, i.e.

- Management
- Designers
- Clients
- Project characters.

However, this classification is a common feature of most models studying errors (Andrew 1996; Whittington et al., 1992) as they divide causes into three categories:

- Causes related to the individual.
- Causes related to managerial ineptitude such as lack of supervision and control
- Causes related to wider factors such as economic climate, pressures of time and political constraints.

As erroneous actions that lead to bad consequences involve multiple people embedded in larger systems, it is this operational system that fails. When this system fails, there is a breakdown in cognitive activities which are distributed across multiple agents and influenced by the artifacts used by those agents. This is perhaps best illustrated in the process of error detection and recovery, which are inherently distributed and play a key role in determining system reliability in practice (Rochlin et al., 1987).

Therefore it is natural to classify the factors affecting the occurrence of errors as per the originator of the errors in the design document, which are the management of project, the designers and clients, and factors beyond their influence which are the project characters. This classification will enable us when constructing the model to pinpoint the source of the problem and define the variables that are within the boundary identified for the thesis.

Based on the above concept of system and as the model is relatively large, and for discussion purposes, the model (system) will be disaggregated into above sub-systems (main classification) and the sub-system will be disaggregated further into sectors (individual factors). These subsystems are tightly linked through shared parameters. This allow better understanding of the behaviour of the action of the factors, while the very dynamic interactions of the factors with each other will be indicated at the end of each section (Figure 2).

### **5.5 Factors influencing the occurrence of errors in the pre-contract-stage**

To understand the occurrence of the errors in the pre-contract stages it is necessary to understand the root cause of errors in construction documents, that is, the basic reason for its existence or set of conditions that stimulate its occurrence in the process. A process consists of a number of activities or operations which acting on inputs in a given sequence transforms them into outputs. Therefore, to reduce errors its cause must be identified, and then understand how these causes are interrelated

From the above analysis and review of literature, case study projects, interviews and validation process, the following factors and relationships are explaining the causal occurrence of errors in construction documents:.

**For clarity in all upcoming diagrams "O" means Opposite direction (Increase in the first factor will decrease the second factor); "S' means Same direction (Increase in the first factor will increase the second factor). "R1", "R2", "Rn" indicates Reinforcing loop. "B1", "B2", "Bn" indicates Balancing loop.**

#### **5.5.1 Management**

Juran and Deming both maintain that 85% of the problems are management controllable and not worker controllable (Stasiowski et al., 1994, p37).

Management theory has been evolving for centuries in response to technical advances. Technologies were rudimentary and change was slow, allowing plenty of time to make adjustments to the way in which resources could be organized to achieve identified objectives. It is generally agreed that the rate of change has increased dramatically over recent decades so that managing teams has become a focal point in managing for success.

Stoner et al. (1985, section 2) trace the evolution of management theory from the early 1980s to the present. Management theorists such as Robert Owen, Frederick Taylor and Gantt are cited as contributors to a scientific approach to management. These theorists had varying levels of concern for the workers welfare to achieve a productive workforce that could live in dignity. Much of their work, however, led to workers losing the connection between individual effort and the end product, as each worker performed only a small part of the total labour content of the product. The differentiation of effort and specialization of tasks was a response to technological development, mass production techniques, mechanization and de-skilling of work in an endeavour to replace manual labour with machine power.

The recognition that workers are not machines but humans resulted in the development of the classical organization theory. Henri Fayol developed guidelines and procedures for managing people. He recognized human group behaviour and saw people as part of an organizational system. This work was extended by others. Weber offered bureaucracy as an ideal organizational form; however as March and Simon (1958, pp36-47) note: “the application of classical management theory principles has often produced unintended and unwelcome consequences for managers. Some of these problems include excessive depersonalization within organizations leading to alienation rigidity in behaviour, and problems of employee motivation and innovation.”

Constraints to models proposed by the classical management theorists became evident as organizations became more complex, job functions blurred and the workforce began to react and think independently. New elements of a model were added by theorists such as Mary Parker Follett, Chester Barnard, Lyndall Fowles Urwick and March and Simon. These later groups of theorists viewed companies as organic, not mechanistic entities. System theory was applied to organizational theory and some understanding of individual and group behaviour was incorporated into productivity models.

### **5.5.1.1 Management organizational structure**

Morris (1994, ch9) believes that organizational forms that achieve effective communication are appropriately responsive to client objectives, project and external environment characteristics, management style, and the organizational cultures of project stake holders. Organizational structure should be responsive to the level of risk accepted by the project team. This may not necessarily mean the number of people on a team but rather finding the right skills and attributes mix in individuals comprising a team so that it matches what is required of it. Walker (1989, p210) highlights the complexity of designing organizational structures based on interdependency and relationships between teams.

Walker (1990/91, p15) identified factors shaping an organization. The implication of these finding is that it may be unwise to assume that models can easily be established to represent an ideal management structure. Many factors shape the ultimate management structure that will be effective. Such factors include company policy, client characteristics, the industrial relations, climate prevailing at the time of project and available skills of the proposed team which itself may be affected by changing technology. The study indicated that the project characteristics may have only a minor impact. Other situational factors may also contribute to the effectiveness of teams, such as team motivation, level of integration and company cultural influences. Many of these situational factors are difficult to measure and model.

Walker and Hughes (1984) believe that an organization structure is necessary to ensure that:

- I. planning is undertaken to anticipate potential problems, forecast data to investigate plans of action to overcome potential problems and to support decision making;
- II. planned courses of action are communicated to concerned parties and to allow feedback on progress achieved against that anticipated;
- III. coordinated action to be undertaken is identified and that parties agree to take responsibility for carrying out those actions as communicated;
- IV. action undertaken is supervised to ensure that priorities and objectives are met.

There are cases where a project organization is established but lines of authority may be blurred, accountability for making and/or carrying out decisions may be unclear, and lines of communication between parties to the process ineffective.

Self-directed teams are gradually replacing the traditional, more hierarchically structured project team, and are seen as a significant tool for orchestrating and eventually controlling complex projects. However, they also require a more sophisticated management style that relies strongly on group interaction, resource and power sharing, individual accountability, commitment, self direction and control. These complex projects and their integration also rely to a considerable extent on member-generated performance norms and evaluations rather than hierarchical guidelines, policies and procedures. While this paradigm shift is the result of changing organizational complexities, capabilities, demands and cultures, it also requires radical departures from traditional management philosophy on organizational structure, motivation, leadership and project control. As a result, traditional management tools, designed largely for top-down control and centralized command and communications, are no longer sufficient for generating satisfactory results (Thamhain and Wilemon, 1996).

This suggests that project control has radically departed from its narrow focus of satisfying schedule and budget constraints to a much broader and more balanced managerial approach that focuses on the effective search for solutions to complex problems. This requires trade-offs among many parameters, such as creativity, change-orientation, quality and traditional schedule and budget constraints. Control also requires accountability and commitment from the team members toward the project objectives (Abdel-Hamid and Madnick, 1990; Thamhain, 1996, pp 37-38).

Thamhain (Thamhain, 1996, pp 37-38) states: "one wonders why managerial tools, designed to improve project performance and highly recommended for their effectiveness, have not been more widely adopted". Popularity of a particular control technique in the management literature and actual applications to project situations are two different things. Few companies go into a major restructuring of their business processes lightly. At best, the introduction of a new project control technique is painful, costly and disruptive to ongoing operations. At worst, it can destroy existing managerial controls. It can lead to mistrust among team members and management, game playing, power struggles, conflict, and misleading information. It also can lead to a transfer of accountability and action oriented away from team members and project leaders and to the control tool mechanics. In facts, the risks of introducing new

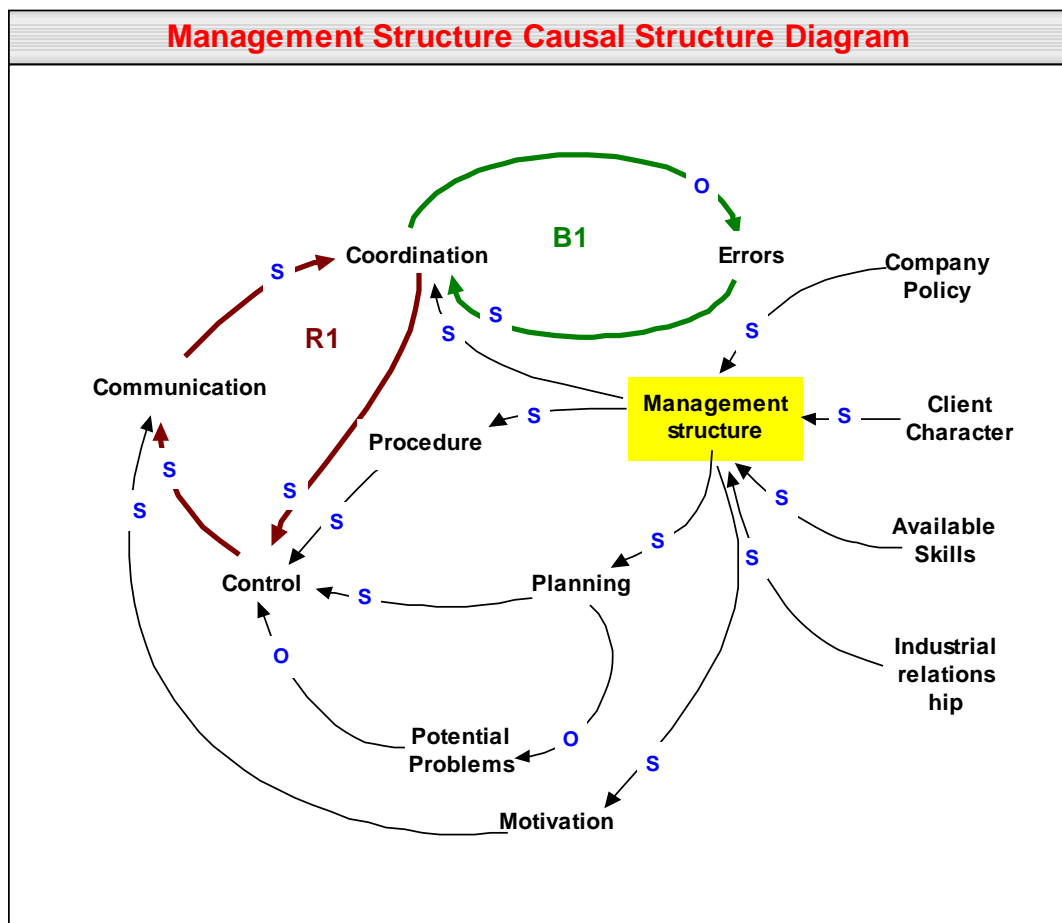
project control tools are so substantial that many managers are willing to live with an inefficient system rather than go through the trouble of changing it. Most sceptical are managers who have tried a specific tool and obtained disappointing results or outright failure. These negative impressions are often most intensive for complex process-oriented controls such as stage-gate techniques, which rely on complex and often fuzzy measures of performance (Thamhain, 1996, pp37-48).

The reasons for under-using or rejecting controls as have been found by research (Thamhain 1996) can be divided into four classes:

- lack of confidence that tools will produce benefits
- anxieties over the potentially harmful side effects
- conflict among users over the method or results
- the method is too difficult and burdensome, or interferes with the work process.

To overcome these limitations, management must recognise the potential barriers toward project control tools, which might result in anxieties, misunderstandings, unpleasant experiences, or other unfavourable perceptions. Management must deal with these perceptions and develop a positive attitude among project team members toward these new tools to avoid rejection before a fair evaluation is made of their usability and value (Thamhain, 1996, pp37-48).

The following diagram explains the influence of management structure on the generation of error in the construction documents.

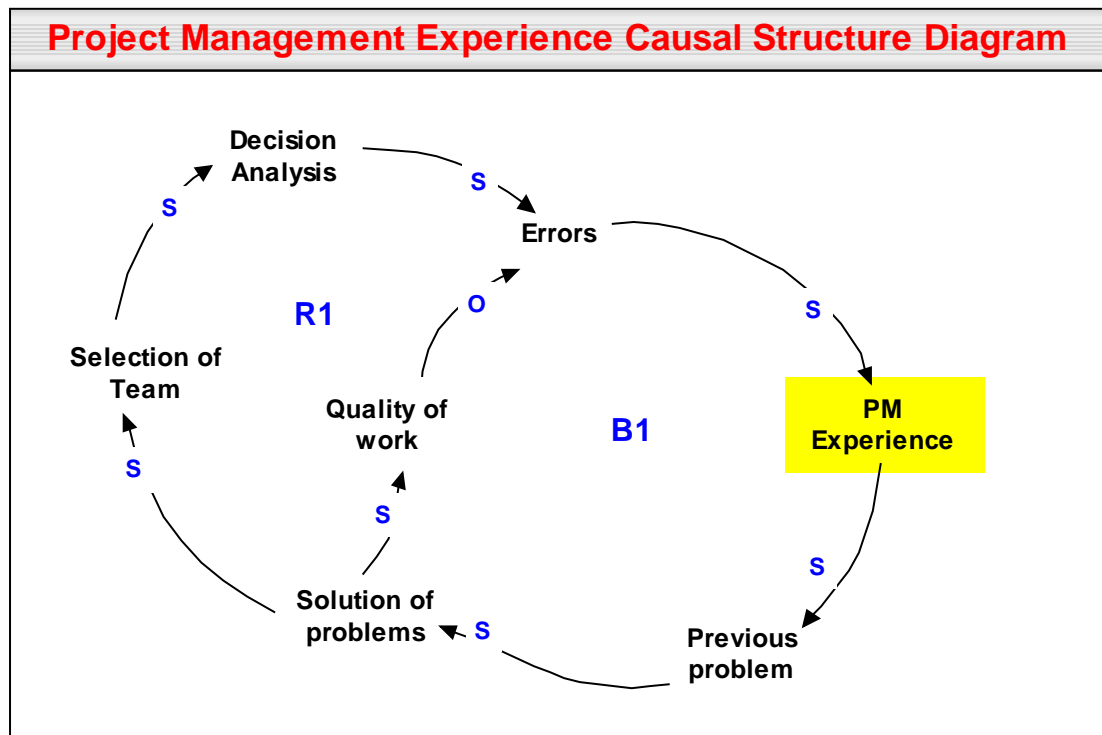


**Figure 3 : Management Structure Causal Diagram**

The causal diagram shows that management structure will affect the planning, procedure and motivation of the team. These intermediate variables will influence the control of the project. From the control variables, there will be a reinforcing loop, where control will increase the communication that will increase coordination. Increasing the coordination within the team will increase control of the production of the construction documents. The other loop is a balancing loop where coordination will increase the number of errors solved: the more errors solved, the less coordination needed in the project.

### 5.5.1.2 Project manager experience

The experience of the project manager in handling previous projects of the same nature will help in guiding the project to predicate the consequence of decisions and preventing errors which occurred in previous projects in selecting the most efficient and effective project team members, in selection of the proper procurement of handling the project, and transferring the risk to the proper party of the project team.



**Figure 4 : Project Management Experience Causal Diagram**

The diagram shows two types of loop. The first one is a balancing loop where the experience of the project manager in solving previous problems will increase the possibility of solving problems that will increase the quality of work that will decrease the number of errors in the construction documents that will be entered again in the experience of the project manager.

The second loop is a reinforcing loop, where experience in the solving of problems will help in selecting an appropriate team for the project, which will increase the ability in decision analysis that will help in an increase in the number of errors solved which will be entered again in the project manager's experience.

### 5.5.1.3 Project brief

A project brief is described as a document showing the background and requirements for a building project. It forms the basis for design. 'The project brief defines the project in terms of quantities, quality, costs and time. The brief describes specifications with regard to functions, connections, area needs, technical systems, working environment, architectural design, budget, etc. (Nina-2004). Nina's study suggested that the ways in which brief requirements are formulated and used for communication between the client and the contractor are very important factors in the success of a building project.



The project manager prepares the project brief in coordination with the client. The project brief purpose is to make sure that the project team members understand the client requirements and are updated with current requirements and plans.

The brief may include (AIA-1994, p559):

- Review of project requirements as developed by the client and the designer. This may cover project goals, scope, quality, schedule, budget, codes and regulations, key design and construction standards, and other project information.
- Review of the project work plan, critical tasks, responsibility, uncertainties, and potential problem areas.
- Review of schedule and milestone dates.
- Review of project policies. These include (as relevant) project responsibility and authorities, client structure and relationships, approaches to identifying and resolving problems, team meetings and communications, project charges and reports, and other key management issues.

There are various factors influencing the way a brief is developed. These factors are related to the information required, and they include the nature of the project, type and size of client, and the skills of those involved in the process. Complex projects require much more information, involve many multi-disciplinary professionals, and may therefore present greater challenges for briefing. Similarly, inexperienced client organisations also find it relatively difficult to define their requirements in briefing (John M. et al., 2001).

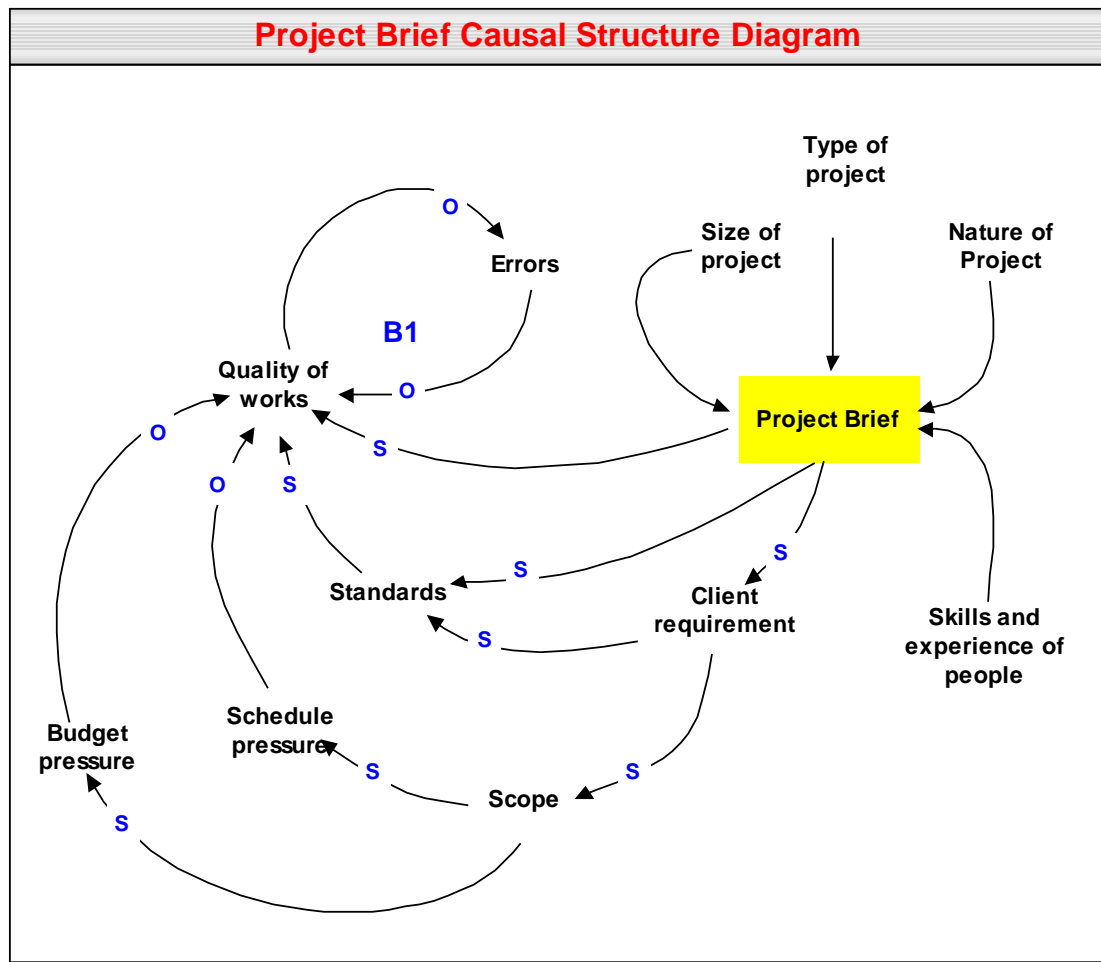
NEDO (1988, p63) suggests that it is not essential that a brief be detailed so long as instructions were defined, stating the client's priorities in terms that could be responded to by the consultants involved in the development of the brief. It is important that clients be clear about the nature and degree of help required to develop a brief, as distinct from design development where a brief evolves from dialogue between client and consultant. This is because a number of specialists, such as space to use consultants, marketing consultants, interior designers or other specialists familiar with specific technologies such as materials movement, security, computer installations etc., may be required to contribute their expertise

In Australia, in the analysis of 20 major projects (BCA 1993, p3) the following conclusions were drawn, which pertains to client-generated delay. The report statistics highlight:

“ A need for a greater assumption of the responsibility by the client for a firm brief, a realistic timing of commitment and a comprehensive analysis of project delivery needs and methods; and the creation of a climate in which the parties can operate efficiently and the supply of clear decision making”.

In a second BCA report (1993b, p3), the requirements for success are specified; these include the need for definition of project roles, detailed expression of client needs and ensuring accountability and responsibility by assigning power to individuals or units that have the capacity to bring needed results. Both BCA and NEDO stress the importance of the client dealing with the design brief and design development in a unified and coherent manner. The latter report indicates confusion and delay occurring in cases where diffused briefing from inside a client's organization had occurred. Drucker's work (1974, p436) on management by objectives concluded that clear objectives have a strong effect upon management performance. Clear objectives form the basis for a clear brief.

Understanding and transferring such a brief to the team members will reduce the number of errors in the pre-contract stages of the projects, because it identifies and clarifies all the ambiguities in the project from the early stage of the project, and the client will not be surprised during and after the construction.



**Figure 5 : Project Brief Causal Diagram**

The diagram shows that a clear project brief will give a clearer picture about the client requirements, a better understanding of the standards following in the document production and better quality of work. The more defined the client requirement, the better management of the scope of the project, which will give better schedule and cost control that will influence negatively the quality of work. Increasing the quality will decrease the number of errors. An increase in the number of errors will decrease the quality of the work.

#### 5.5.1.4 Changes to key project personnel

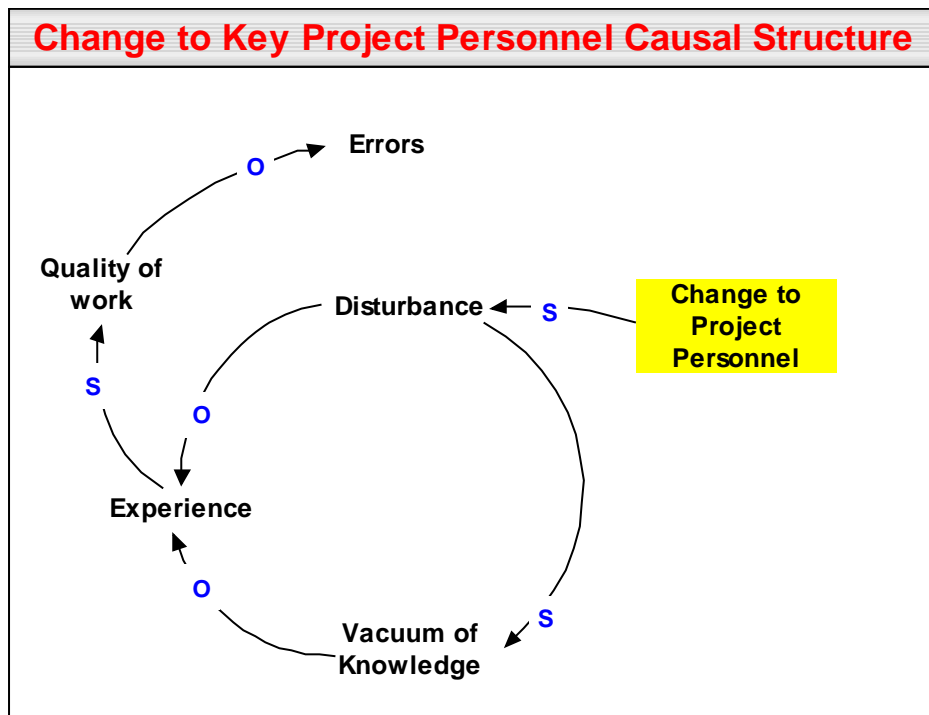
People have been identified as a cause of project failure and have been considered as the biggest risk of all, since it is people who undertake the project tasks to achieve the end result (CCTA, 1995).

Industries outside construction have focused on the management of human resources as it is seen as a subject requiring special attention. Oglesby and Urban (1986) state that people issues have gained recognition in recent years as being at the core of effective project management. Aggarwal and Rezaee (1996) highlight the significance of staff changes by their observation: “in many instances project staff turnover has forced management to abandon projects”.

The dramatic disruption caused during the design process by a change of design personnel and the knowledge vacuum created when a member of staff departs are the main effects of this factor and consequently affects the number of errors generated during different stages of producing the construction documents.

Chapman (1999) states that the construction industry has overlooked this important issue and, through habitual introspective examination, has not benefited from the research conducted in more progressive fields.

The changes in key project members influence the performance of the client and designer as well.



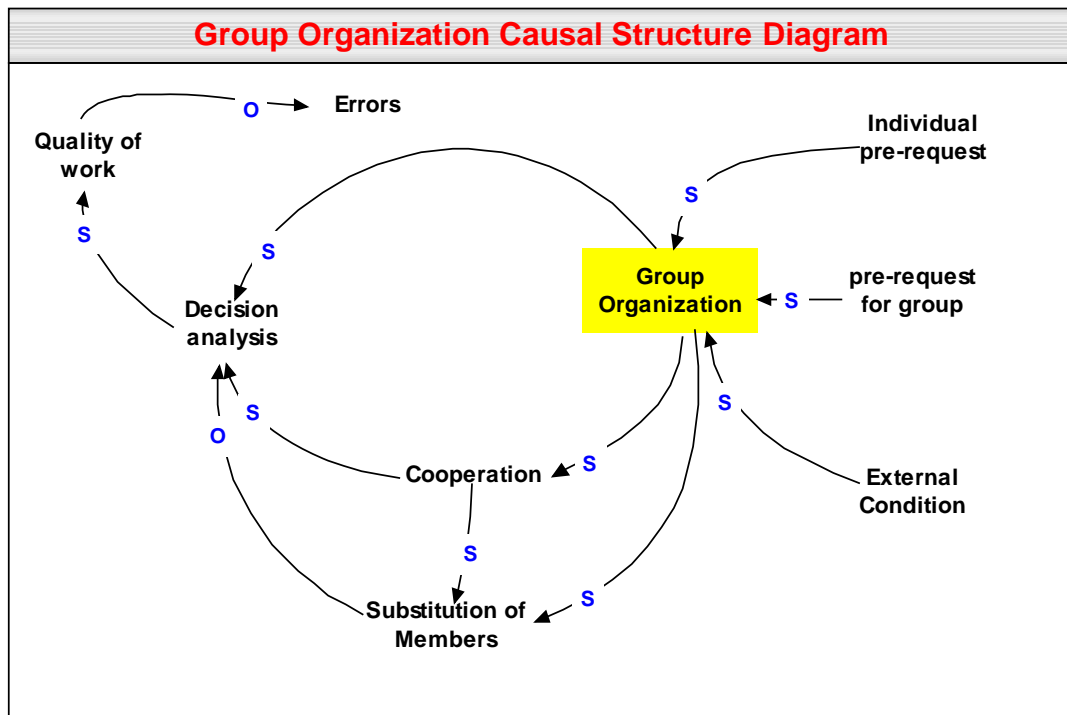
**Figure 6 : Change to Key Personnel Causal Diagram**

The diagram indicates that changes to project personnel will increase disturbance in the project team that will lead to a vacuum of knowledge and losses in the experience of the team, which will lead to fewer quality design documents. Increase in the quality of work will lead to a decrease in the number of errors generated in the construction documents.

### 5.5.1.5 Group organization

Frankenberger (E. Frankenberger et al., 1998) found that group organization is the most important group-related factor responsible for the deficient analysis of solutions and wrong decisions during the development stage of the project.

Frankenberger's research also concluded that close co-operation between the group members is very helpful because the main principles are then known by each group member. Group organization thus means that group members may substitute for each other up to a certain level.



**Figure 7 : Group Organization Causal Diagram**

The diagram indicates that better group organization will make better decisions analysis, cooperation and proper substitution of members. Better cooperation and proper substitution of the team member will again support proper decision analysis. Proper decision analysis will lead to an increase in the quality of work, which will lead to a decrease in the number of errors generated in the construction documents.

However, all these factors are interrelated and interact with each other and with other intermediate factors as indicated in the following figure, which shows how the factors influence each other in a dynamic and complex manner

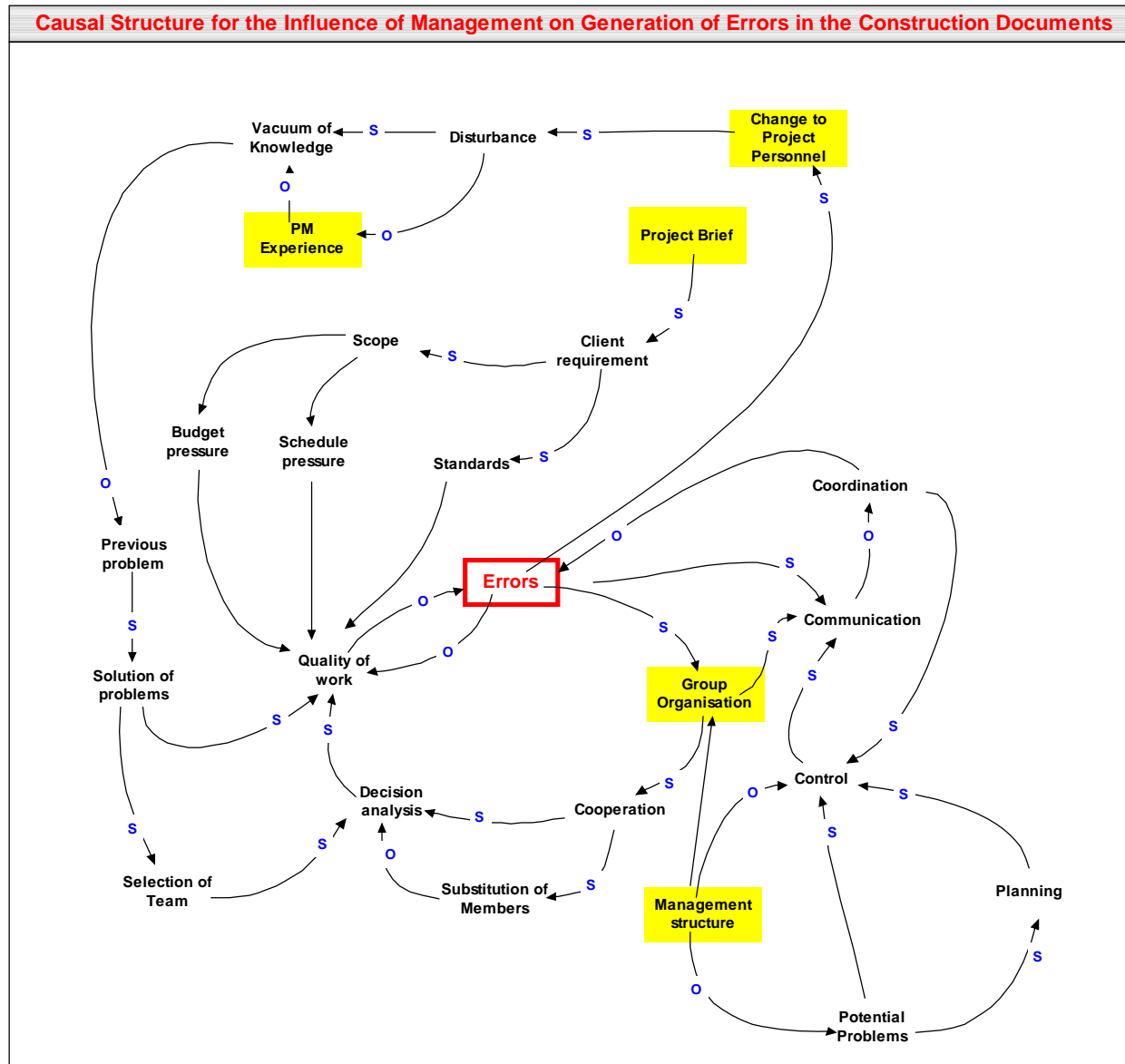


Figure 8 : Causal Diagram For The Influence Of Management On Occurrence Of Errors In The Construction Documents

### **5.5.2 Designer**

Designers can contribute to construction productivity in a number of ways without detracting from the quality of design. Intricate design details may not necessary lead to high cost, and design details that may appear simple and straightforward may prove to be expensive.

A complex looking design may be considered simple if the design team bear in mind that contractors can achieve high productivity when a steady workflow is maintained. It is possible, therefore, for a well thought-through design to meet aesthetical high standards and be of a buildable design with the potential for high rate of productivity. Ireland's (1983, p106-107) conclusions that production performance is related to project scale, with greater performance for larger floor area buildings can be explained in the light of a contractor's capacity to adopt a production line approach and/or opening up of multiple work faces. This may be the result of large areas of low rise construction being available for work to proceed. Typically large shopping centres, factories or warehouses, and medium- to low-rise office projects offer opportunity for flexibility of work rescheduling to overcome bottlenecks in production or materials delivery/supply problems. It follows from this interpretation that buildability may not be intrinsically a factor, rather owing to construction management planning and control performance, which may be enhanced or simplified by a design that promotes good workflow.

However, the following factors have been identified in the literature to influence the generation of errors in the construction documents:

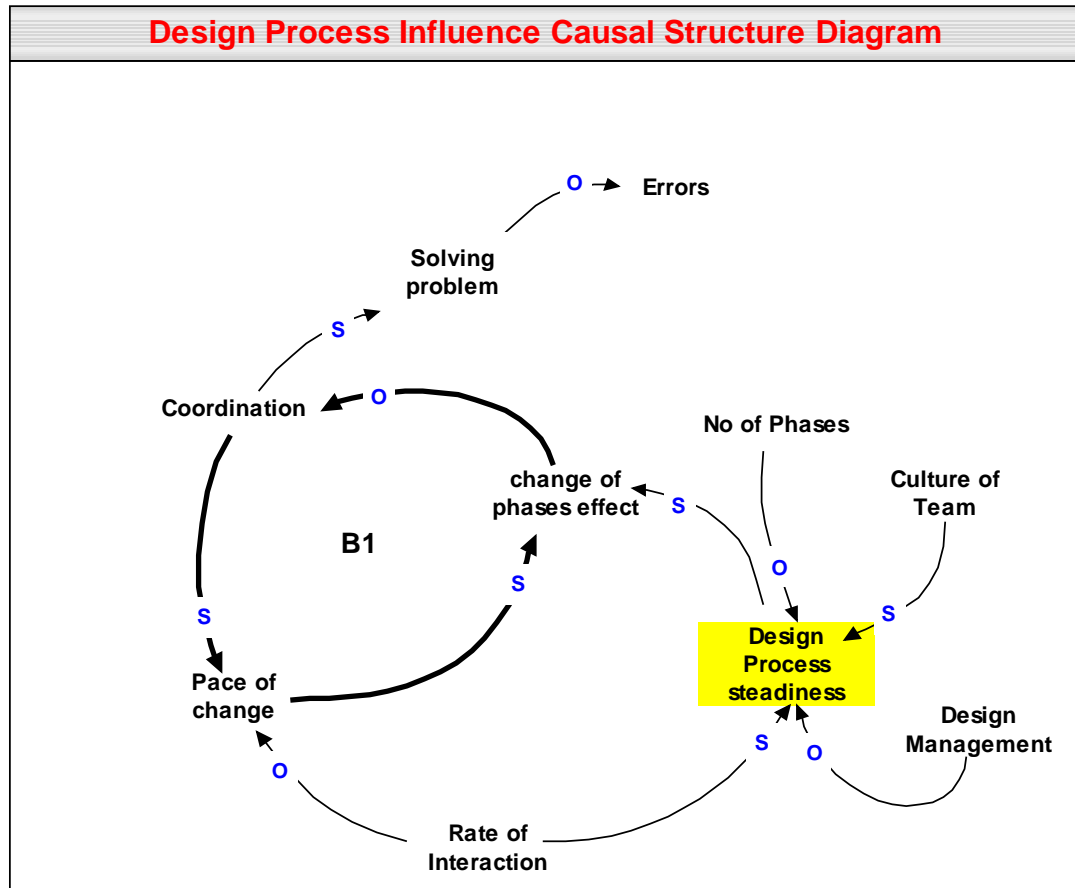
#### **5.5.2.1 Design process**

NEDO (1987, p3) states; “ The design process is difficult enough to control when there are several disciplines to bring together, each of which can affect the performance of others. If information is incomplete or erroneous at time of tender, tenders have little chance to assess the resources required and price accordingly. The customer's principal advisor should coordinate the contributions from all the design specialists”.

On the other hand, the major problem facing project teams is that once a project is committed to start there is often little time to stop and contemplate. The pace of



change in this environment is far greater than most observers can appreciate. The culture of the project team organisation changes rapidly from a creative phase of design, planning and problem solving to a production phase. Those involved at the early stage may not have the temperament to continue. The concept architects, for example, may become very agitated as their designs change to meet the exigency of achieving practical construction time and cost budgets constraints (Walker, 1994, p93).



**Figure 9 : Design Process Causal Diagram**

The diagram indicates that design process will influence the change of phase that will influence negatively the coordination. Increase in the coordination will decrease the number of errors proportionally.

On the other side, there is a balancing loop; an increase in the coordination will increase the pace of change which will also increase the change in the phase effect that will increase coordination.

### 5.5.2.2 Design Management Experience

Experience is the knowledge or skill of a particular job that has been gained because of working at the job for a long time.

This is related to the experience of project Lead Architect / Lead Engineers (sometimes he is the Head of Discipline) who is responsible for guiding other member of the team to finish the work. His experience and knowledge will affect the number of errors generated in the contract documents.

Rounce (1998) has suggested that much of the design-related rework generated in projects is attributable to poor managerial practices of architectural firms.

Sverlinger (1996) found that the most frequent causes for severe deviations during design were deficient planning and/or resource allocation, deficient or missing input information, and changes. Similarly, Coles (1990) found that the most significant causes of design problem are poor briefing and communication, inadequacies in the technical knowledge of designers and lack of confidence in preplanning for design work. Burbridge (1987, p16) found that the remedy for the main faults identified as causing failure in design quality lies in management of the design process.

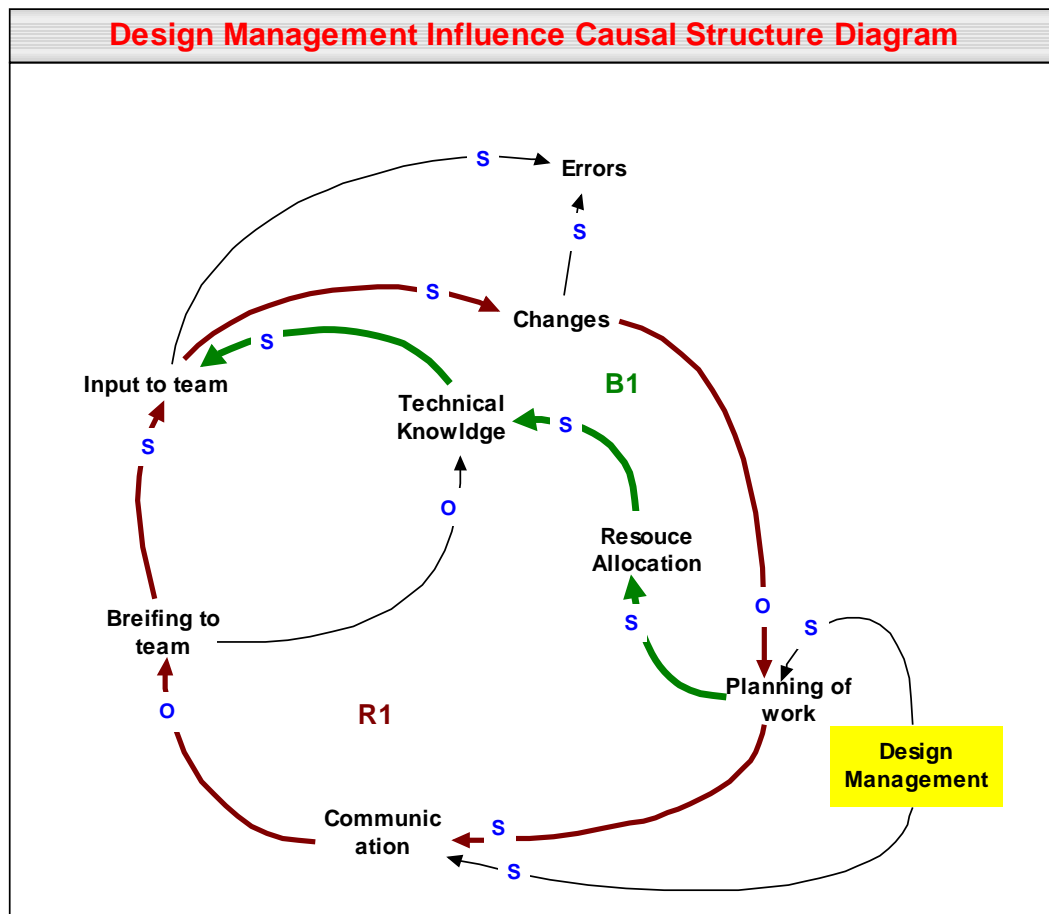


Figure 10 : Design Management Causal Diagram

The diagram indicates that better design management is an indication of better planning of work and better communication among the team members.

There are two balancing loops in the diagram. The first loop is where better planning will increase the communication that will support the briefing to the team and accordingly the input, which will support the changes. An increase in the changes during the production of documents will impact negatively on the planning.

The second balancing loop, where an increase in the planning will give better resource allocation, which will increase the total knowledge, which will support the input of the team, which will affect changes. As indicated in the previous loop, an increase in changes will negatively affect the planning.

### 5.5.2.3 Designer professional education

The amount and quality of education the designer has influences the generation of errors. Proper education provides all the necessary knowledge about the process of the developing the documents, how to solve problems, how to communicate and coordinate with other disciplines, etc.

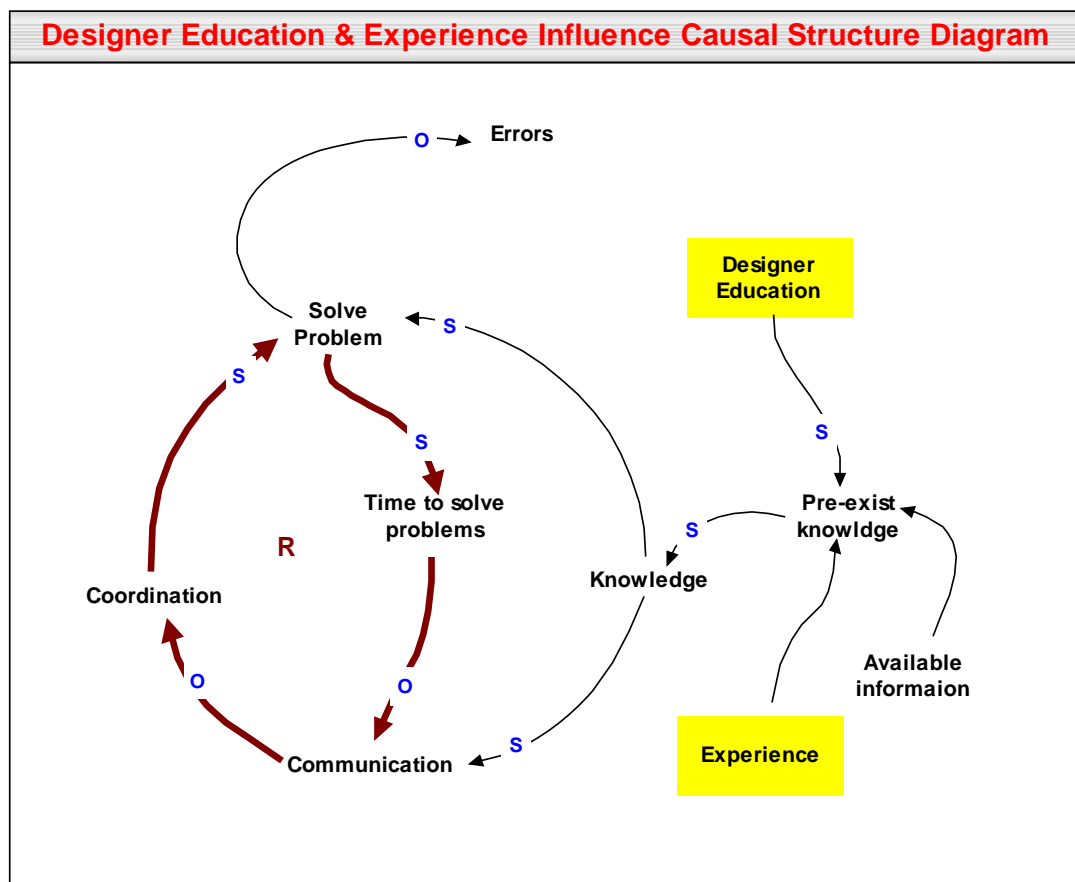


Figure 11 : Designer Education & Experience Causal Diagram

#### **5.5.2.4 Designer experience**

Enough design experience for the type of the project in hand influences the number and types of errors in the construction documents (AIA 1994, p453). Similarly, Burbridge (1987, p16) identified lack of technical expertise as a main cause of failure in design quality. Lyneis (Lyneis et al., 2001) is of the opinion that less experienced people make more errors and work more slowly than more experienced people.

However, Frankenberger (E. Frankenberger et al., 1998) found that experience has nearly no relevance for deficient analysis and decisions. This was because a lack of experience can be balanced by other factors, e.g., the theoretical education, the motivation and /or the open-mindedness of the designer. Very often, the consultation of colleagues in the design process compensates for a lack of experience. The combined diagram indicates that better designer education and experience will support the built in knowledge that support the knowledge for the project and will increase the number of problems solved and communication among the team members.

The balancing loop (the diagram is combined with education) have indicates that an increase in the solving of the problems will increase the time required to solve the problems. An increase in the time to solve problems will decrease that amount of time to carry out communication. Increasing the amount of communication will increase coordination, which will solve more problems.

#### **5.5.2.5 Design fees**

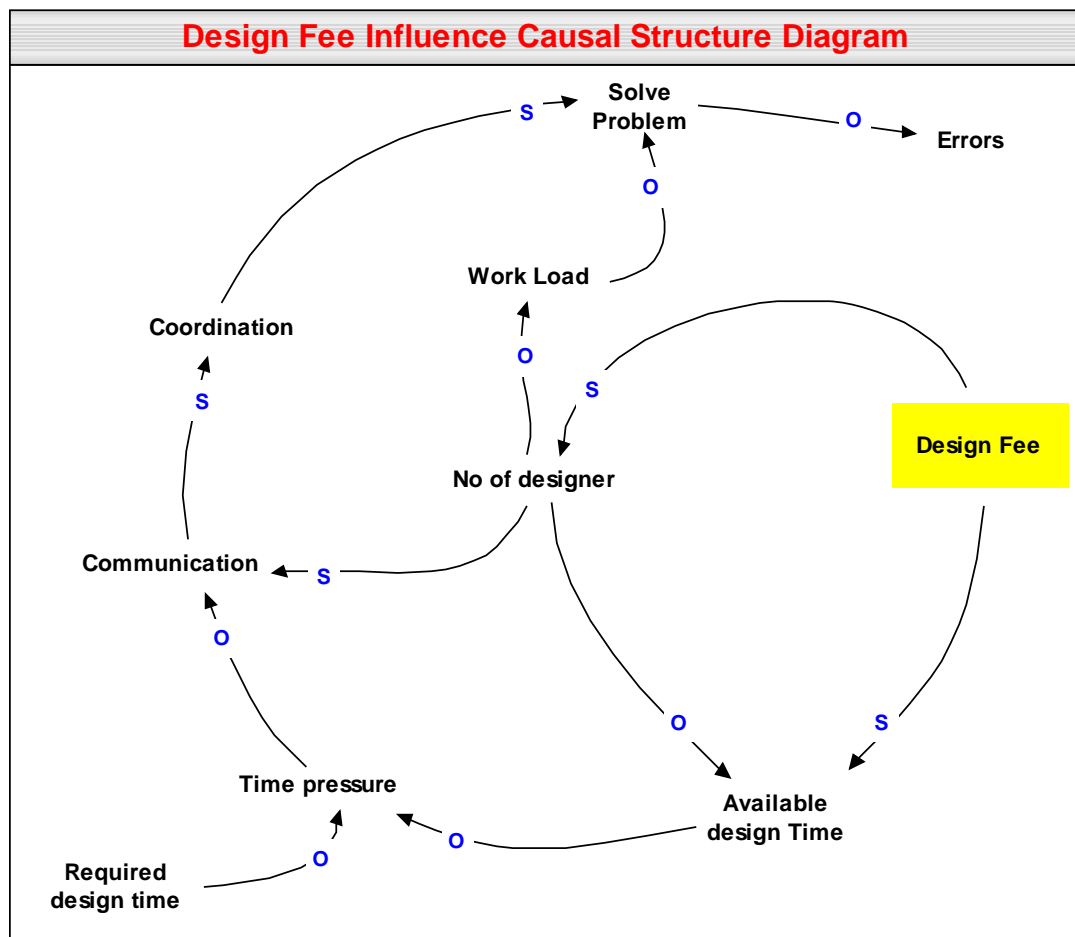
Overtight fees for professional services and financial pressure as causes of error are mentioned by several writers (Andrew, 1996; Chadwick, 1986; Brow et al., 1988; Petroski 1985). Where designers are selected based on low design fees, then the level and quality of the service provided is likely to be limited and generally translates into additional project costs to the owner (Abolnour, 1994). Similarly, the expected profit from the project influences the generating of errors in the construction documents (Bubshait et al., 1998; AIA 1994, p453). Also, research by Andi (Andi et al., 2003) found that designers regarded the client's tendency to shop around for design fees and a low design fee as most important factors affecting the quality of design documents.

Contrary to the above, ACSNI points to research reviewed in their publication which indicates that there may be a link between a low error rate and increased economic

efficiency; in other words an intervening factor (such as management style) may both improve performance and reduce costs (ACSNI, 1993; Blockley, 1992).

This is based on the number of staff and amount of time which can be allocated to the project. When a firm submits a low design fee for a project, it may allocate a fixed time to complete each task, irrespective of whether the documentation is complete or not. In turn this can also cause errors being made by other parties who rely on the designer's curtailed information.

Whenever there is contradiction in the explaining, there is something missing in explaining the intervening variables, as indicated in the following diagram. The practice of determining the design fees is different from that of the USA and UK, where the fees are a percentage of construction cost. The design fee in Saudi Arabia is normally defined on the bases of negotiation and competition (Bubshait et al., 1998).



**Figure 12 : Design Fee Causal Diagram**

The diagram indicates that design fees will normally increase the amount of time available for the production of the construction documents, and will also increase the number of designers available for the project. The increase in the available design time will decrease the time pressure. An increase in the time pressure will decrease

the amount of communication carried for the job that will decrease communication and the number of problems solved correctly. On the other hand, an increase in the number of designers will decrease the workload of the designers, which will increase the opportunity of solving the problems correctly.

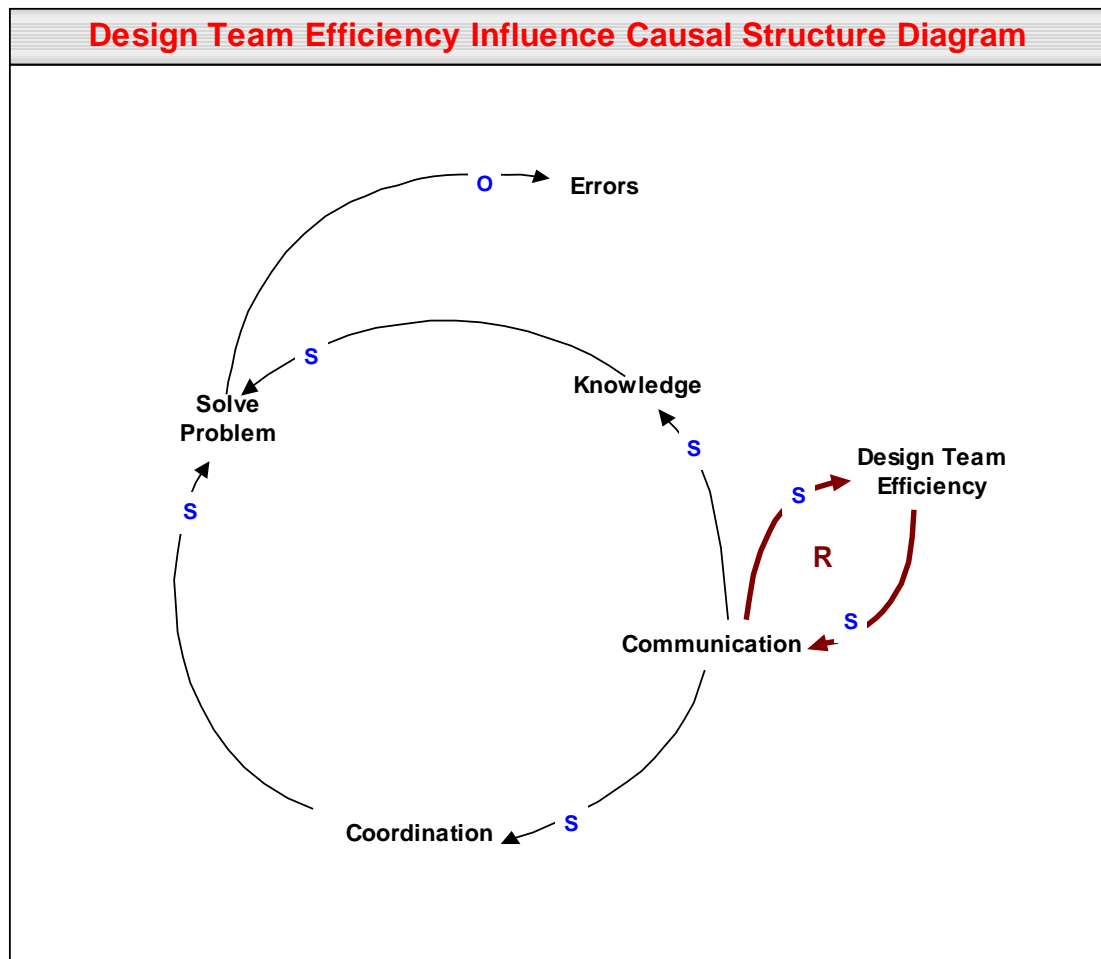
#### **5.5.2.6 Design team efficiencies**

The effectiveness of the design team is intricately linked with the ability of the project team to be cohesive. Cohesiveness is the extent to which individuals or groups are attracted to a team and desire to remain in it. The degree of cohesiveness in a group is a complex phenomenon that results from combining the net attraction repulsion for each member. As values, norms and attitudes invariably differ, there will be instances when either attraction or repulsion will occur. Hence, there may be instances that lead to either highly functional or dysfunctional teams.

The degree of cohesiveness in a team can lead toward uncoordinated or coordinated behaviour. If each individual and group align their goals with those of the project organization (e.g. time, cost, quality, client satisfaction, innovation etc) then behaviour will most likely be functional from an organizational perspective. Nevertheless, each participating individual and group will invariably have sub-goals which they will follow (e.g. marketing, turnover, survival, training, etc.). These may clash with one another and may not be compatible with those of the project. Overall project effectiveness and efficiency will depend on the coordinated efforts of the individual and the group's ability to become customer focused and work together toward common goals within a project organizational system (Love, 1998).

The diagram indicates that an efficient team will have an increase in the communication. Communication on the other hand will increase the efficiency of the team. An increase in communication will increase knowledge among the team members and will lead to more solving of errors correctly and fewer errors in the construction documents.

The increase of communication will also lead to coordination, as indicated earlier.



**Figure 13 : Design Team Efficiency Causal Diagram**

### 5.5.2.7 Design time

A realistic time schedule for design is important for the number of errors generated in the construction documents (AIA 1994, p450). Andi (Andi et al., 2003) found that the designers regarded insufficient design time as the most important issue influencing design document quality. NEDO (1987, p17) citing Building Research Establishment (BRE) studies of communication and control of quality on a wide variety of non-housing projects, stated that “Projects with quality problems were often those which are behind with their program. Tight contract times did not necessarily militate against quality”.

Contrary to the above, it is possible that lack of time may not in itself be a cause of error, but that good time performance may be associated with low error rates (Andrew, 1996).

Effective management of quality does not mean that time is traded for quality. Szafraniec (1989) and Rosenfeld et al. (1992, p31) maintain that quality, cost and

productivity are interrelated so that when quality is raised, costs are lowered and productivity is enhanced through lower rejection rates, fewer instances of re-working completed products and improved flow of work.

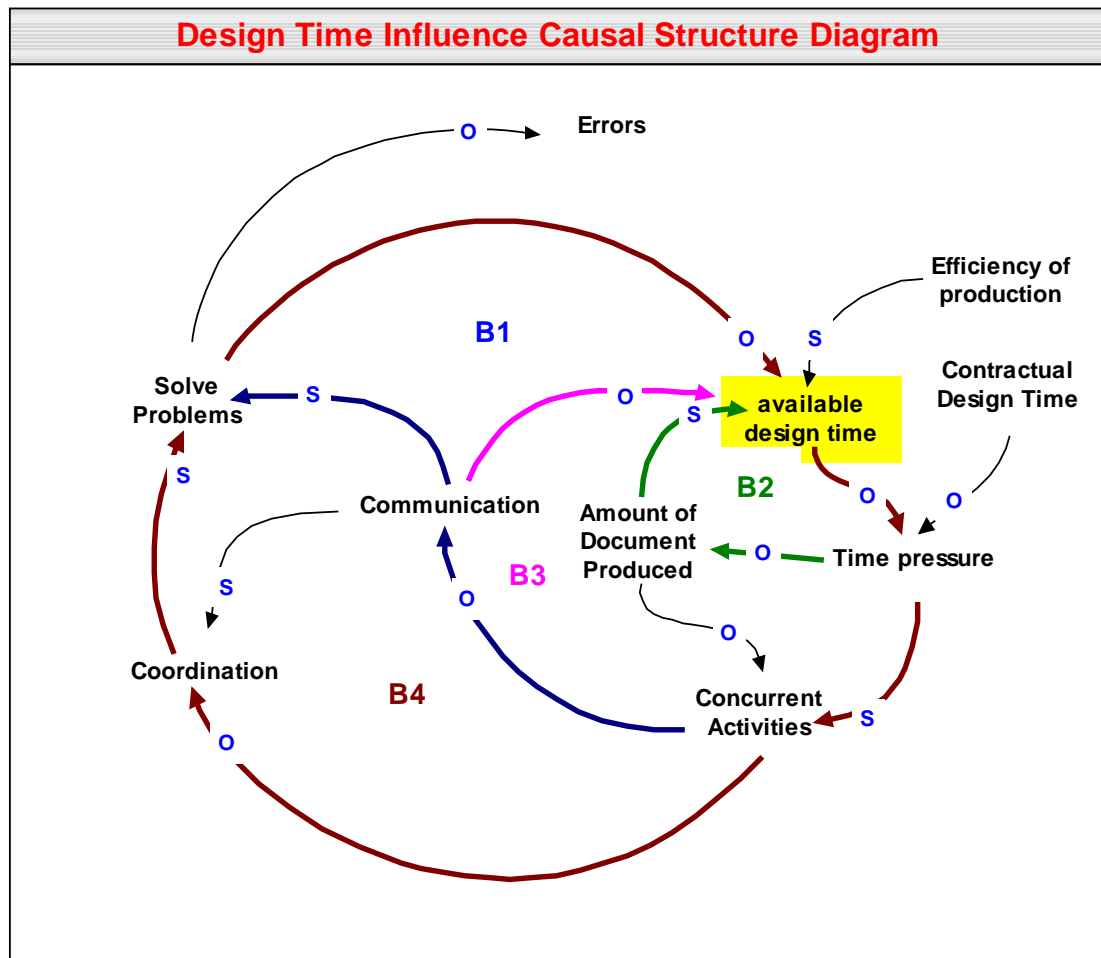


Figure 14 : Design Time Causal Diagram

The key QM issues affecting time performance in construction documents are the impact of quality management procedures on the workflow and resolution of disputes that relate to contract documents. Part of this may be determined by the design team’s response to requests for information or resolving quality issue disputes. Contract documents should determine the extent and degree of inspection, approval and quality management procedures. Contract documents should also provide an indication of mechanisms available to resolve disputes over quality and other matters (Walker, 1994).

The diagram indicates that an increase in the available design time will reduce the time pressure during the production of the construction documents. An increase in the time pressure will reduce the number of documents produced for the project. A



decrease in the time pressure will also accordingly decrease the concurrent activities. An increase in the concurrent activities will decrease the coordination and communication that will lead to fewer problems being solved correctly, which will finally increase the number of errors in the construction documents.

An increase in solving problems and communication will lead to less time being available to solve other issues in the construction documents.

### 5.5.2.8 Procedure for producing documents

As elaborated in chapter 2, the design phases, as defined in RIBA and AIA, provide the basis for managing the movement of incomplete work through the various design specialists. Each of these is an attempt to get a commitment to progressively more detailed design in the hope of preventing backtracking. This sequential movement ensures proper understanding of all issues related to the project and resolves coordinating problems between different disciplines, and finally will lead to a reduction in the number of errors related to coordination and misinterpretations of the system used.

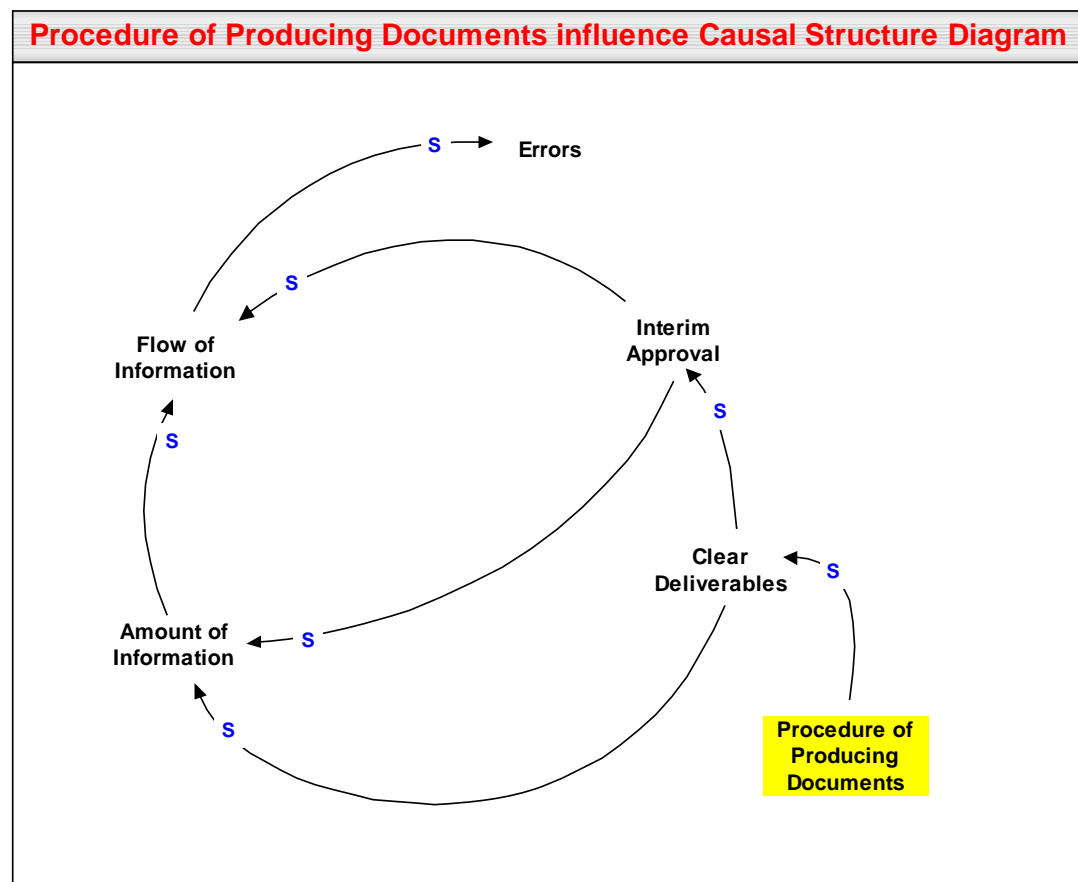


Figure 15 : Procedure of Producing Documents Causal Diagram

On the other hand, if the project is sufficiently well defined to establish the professional services required, the number of errors will be reduced; this is because when there are phases of producing the documents, the designer will bring the design to an interim level of development; the owner reviews and approves it, and the project moves forward based on mutual understanding.

The problem rise when the project is fast tracked and the stages of works are mixed together to finish the project within the allowable time.

Errors below: title, as before, and spelling of efficiency

### 5.5.2.9 Designer salary

Asad et al. (2005) found that professional employees are generally more motivated by intrinsic rewards than skilled and unskilled operatives. However; low salaries can act as de-motivators, which in turn may also contribute to the incidence of errors (Love et al., 2000; Abdel-Hamid, 1998; Ogunlana 1993).

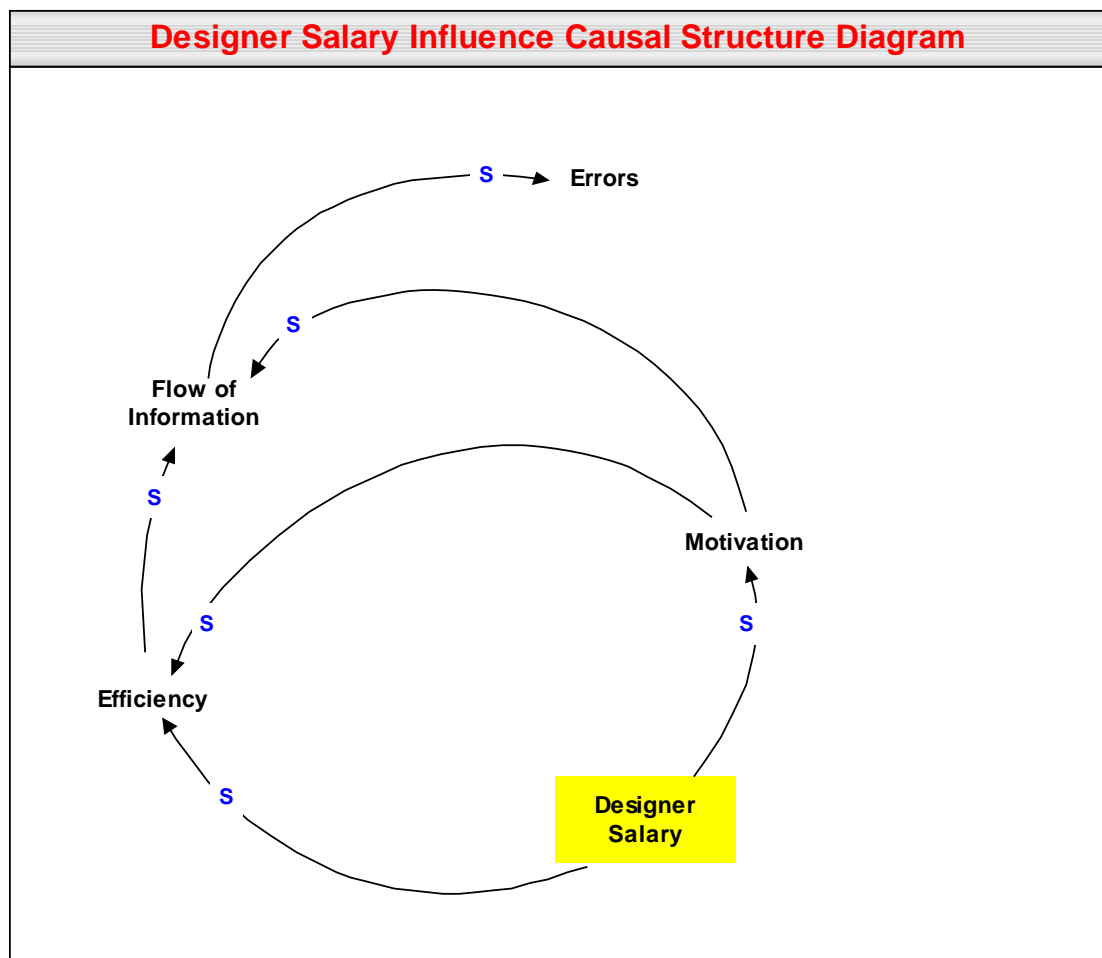


Figure 16 : Designer Salary Causal Diagram

The diagram indicates that higher designer salary will increase the motivation and efficiency of the design team. A team with increased motivation will increase the efficiency as well. However, an increase in both factors will increase the flow of information within the team producing the construction documents. An increase in flow of information will reduce the number of errors in the construction documents.

### 5.5.2.10 Number of Designers

The availability of sufficient staff with sufficient time to focus on the project and on the client (AIA 1994, p450) will influence the number of errors generated in the documents.

The diagram indicates that increase in the number of designers available for the project will decrease the workload. An increase in the workload will increase the pressure of time. An increase in the pressure of time will lead to a decrease in the share of knowledge.

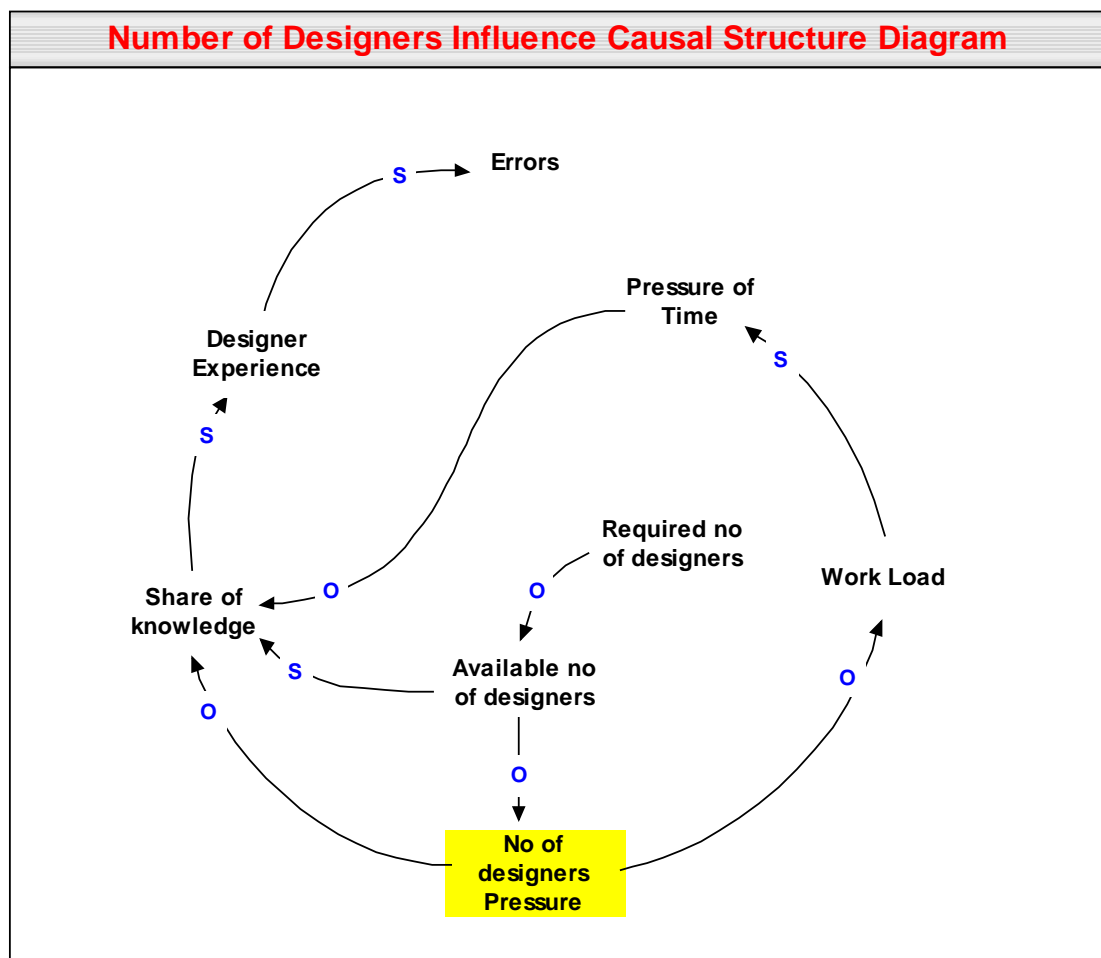


Figure 17 : Number of Designers Causal Diagram

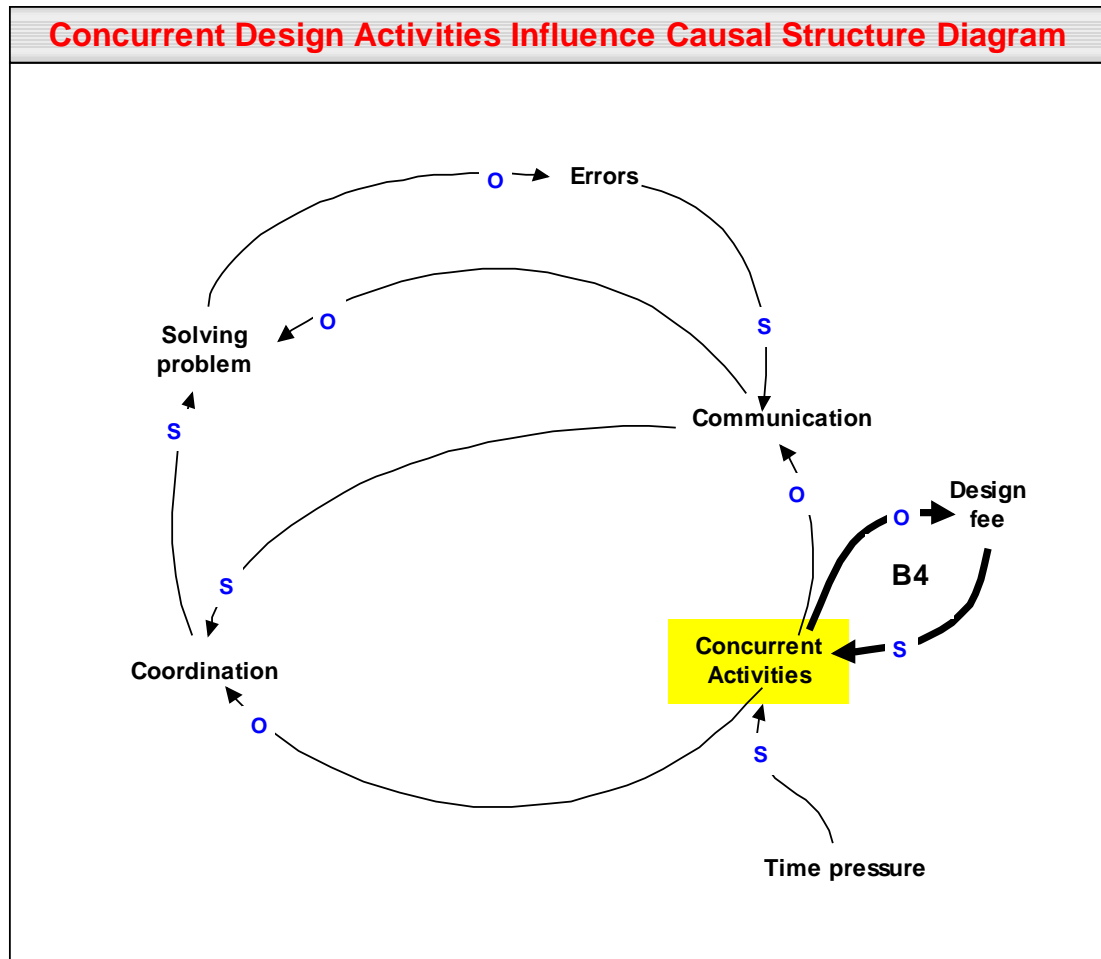
On the other hand, an increase in the number of designers on one side will increase the share of knowledge, while on the other side an increase in the number of designers will reduce the pressure on the designers. An increase in the amount of designer pressure will decrease the share of knowledge. An increase the share of knowledge will increase the designer's experience which will lead to a decrease in the number of errors generated in the construction documents of communication

#### **5.5.2.11 Concurrent design activities**

The general demand to develop products of higher quality at lower costs in even less time require a more parallel cycle of work in product development as opposed to the traditional mainly sequential cycle. Consequently, designers are collaborating more and more

in teams crossing both department and even company borders (E. Frankenberger et al., 1998). Concurrency is cited frequently by implication in the construction management literature as a cause of errors (Andrew, 1996).

The number of errors is deemed to rise as schedule pressure increases, when design fees are low, and when the degree of parallelism between tasks carried out by different designers increases. Inevitably, accelerated drawings and specifications are often prepared hurriedly, leaving room for a greater margin of errors and omissions (Fazio et al., 1988; Lyneis 2001). In other words, as tasks are performed concurrently, the number of interactions increases and the likelihood for errors occurring also increases (Williams et al., 1995). On the other hand, other researchers have found that the concurrent design activities will lead to the reduction of errors and minimize the rework, as more coordination and communication normally take place (Love et al., 1997, 155-162).



**Figure 18 : Concurrent Design Activities Causal Diagram**

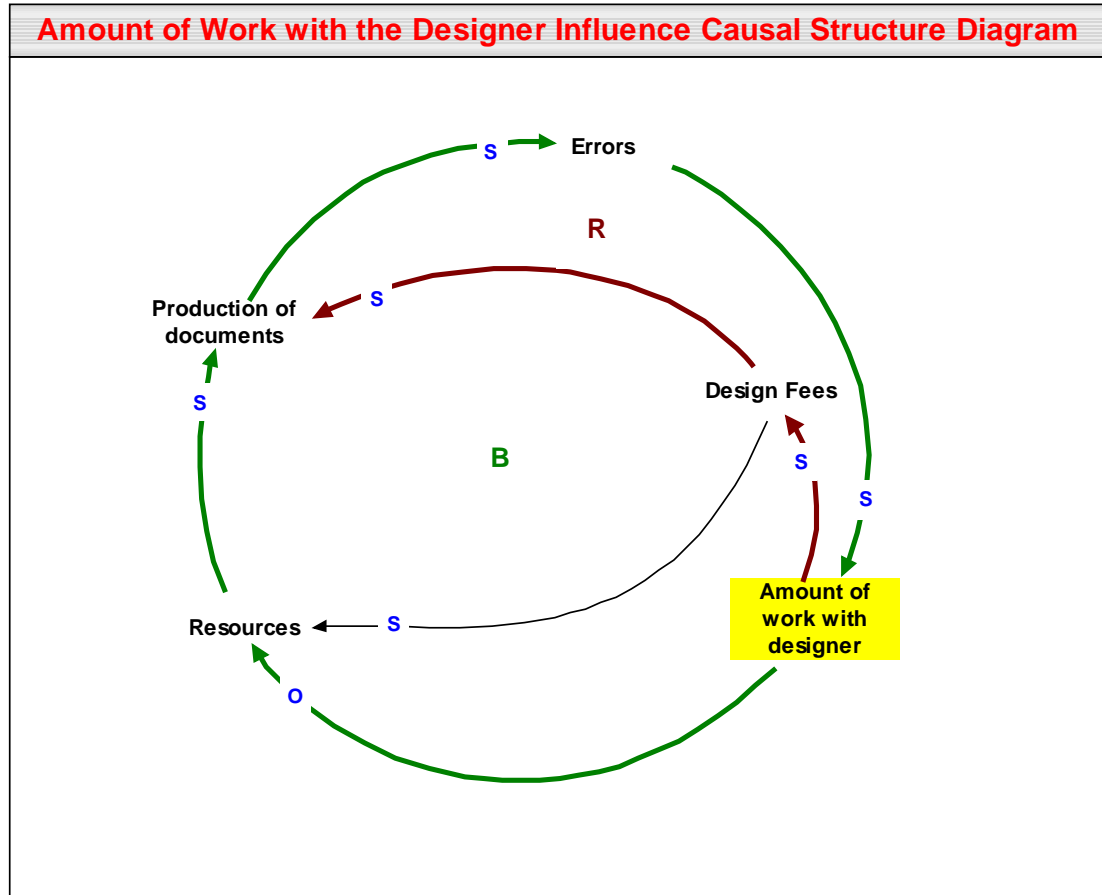
The diagram indicates a balancing loop when an increase in the concurrent activities will increase the design fees. An increase in the design fees will reduce the concurrent activities.

On the other hand, an increase in the concurrent activities will decrease the communication and coordination because of the pressure of the time. An increase in communication and coordination will increase the number of correctly solved problems. An increase in the solving of errors will reduce the number of errors generated in the construction documents.

#### 5.5.2.12 Amount of work with the Designer

In an organization in which multiple projects are being developed, scarce resources must be allocated between competing projects in different phases of the development process. The capacity of the design office to handle the number of projects will influence the number of errors generated in the construction documents (AIA 1994, p449).

The diagram indicates that amount of work with the designer will decrease the resources required for the job. An increase in the resource of the project will increase the production of documents. An increase in the production of documents will increase the number of errors generated.



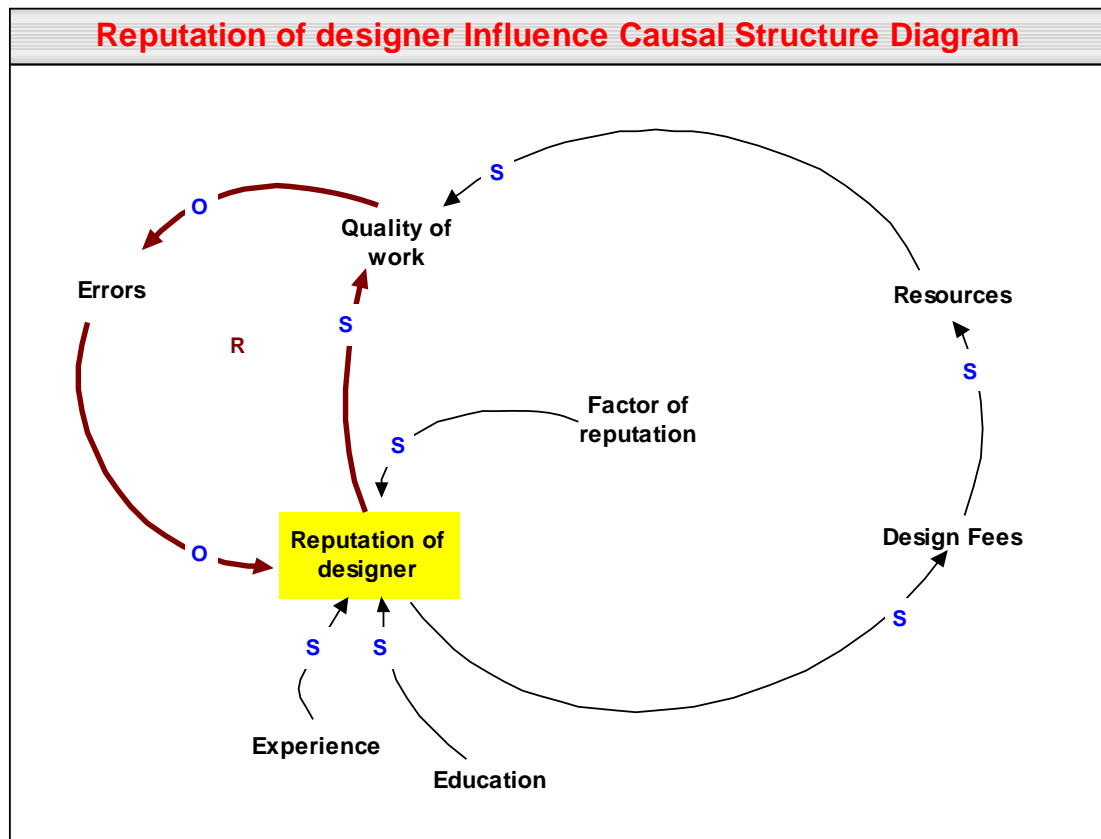
**Figure 19 : Amount of Work with the Designer Causal Diagram**

On the other hand, an increase in the amount of work with the designer will increase the design fees. An increase in the design fees will lead to an increase in the production of documents.

An increase in the number of errors generated in the documents will increase the amount of work with the designer.

### 5.5.2.13 Reputation of designer

The constancy of purpose toward improvement of product and services with the aim of becoming competitive and staying in business will influence the number of errors generated in the documents (AIA 1994, p328).



**Figure 20 : Reputation of Designer Causal Diagram**

The diagram indicates that reputation of the designer will lead to an increase in the quality of work. An increase in the quality of work will lead to a decrease in the number of errors generated in the construction documents

On the other hand, an increase in the reputation will lead to an increase in the design fees. An increase in the design fees will increase the amount of resources available for the project. An increase in the resources will increase the quality of work.

AN increase in the number of errors generated in the construction documents will decrease the reputation of the designer.

#### 5.5.2.14 Availability of quality management

Burbridge (1987, p16) found inadequate reviews, check and corrective control to be the main cause of failure in design quality. However, despite its widespread advocacy, the use of checking and inspection suffers from three limitations. First, checking is intermittent and cannot be expected to detect all errors (Kaminetzky, 1991). Second, checkers frequently make the same errors as the original perpetrators, thus rendering the process ineffective (Jones and Nathan, 1990; Petroski, 1994). Third, checking assumes that errors 'percolate' upwards from the work-face. Errors are as likely to

come from the checkers (Andrew 1996). These limitations indicate that checking alone will not remove all errors.

Tools exist for keeping track of quality in every phase of pre-design and design. These include project checklists, CAD standards, document formats, detail libraries, documents coordination and checking systems, punch lists, and a variety of other quality management methods and systems. Many firms have instituted process improvements as well, e.g. employing third party review of evolving projects within the firm.

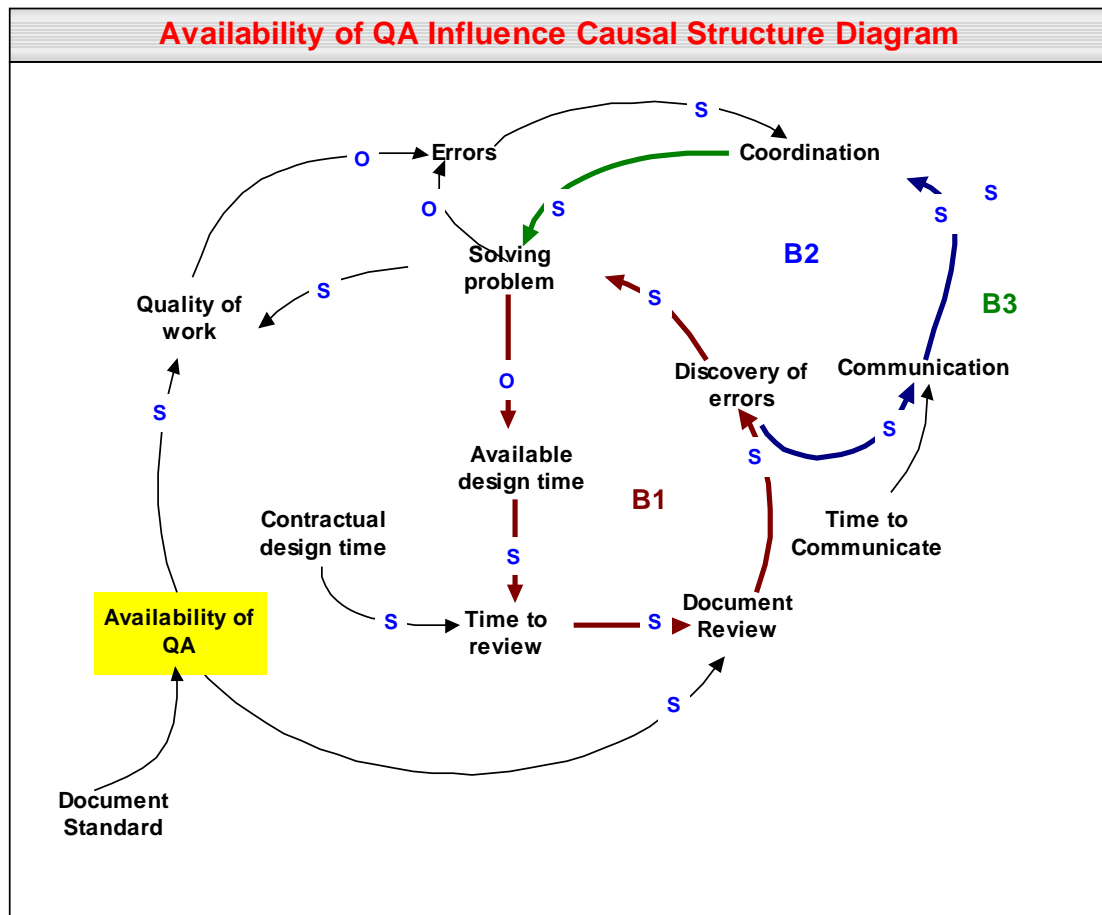
Traditionally, quality control mechanisms have been regarded as defence mechanisms. They are seen as a means of checking for deficiencies, catching and correcting errors, and as a means of avoiding liability and other unhappy consequences (Kirby et al., 1988 p69; AIA 1994, p327).

Burbridge (1987, p16) lists five main faults identified as causing failure in design quality:

- faulty lines of communication between participants in the design process;
- inadequate information available, or failure to check necessary information;
- inadequate reviews, check and corrective control;
- lack of technical expertise;
- failure to obtain feedback and learn from mistakes”

In conclusion, the availability of quality management in place will influence the number of errors generated in the construction documents.





**Figure 21 : Availability of QA Causal Diagram**

The diagram indicates that an increase in the availability of QA within the project will help in increasing the quality of work that will reduce the number of errors in the construction documents. The other benefit of QA is the document review that takes place during the QA. There is one balancing loop: increasing the document review will increase the discovery of errors in the documents. Increasing the discovery of errors will increase the problem solved, which will reduce the number of errors generated in the documents. On the other side, an increase in the discovery of errors will decrease the time available to carry out the work. The decrease in time will lead to a reduction of time available for review. A decrease in the time of the review will lead to a decrease in the number of documents reviewed.

#### 5.5.2.15 Effective design team

Effective management during the design phase is stressed in several papers (White, 1980; Schich, 1982; Fazio et al., 1988). An effective team is much more than the sum of the individuals who populate it. AIA (AIA-1994 p 553) has stated the following characteristics of effective design teams:

- Discussions that are interactive and open to all members.
- Mutual understanding of each other's role and skills.
- Appropriate combination of functional /technical, problem solving, and interpersonal skills among the members.
- A specific set of team goals in addition to individual and organisational goals.
- Realistic, ambitious goals that are clear and important to all team members.
- A specific set of team work products.
- A sense of mutual accountability, with members feeling individually and jointly responsible for the team's purpose, goals, approach, and work products.
- Ability to measure progress against specific goals.

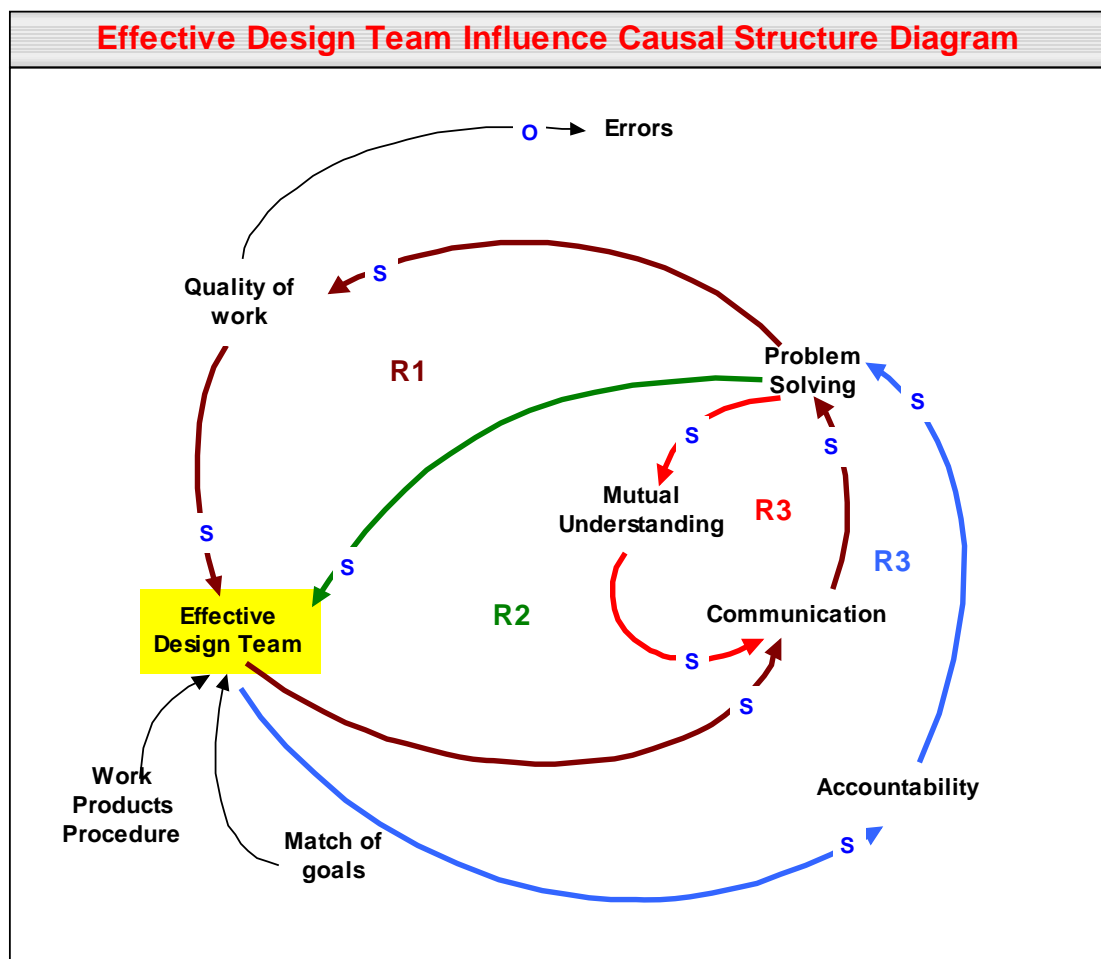


Figure 22 : Effective Design Team Causal Diagram

The existence of such an effective design team will minimize the occurrence of errors in the pre-contract stages because these teams will capitalize on and enhance the skills of those on the team and the work will be modified and improved over time.

The diagram indicates four reinforcing loops. The first reinforcing loop is where an increase in the effectiveness of the design team will increase the amount of communication which will increase the number of problems solved correctly which will increase the quality of work which will lead to a more effective design team.

The second reinforcing loop is where an increase in problem solving will increase the effectiveness of the design team. These will increase communication which will solve more problems.

The third reinforcing loop is where an increase in problem solving will lead to an increase in mutual understanding which will lead to an increase in communication which will solve more problems.

The fourth reinforcing loop is where an increase in the effectiveness of the design team will increase the accountability which will help to solve more problems, which will again increase the effectiveness of the design team.

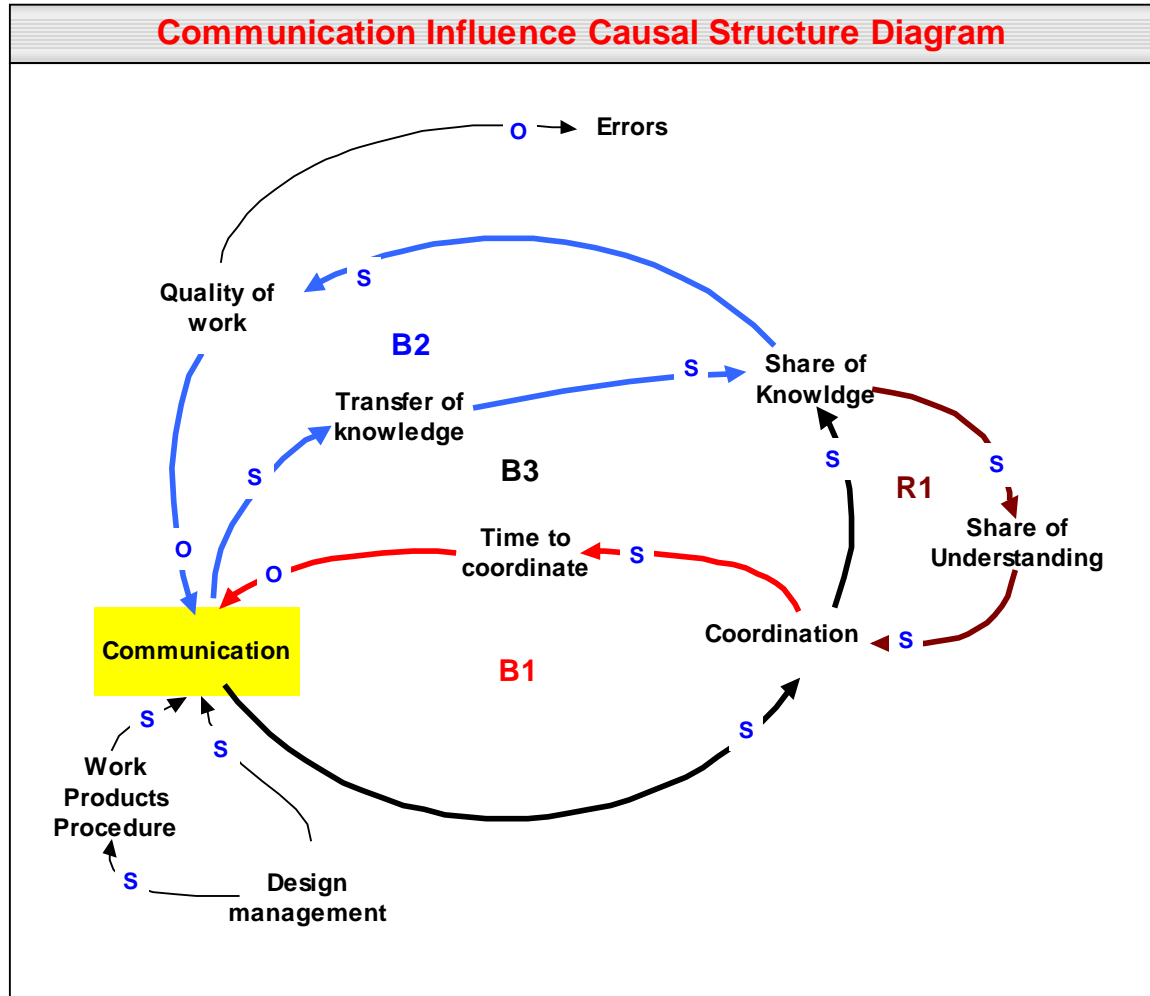
#### **5.5.2.16 Communication**

Working in a team requires the skills of the team members to communicate and collaborate. The aim of the design team is to share knowledge and information in order to achieve a better design. Shared understanding is a mutual view amongst the team members on relevant design topics and design activities. Therefore shared understanding is an important condition for team design and team decision making (Rianne, 1998).

Burbridge (1987, p16), found that a faulty line of communication between participants in the design process is a significant cause of failure in design quality. Similarly, Josephson (1996) found that, when measured by cost, design-caused defects are the biggest category. From design caused defects, those originating from lack of coordination between disciplines are the largest category.

The diagram indicates three balancing loops and one reinforcing loop. The first balancing loop is where an increase of communication is an increase in coordination which is an increase in the time required to perform coordination. An increase in the time of coordination will reduce the time remaining for the communication.

The second balancing loop is where an increase of communication will increase the transfer of the knowledge which will increase again the quality of work. An increase in the quality of work again will lead to less time being required to carry out communication.



**Figure 23 : Communication Causal Diagram**

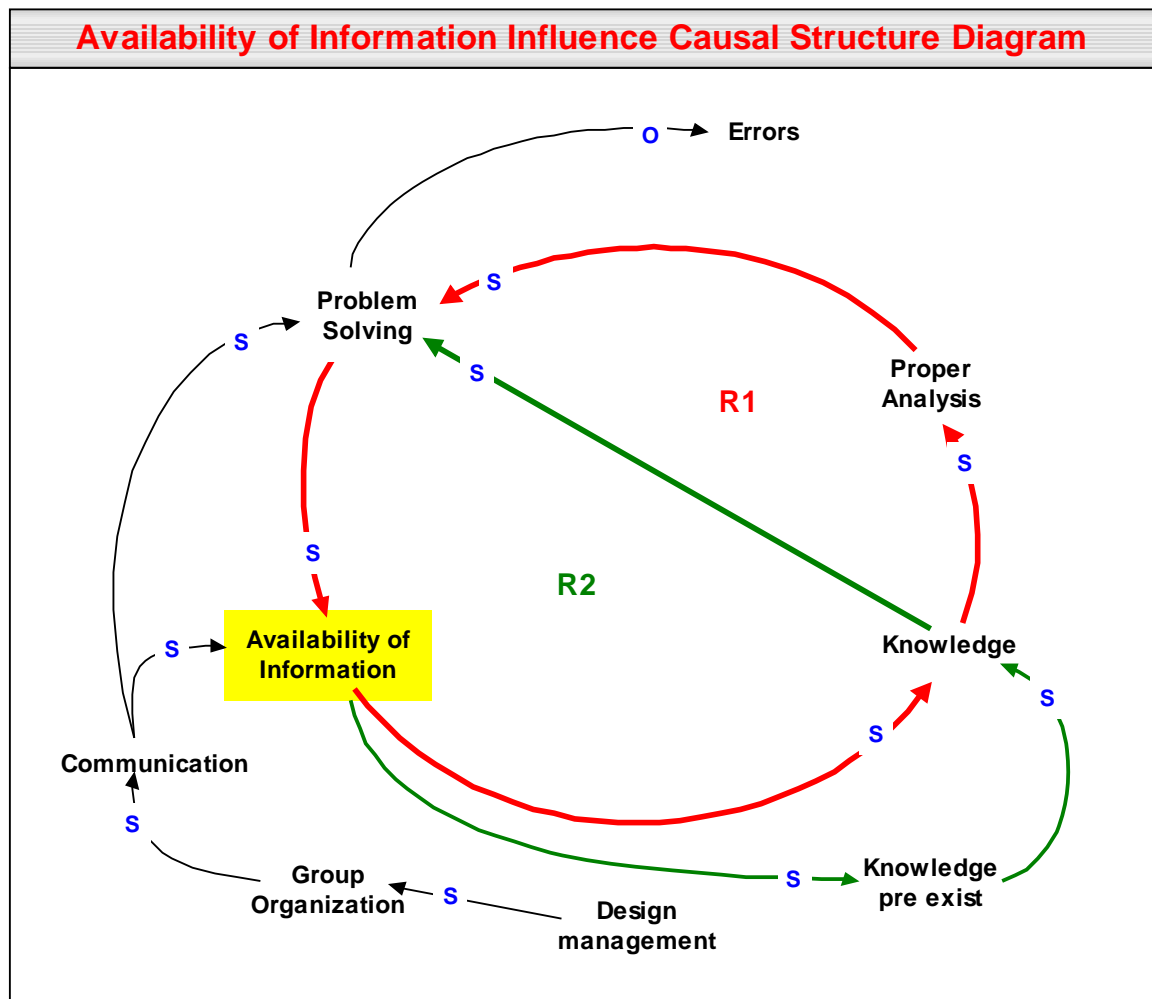
The first balancing loop is where an increase in the communication among team members will increase coordination which will increase the share of knowledge that will produce quality work. An increase in the quality of work will necessitate less required communication among the team.

The reinforcing loop is where an increase in coordination will increase the share of knowledge which will increase the share of understanding which will lead to an increase in the coordination again.

### 5.5.2.17 Availability of information

Burbridge (1987, p16) found that inadequate information available, or failure to check necessary information, is also a main cause of failure in design quality.

The availability of information for designers is the most frequent reason for both deficient analysis and wrong decisions (E. Frankenberger et al., 1998). Frankenberger found also that the main causes of non-availability of information are the quality of the leadership and the group-organisation, e.g. restricted access to the experience of colleagues.



**Figure 24 : Availability of Information Causal Diagram**

The diagram indicates that availability of information will increase the knowledge among the team members which will increase the problem solving. Increasing the problem solving will in turn increase the available information and create a reinforcing loop. The other reinforcing loop is where an increase in the available information will increase knowledge. An increase in knowledge will increase the proper analysis which will increase the problem solving. An increase in the problem solving will again increase the available information to the team members.

On the other hand, an increase of available information will increase the existing knowledge for the team members which add to the knowledge required to carry out the work.

### 5.5.2.18 Transfer of knowledge and experience between designers

The individual must also have the necessary knowledge and the necessary information for the specific task. Knowledge is information and understanding about a subject which a person has in his mind or which is shared by all human beings. Knowledge includes skill and experience. Skill is the knowledge and ability that enables a person to do something, such as a job, game, or sport very well (Collins, 1987).

Burbridge (1987, p16) found that failure to obtain feedback and learn from mistakes is a main cause of failure in design quality.

Experience and knowledge are gained through years of working. A lack of the mechanism to transfer this knowledge will result in restarting the work from scratch each time and this will lead to a repetition of errors which had occurred previously on another project.

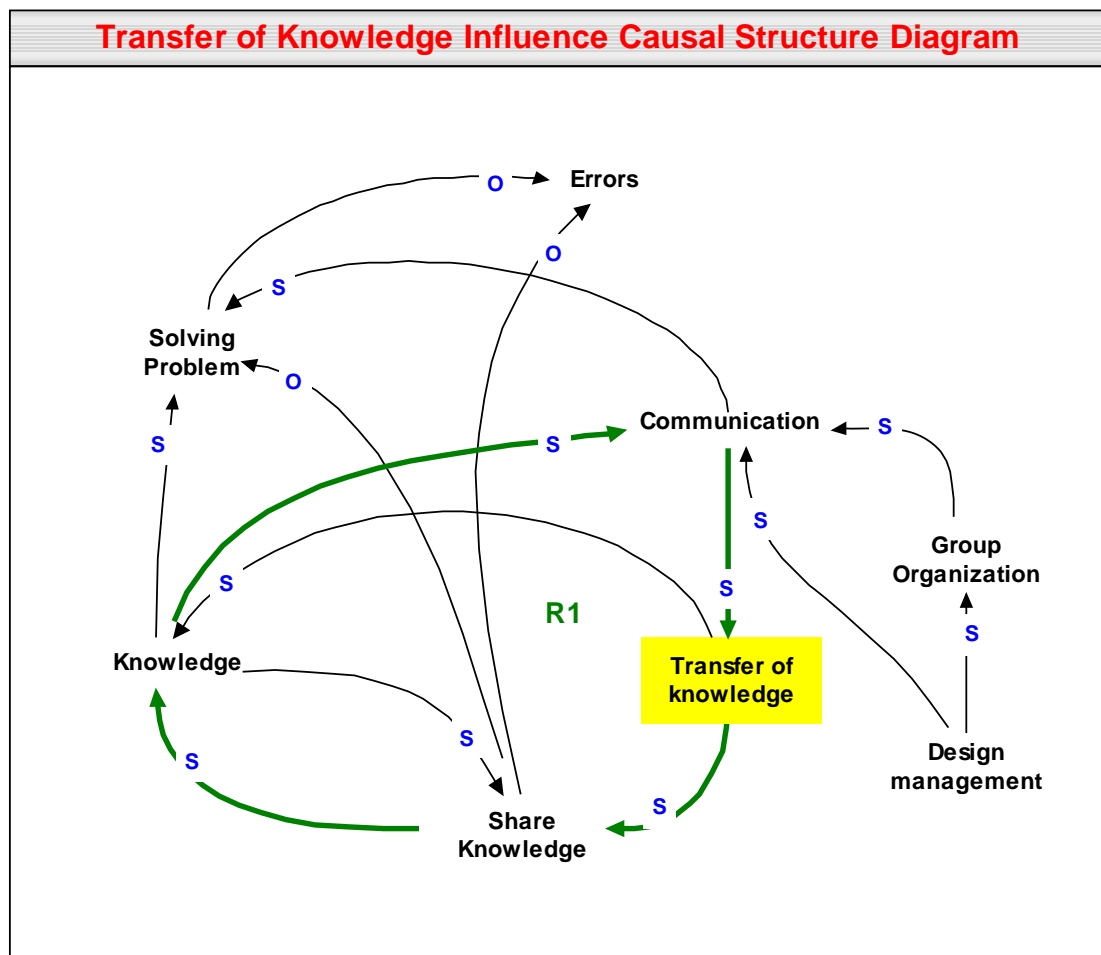


Figure 25 : Transfer of Knowledge Causal Diagram

The diagram indicates that an increase in the transfer of knowledge among the team members will increase the sharing of knowledge. An increase of the sharing of

knowledge will increase the knowledge required for the project. An increase of knowledge will increase communication. An increase of communication will again increase the transfer of knowledge and create a reinforcing loop.

On the other hand, an increase in transfer will increase the knowledge. An increase of knowledge will increase the sharing of knowledge.

However; all these factors are interrelated and interact with each other and with other intermediate factors, as indicated in the following figure which shows how the factors influence each other in a dynamic and complex manner.



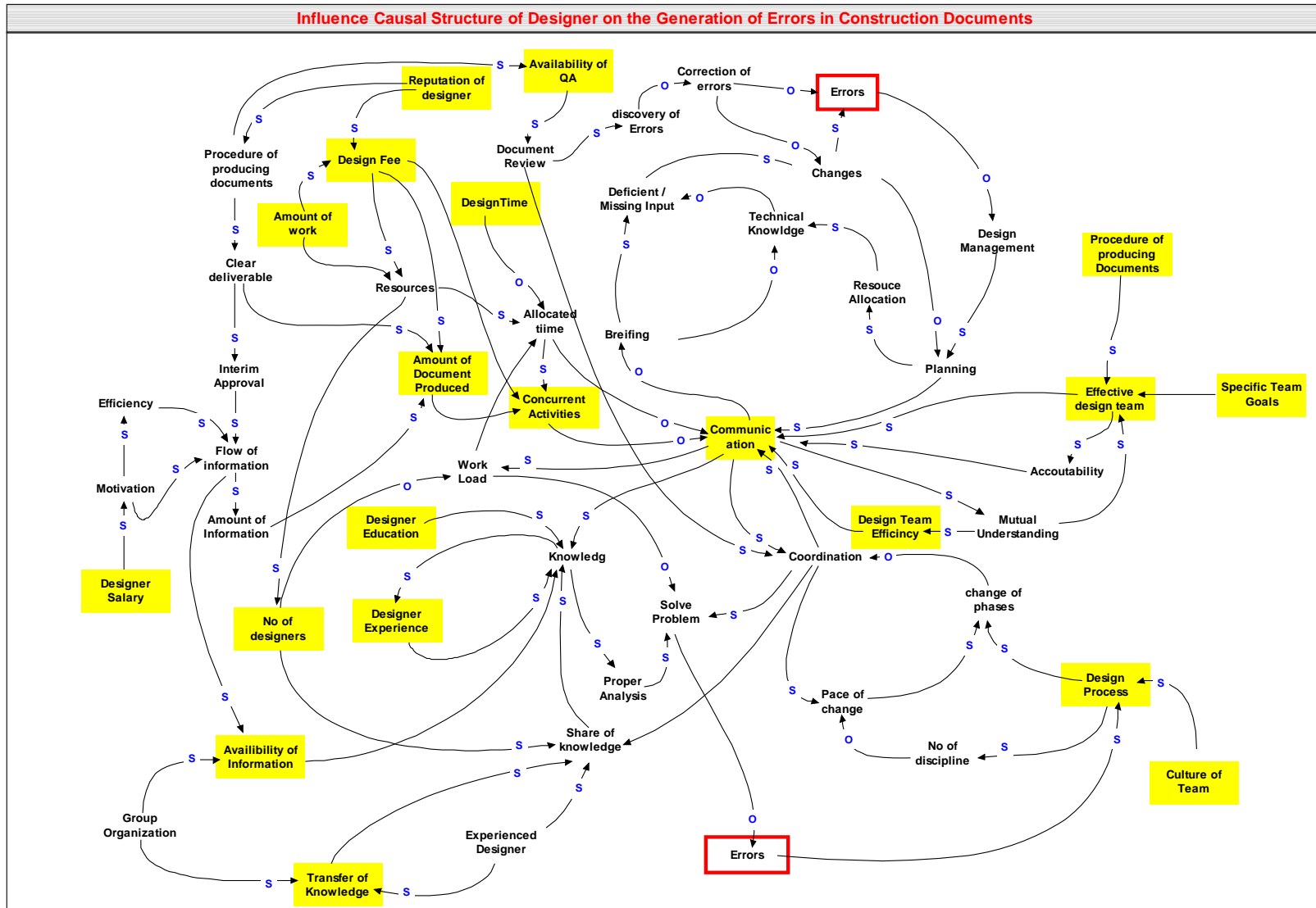


Figure 26 : Causal Diagram Of Designer Influence On The Occurrence Of Errors In The Construction Documents

### **5.5.3 Client**

The client is the entity that identifies the need for a building and is the genesis of the construction process. The client defines project objectives independently or in conjunction with advisers. Shaping a project's scope and complexity, therefore, lies very much in the hands of the client and project inception team. As Sidwell (1984, p90) observes, "clients who get the quickest result are those who provide the building team with well defined specialized needs and are able to become closely involved with the building process".

The client also commissions principal consultants and has input into the approval of sub-consultants. The moulding of a project team into a cohesive entity that can achieve shared objectives was identified as having an important influence on project success in a report of the Construction Industry Institute (CII) in the USA (Rowings et al., 1987). The importance of clear goal definition to management success has also been identified by others (Hersey and Blanchard 1982, p117-118). If the client has clear, well-enunciated goals which are effectively communicated in the briefing and team selection process, then it can be expected that a better climate exists for goal congruence. A better chance of project success is a consequence of this. The client also needs to have a clear idea of the expected performance and reputation of key project team members to build effectively a project team that has a promising chance of success.

NEDO (1988, p76-77) notes that superficial design changes caused "inordinate upheaval and extension to programs". The report notes that disorder can be contained if variations are administered effectively and decisions are made quickly in a climate of trust between all participants.

The client has a role to play in project (Walker 1994) by: "Maintaining control over the design development even if it means periodically auditing design documentation to minimize design errors".

Ensuring that design resources are adequate to design to the detail required so that design in haste is not an outcome. This may result in the appointment of a document-planning advisor to assist in the planning and monitoring of design development and to permit processing.

Ensuring the construction time performance implications of design variations generated by the client are fully understood, appreciated and considered so that

appropriate action may be taken to integrate them into the construction process, shelve them or to release contingency budgeted cost and time to accommodate them. Ensuring the conflicting requirements and/or objectives are not given. This can be avoided by appointing a strong project manager with authority and sufficient credibility to interact with key client decision makers to present cases and discuss policy so that a unified response emerges from the client organization on all decisions made. "

To achieve the above role, the clients can perform a useful role in ensuring that a brief is properly and clearly given, that appropriate consultants are commissioned and an appropriate management structure for the management of the project and the construction process is established. Sidwell (1982) demonstrated that sophisticated clients (those having built projects before) and specialized clients (who repeat similar buildings) had a better chance of success with their projects than novices.

The following are the factors that come under the client umbrella and impact on the number of errors occurring in the construction documents:-

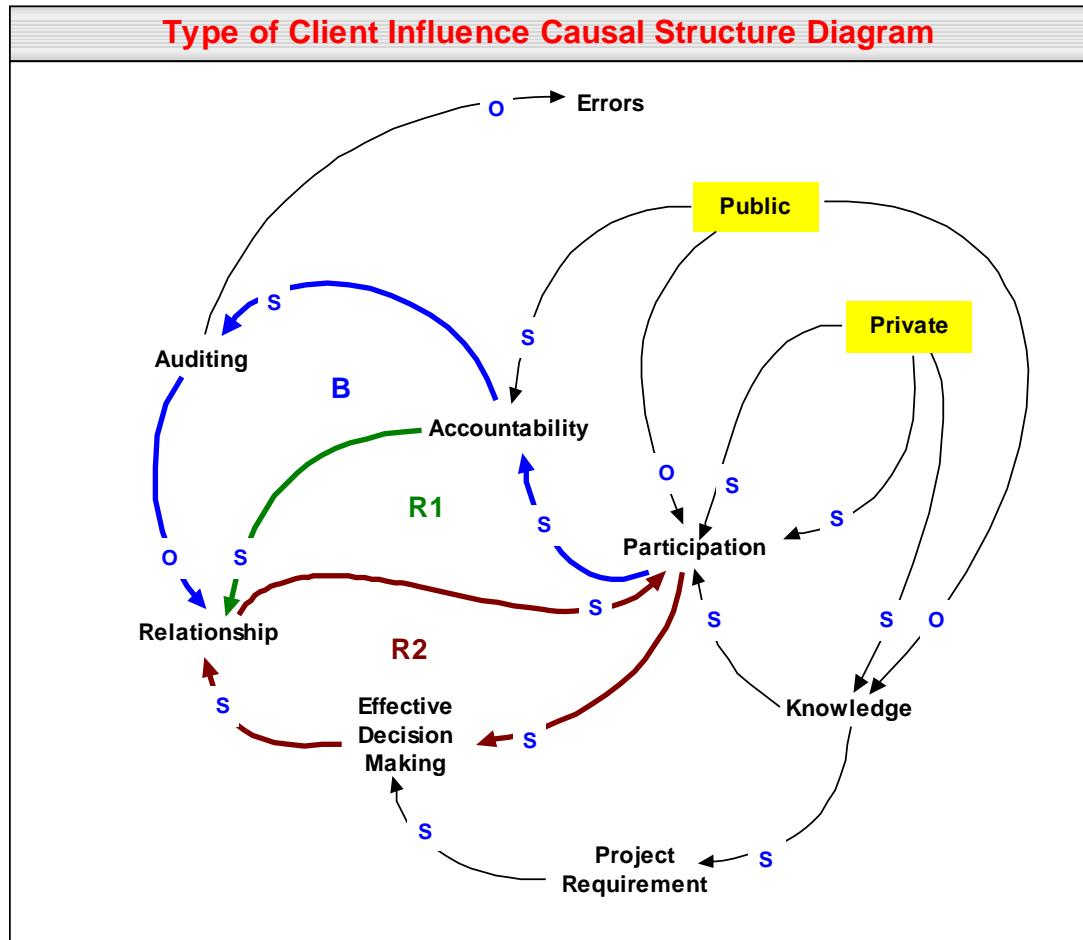
#### **5.5.3.1 Type of client (private, government, developer)**

Sidwell (1982) established that public clients, who may well, as an organization, have much experience of commissioning buildings and many similar buildings, can experience higher cost and time over run compared with privately funded clients. He explains this in part by drawing attention to bureaucratic procedures that are publicly funded and to which some privately funded clients are subject. Kaka and Price (1991, p398) in a study of 801 UK projects conclude that public buildings take longer to build than private ones of similar construction cost. Similarly in his study of many cases of Australian projects, Walker (1994) found that government projects are likely to take longer to construct than similar private sector client projects.

However this view may be missing the point in that the real issue may be accountability and rigid adherence to procedures for decision making, approval and control mechanisms that inhibit innovative approaches which place a brake upon the pace of the decision-making process.

Walker (1994) found that the client’s sophistication needed to be measured in terms of performance (rather than designation of being from the public or private sector or experienced in terms of having being involved in few or many projects).

A sophisticated client can overcome design team inefficiencies by imposing a high level of design management over weak design consultants. A project management consultant can likewise impose measures to counter construction team inefficiencies if required when empowered by the client.



**Figure 27 : Type of Client Causal Diagram**

The diagram indicates that the type of client will influence the accountability, participation and knowledge available to carry out the job. An increase of knowledge will increase participation and better definition of the project requirements. More participation and more defined project requirement will support better decision making.

The first loop is a balancing loop where increasing in participation will increase the accountability which will increase auditing which deteriorates the relationship among the team members. An increase in the relationship will increase the participation.

The second loop is a reinforcing loop, where An increase of participation will increase accountability. An increase in the accountability will increase the relationship. An increase in the relationship will increase participation.

The third loop is reinforcing as well, where an increase in the participation will increase the effectiveness in decision making, which will increase the good relationship which will increase as well as the participation.

### **5.5.3.2 Client experience**

Less experienced clients may have unrealistic expectations of consultants. They may expect more than the law requires of architects and will be disappointed with anything less.

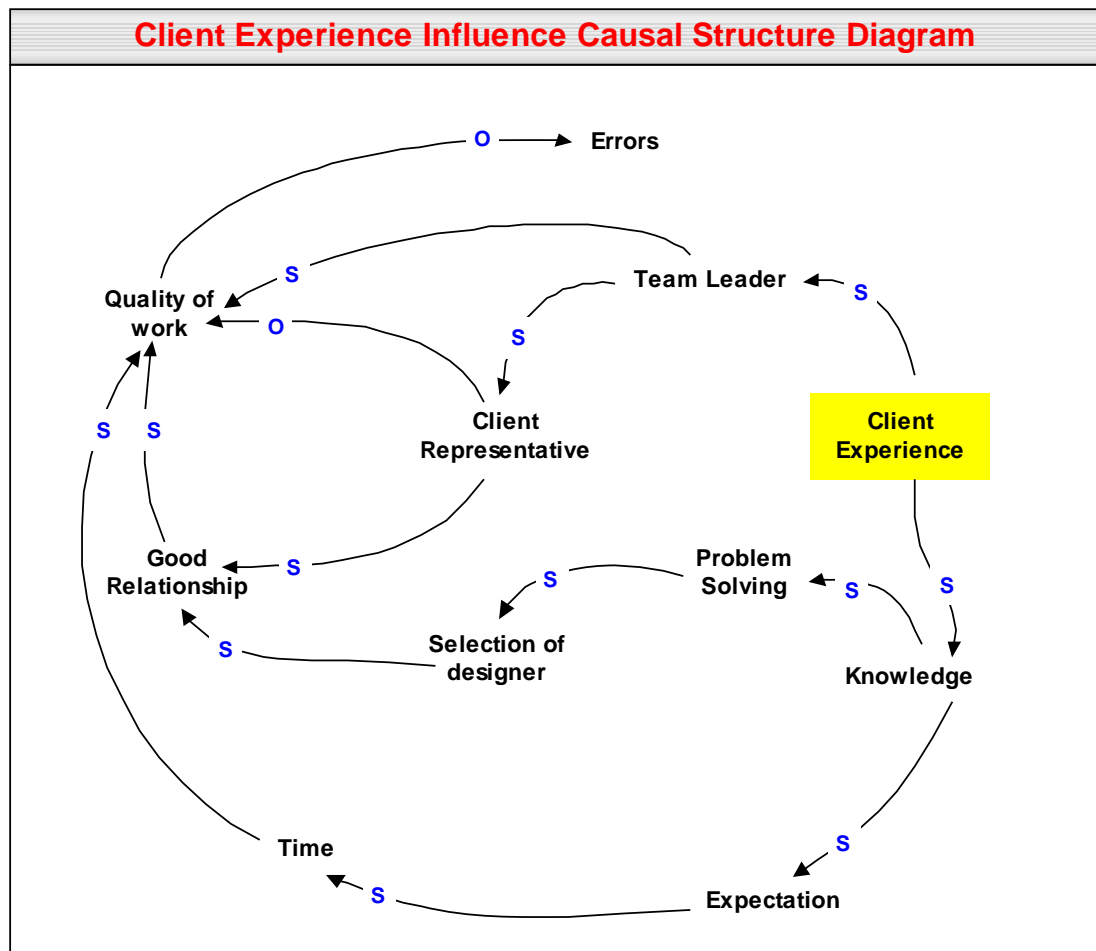
A client who is experienced and sophisticated in terms of project management may choose to take the initiative and lead the process. In many instances the client is a corporation, government department or syndicate of joint ventures. In these circumstances it is usual to appoint a project manager as client representative (CR); this can be accomplished in ways outlined by Barnett (1988/89) and Ireland (1987). The client or CR often chooses to allow other team members to take much of the initiative, e.g. the architect or project manager for reasons that may include a lack of desire, resources or experience. The characteristic of experience may be individual and not organizational. If an organization has built up experience, then knowledge and expertise are available to an individual; however, the individual may not have access to or be aware of this resource.

NEDO (1988, p53) demonstrated the key influence of the client on the outcome of building projects which is mirrored by the client's skill in "...clearly expressing project objectives in terms of building requirements, cost and time budgets; defining the procurement strategy and the input that the client can make to the project; bringing together a possibly unique configuration of specialists to work as a team; determining the level of service expected from each member of the project team".

Clients express their brief in a variety of ways, ranging from highly developed requirements, such as extension or expansion plans for manufacturing plants, to vague impressions of shortcomings in an existing facility.

NEDO (1988) illustrates examples of actions taken by "very professional" clients and their approach to the development of the brief, design and construction process. These customers, typically supermarket and chain store developers, have standard briefs

which succinctly define their requirements. Instructions include distribution of responsibilities between project team members, lists of preferred suppliers and specialist contractors and even proposed design concepts and construction techniques. The brief also commits principal consultants to produce a plan of key decisions required of the customer and a timetable of decisions required of specialist consultants, subcontractors and suppliers as well as planning the design development phase (including detailed design and shop drawing production). NEDO (1988, p65) states: “ ...in the study, this extent of initial effort was vindicated by the success of the projects and the confident spirit in which it was achieved. It demonstrated the usefulness of defining at the outset a comprehensive strategy for the project and a firm context for the responsibilities and contributions of participants”.



**Figure 28 : Client Experience Causal Diagram**

The diagram indicates that an increase in the client experience will increase the leadership and knowledge available for the project team. An increase in the knowledge will help understanding the type of problems that will face the project which will help in selecting appropriate designers which will increase the good relationship among the team members which will lead to increase in the quality of the

work of the construction documents. An increase of the knowledge of the client will determine his expectation which will determine the suitable time required for the project which will allow adequate time to produce quality work.

On the other hand, a proper team leader will lead to the production of quality of work and will allow the selection of appropriate client representatives. The selection of proper client representative will increase the quality of work and will ensure a proper relationship among the team members which will lead again to an increase in the quality of work.

### **5.5.3.3 Construction constraint time (start or finish)**

The construction constraint time imposes a time pressure on the project team to finalise the project, regardless of the actual time required to finish the project. Such pressure will minimize the time for coordination and increase the parallelisation of activities during the preparation of the construction documents, which leads finally to an increase in the number of errors in the pre-contract stages.

NEDO (1987, p18-19) illustrates general design quality problems shared by a fast track approach. Also, NEDO (1987, p31) concluded that “time constraints did not necessarily lead to poor quality; unrealistic constraints led to problems. Late and incomplete project information was a frustration on many sites. It leads site managers to spend an undue amount of their time on chasing information rather than on managing their job and on quality control”

Poor design coordination may result from inadequate attention being given to detailed design or it may follow from a general atmosphere of haste surrounding fast-tracked projects. While overlap of design and construction can save time for the client, it may cause delays during the construction phase from problems associated with design coordination and design detailing. Problems occurring from fast tracking designs include: lack of coordination owing to design instability, unclear or missing information as a result of unavailable finalized documentation; and design details that will not work because of hasty design production betraying a lack of proper consideration.

The diagram indicates that an increase of the constraint time will decrease the number of document produced, will increase the concurrent activities and will decrease the attention to details.

An increase in concurrent activities will reduce the pressure of time and will create a balancing loop.

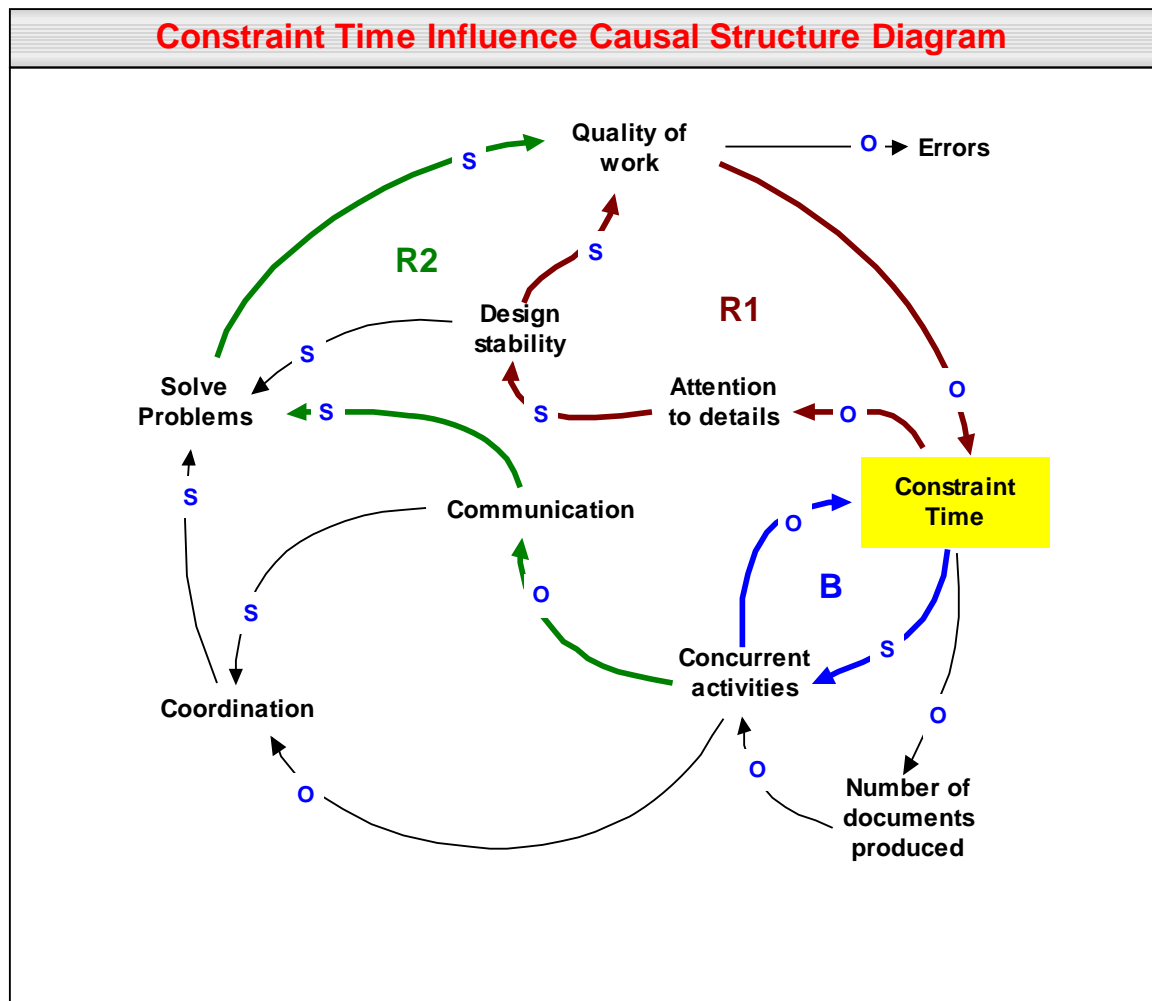


Figure 29 : Constraint Time Causal Diagram

An increase in the concurrent activities will impact the communication and coordination. An increase in communication and coordination will lead to resolution of more problems which will lead to an increase of the quality of work.

On the other hand, an increase in attention to details will increase the design stability which will increase the quality of work. An increase in the quality of work will decrease the pressure of time and will create a second balancing reinforcing loop.

The third loop is a reinforcing loop where the constraint time will increase the concurrent activities. An increase in concurrent activities will decrease communication. An increase in communication will increase problem solving. AN increase in the solving of problems will increase the quality of work. An increase in the quality of work will decrease the pressure of time on the project team members while producing the construction documents.



#### **5.5.3.4 Client Point of contact**

NEDO (1988, p64) has demonstrated that of central importance of a well-managed connection between design and construction for project success is that the client must avoid disunity in his / her interaction with the design team. To this end a single entity should represent the owner's interests and be given sufficient authority to communicate directives and make judgments on behalf of the client. More generally, if a disparate group controls the decision-making process in any project, then a strong likelihood of confusion, decision reversal and untimely decision making may ensue with their attendant problems of generating temporary "holds" on construction work and contract variations (which have been shown to inhibit good performance (Ireland 1983)). This concept of a single point of contact has been stressed by many researchers in the field of project management (Barnett, 1988/9 and Ireland, 1987).

NEDO (1988) provides case-history data for appreciating the effect that a client or client's representatives can have upon the project performance. The following observations from the report (p55-56) are summarized:

“Client representatives were usually members of the customer's own staff who coordinate and express customer requirements for buildings, act throughout the project's cycle as the point of contact for communications and decisions, and participate in the management of projects; they also had the authority, time and knowledge to define and demand the level of service required; customers who built regularly usually had a staff of specialists with a thorough professional understanding of the construction process; typically their first concern was to set the project in motion, taking great care to select and appoint design and construction teams; customer's project managers would move to the site as coordinators or effectively take over management of construction if called upon. Interventions by customer's project managers were decisive on a number of fast projects. More often than not their involvement exceeded that normally expected of a purchaser; on over half of the 60 projects with detailed data collected, and two thirds of shopping developments, customers played a direct part in the construction phase. It is enlightening to note that the average overrun of these

was 1 week with client participants (through on-site representation) and 10 weeks where control was in the hands of professionals and contractors.

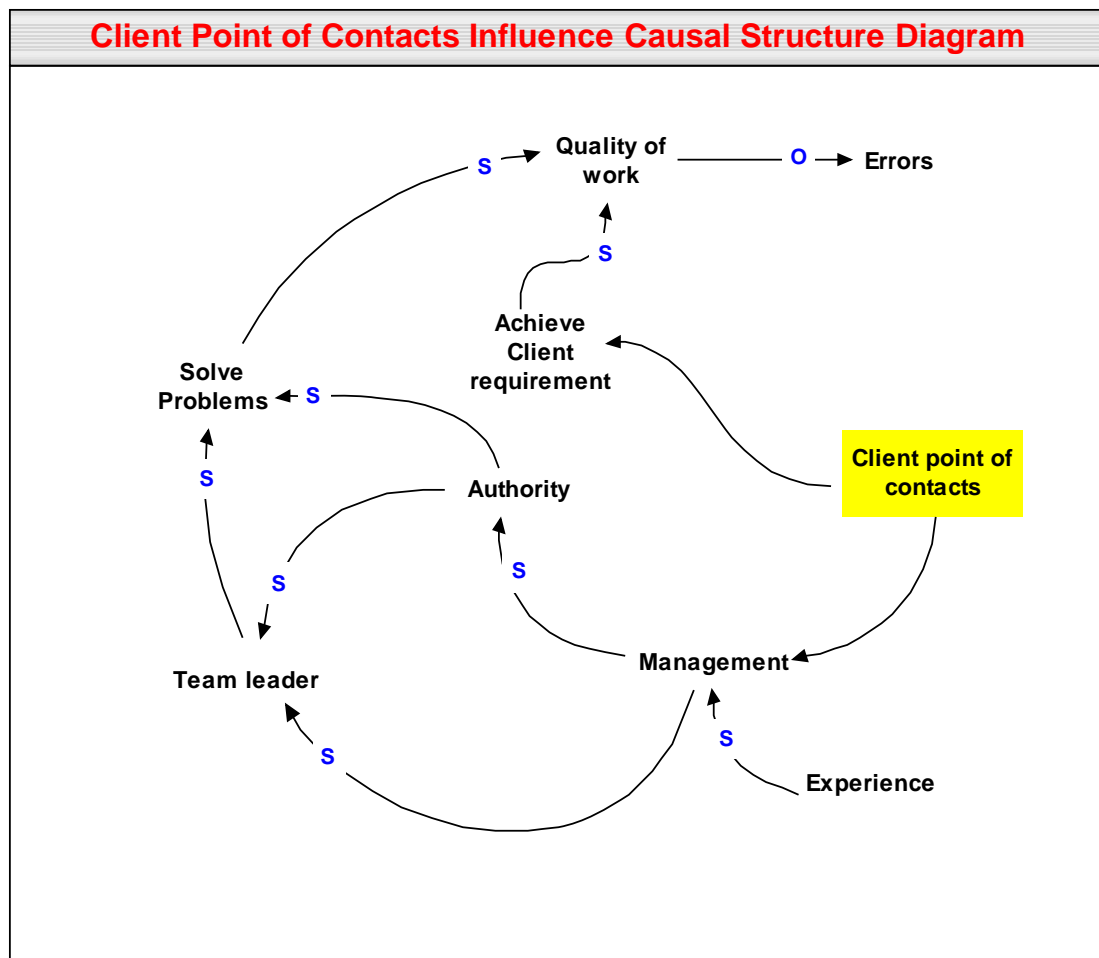
Customer direct influence and participation were motivated by the need to manage design changes effectively, stemming from tenant requirements to minimize in the disruption of construction performance; those clients who performed their role in this manner usually did so as a reflection of their greater stake in the success from their own perspective rather than success measures perceived by other project team members.”

These comments indicate a tendency towards the success of pro-active clients who work with the project team, assuming leadership and control when and where necessary. These clients forge unified goals and maintain focus upon project’s goals rather than goals of individuals or small groups. Their response is also consistent with a “braided-chain” notion, the client underpinning shortcomings in the design or construction team.

The client point of contact must be able to manage the client to ensure that changes to decisions are minimised, that timely decision making is taking place, and that the briefing stage is properly undertaken.

Client organizations may be highly experienced but individuals acting in the role of project sponsor/client may be inexperienced or overloaded with work and relying on delegated persons of lesser experience. Many researchers maintain that clients should participate actively and supportively throughout the project life cycle (Sidwell, 1982; Ireland, 1983; NEDO, 1988, p12-13; Bresnen et al., 1988; Bresnen and Haslam, 1991, p339).

The diagram indicates that the client point of contact will influence the management of the team and implementation of the client requirements. Proper management will support the authority and appointment of the team leader.



**Figure 30 : Client Point of Contacts Causal Diagram**

An increase of authority will increase solving of problems and support the team leader role. An increase in problem solving will increase the quality of work and reduce the number of errors in the construction documents.

On the other hand proper implementation of the client requirement will increase the quality of work.

### 5.5.3.5 Planning of the project

Ireland (1983, p71) concluded that construction performance was positively affected by increased planning prior to taking possession of a site and commencing construction activities. He also found that increased use of time planning and control techniques by contractors also proved significant in reducing construction time. His research indicates that construction during design assisted in good construction performance (Ireland 1983, p111), specifically planning: "Prior to construction by

identifying potential problems and constraints and developing plans to overcome them; during design and incorporating elements of buildability into the design through generation of alternative design solutions; the design documentation process to better coordinate and prepare design solutions and minimize design gaps or omissions that may prove costly to overcome during construction".

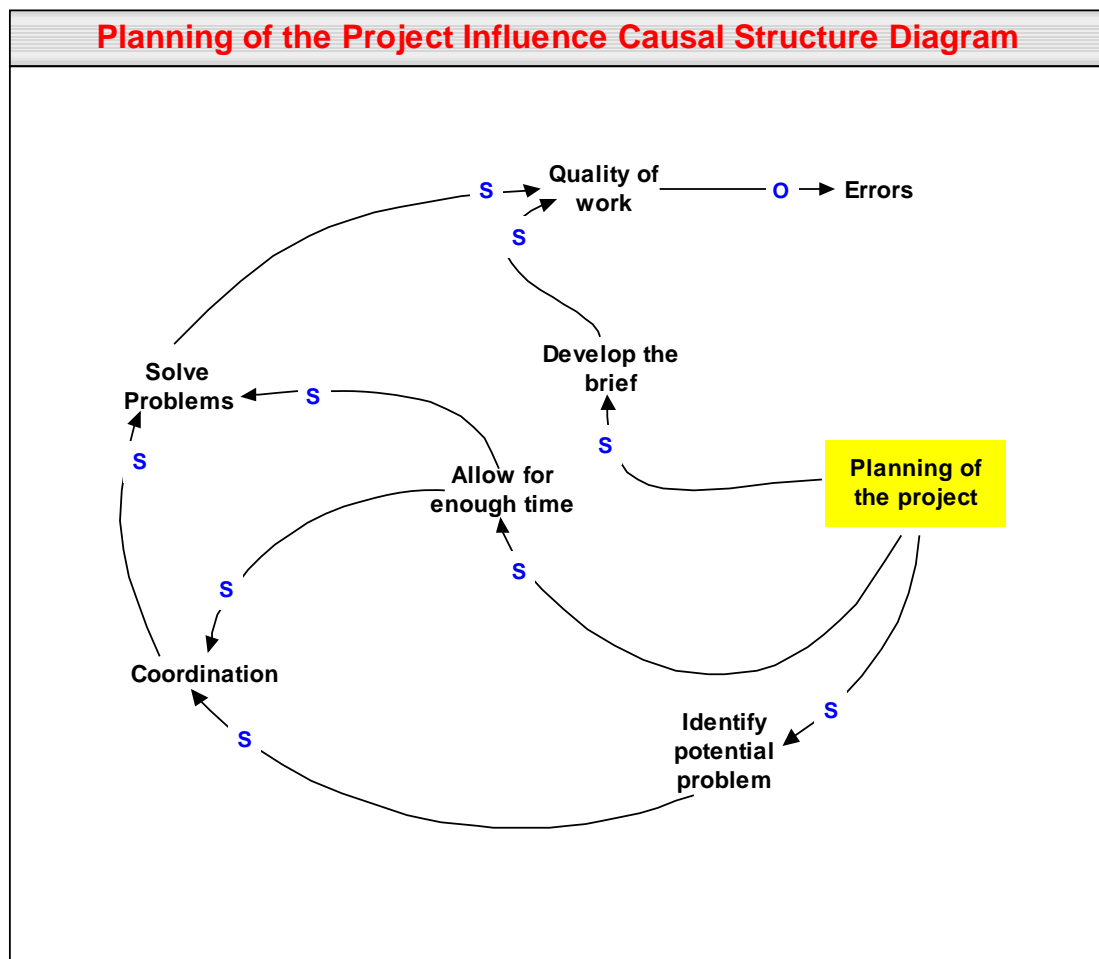
The process of initial planning helps in identifying and quantifying the magnitude of potential problems related to the project, including industrial relations opportunities and threats and construction methods. Plans are, at best, intelligent guesses because they predict probable outcomes in an environment of complexity and uncertainty where too many factors affecting project performance exist to be fully examined and accurately quantified. By accepting that circumstances are constantly changing, it follows that plans quickly become out of date. It further follows that plans need to be regularly updated to reflect changes in circumstances. Failure to monitor plans adequately leads to a "seat of the pant" management approach. This is equally true for management of the design process as it is for the construction process.

Planning and monitoring need to be done by all project stake holders for control to be possible. Many clients appoint planning and scheduling consultants who advise the client on progress achieved by both design and construction team members.

Barnes (1989) suggests that planning and time control is not just a set of techniques but also a management philosophy. His summarized advice is as follows: "set up time control managements, not just planning; always make management decisions with the benefit of a time forecast; look ahead at progress meetings, never back."

Bennett (1993, p4) observes from over seven years of studying the Japanese construction industry that planning is an important element of Japanese success in delivering projects. He states that "the distinctive strength of the Japanese building industry is its ability to plan work on site in exceptional detail and then put the plan into effect, on every project, with remarkable consistency". The thrust of his analysis is: that plans are well considered by all involved in the production process, that planning is carried out at the design stage with adequate input of construction production personnel to influence design to be buildable; and that there is excellent communication of plans. Control is achieved by means of a consistent sequence of daily meetings on site. At the start of each day, teams of subcontractors are brought together to be briefed on the expected milestones for that day.

Project time success indicators derived from the literature appear to revolve around effectiveness of planning, coordination and control. Project planning effectiveness relies upon the basics underpinning the process, i.e. effectively defining objectives and goals, forecasting data used in plans, analyzing proposed work methods and resource requirements and availability, monitoring progress, ensuring flexibility to work around problems encountered or take advantage of opportunities presented, coordinating to meet the plan, and undertaking action. It is contended that these are the core issues relating to construction management procedures.



**Figure 31 : Planning of the Project Causal Diagram**

The diagram indicates that an increase in the planning of the project increases the identification of potential problems, allows for enough time and increases the development of the project brief. By developing the brief, the quality of work will be increased as all the requirements of the project will be identified. By allowing for enough time, coordination will have enough time. By identifying more problems before starting the work, enough time for these problems to be coordinated will be allowed. By allowing enough time and increasing the coordination, the solving of

problems will be increased. Solving more problems will increase the quality of work and reduce the number of errors in the construction documents.

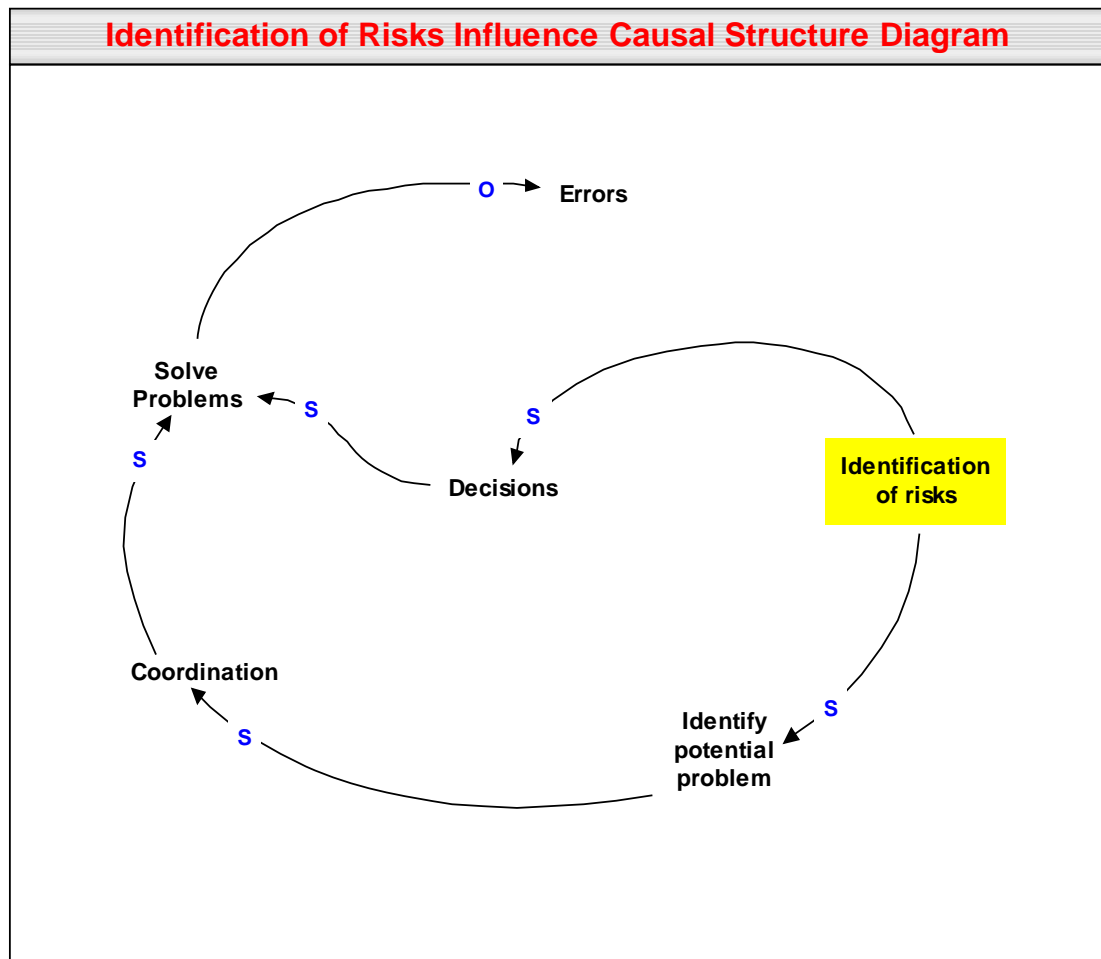
#### **5.5.3.6 Identification of project risks;**

Allocation of risk for parts of the design, construction and management of projects is defined in contractual arrangement. Hayes et al. (1986) state that “the development of a contractual strategy is an important task for a client or project manager, and requires a thorough assessment of the choices available for both the execution and management of the design and construction processes”. The decisions taken during the development of a contract strategy clearly affect the responsibility of those involved in the project. They influence the control of the design, construction and commissioning and hence the coordination of the parties. They also allocate risk and define policies for risk management as well as defining the extent of control transferred to contractors”. A wide range of non-traditional forms of contractual arrangements have been identified by others ( Barnett, 1988/9; Naoum, 1991 and Ireland 1987).

Berkeley et al. (1991, p6) maintain that “no risk should be ignored, no project risk should be dealt with in a completely arbitrary way; project risks should be identified during the earliest project phases; no major project decisions should be made unless those risks having the greatest impact on the project manager’s decisions be clearly understood, practical project risk appraisal should be subject to review. An assessment should also be completed of the variable risk factors acting upon the project and their likely extent and level of interaction; more project effort should be devoted to risk management as a rigorous and continuing activity throughout the project life.”

The recommendations advanced in “No Dispute” (NWPC/NBCC 1990, p6) state that a party to a contract should bear a risk where the risk is within the party’s control”.

MacPherson (1991, p39) discusses the success of phases 5, 9 and 10 of the Broadgate project in London. He describes the great effort expended on identifying risk, negotiating the acceptance of that risk by those able to control it, and the sensible management of people and resources in an environment of self-discipline, self direction and recognition of the advantages of cooperation. The impression given is that risk was well planned for, accommodated, and managed on the project.



**Figure 32 : Identification of Risks Causal Diagram**

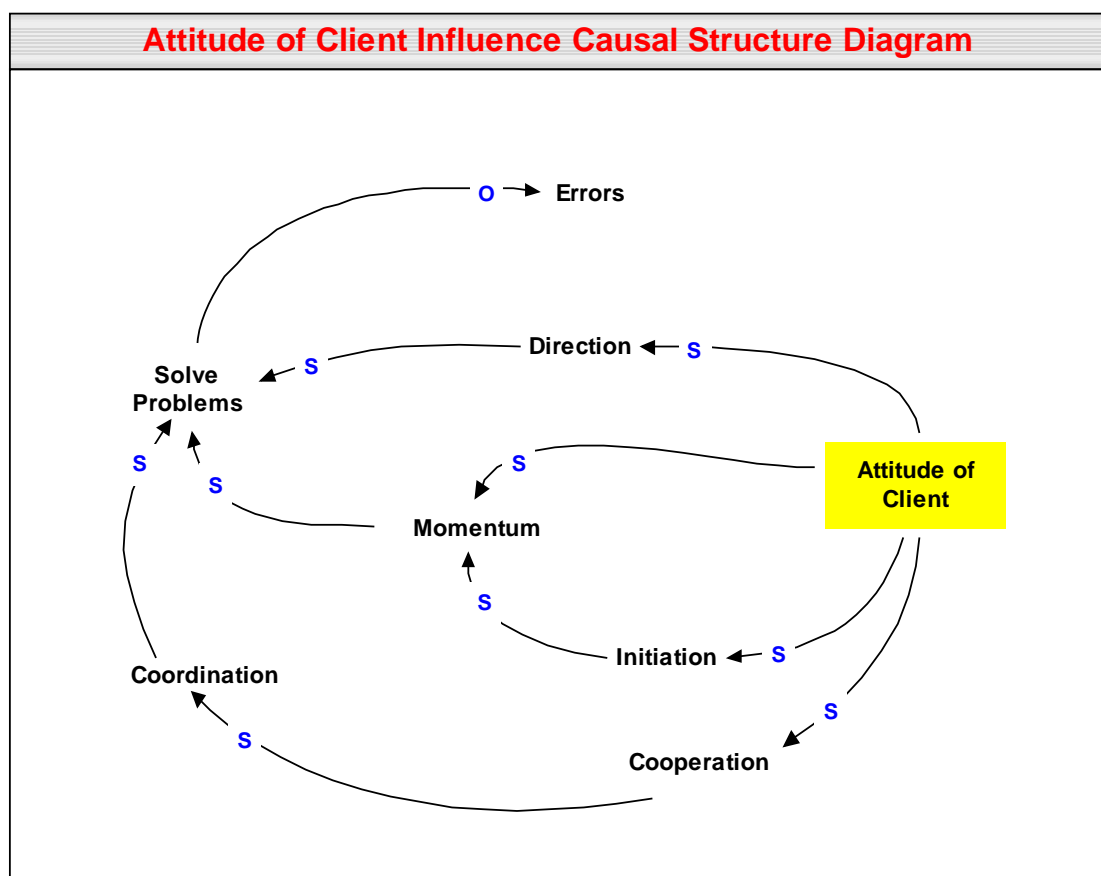
The diagram indicates that identification of risks will impact on the number of decisions to be considered. An increase in the number of decisions will increase the number of problems solved which will lead to reduction in the number of errors shown on the construction documents.

On the other hand, identification of risks will increase the identification of potential problems, which will increase the amount of coordination. An increase in the level of coordination will increase the solving of problems which will lead also to a reduction in the number of errors solved.

### 5.5.3.7 Attitude of Client

Client attitudes will be the key in achieving the most effective and efficient construction industry in the world. This was just one of many messages delivered at "The Big Debate", part of the Constructing Excellence conference held at the DTI Conference Centre, London, on 22nd November 2004.

A client who is cooperative with the project team will help in minimizing his distractive influence in the project. The committed client can play a crucial role in assuming responsibility for initiating, directing and maintaining momentum of a project (Walker, 1994).



**Figure 33 : Attitude of Client Causal Diagram**

The diagram indicates that an increase in the attitude of client impacts positively on the direction of requirements and taking the project forward, an increase in the momentum of the project team, an increase in the initiation and in the cooperation among the team members. An increase in direction and momentum leads to an increase in the number of errors that will be solved. An increase in cooperation will increase coordination which will lead to the solving of more problems. Solving of



more problems will lead to a reduction of the number of errors generated in the construction documents.

However; all these factors are interrelated and interact with each other and with other intermediate factors, as indicated in the following figure which shows how the factors influence each other in a dynamic and complex manner.



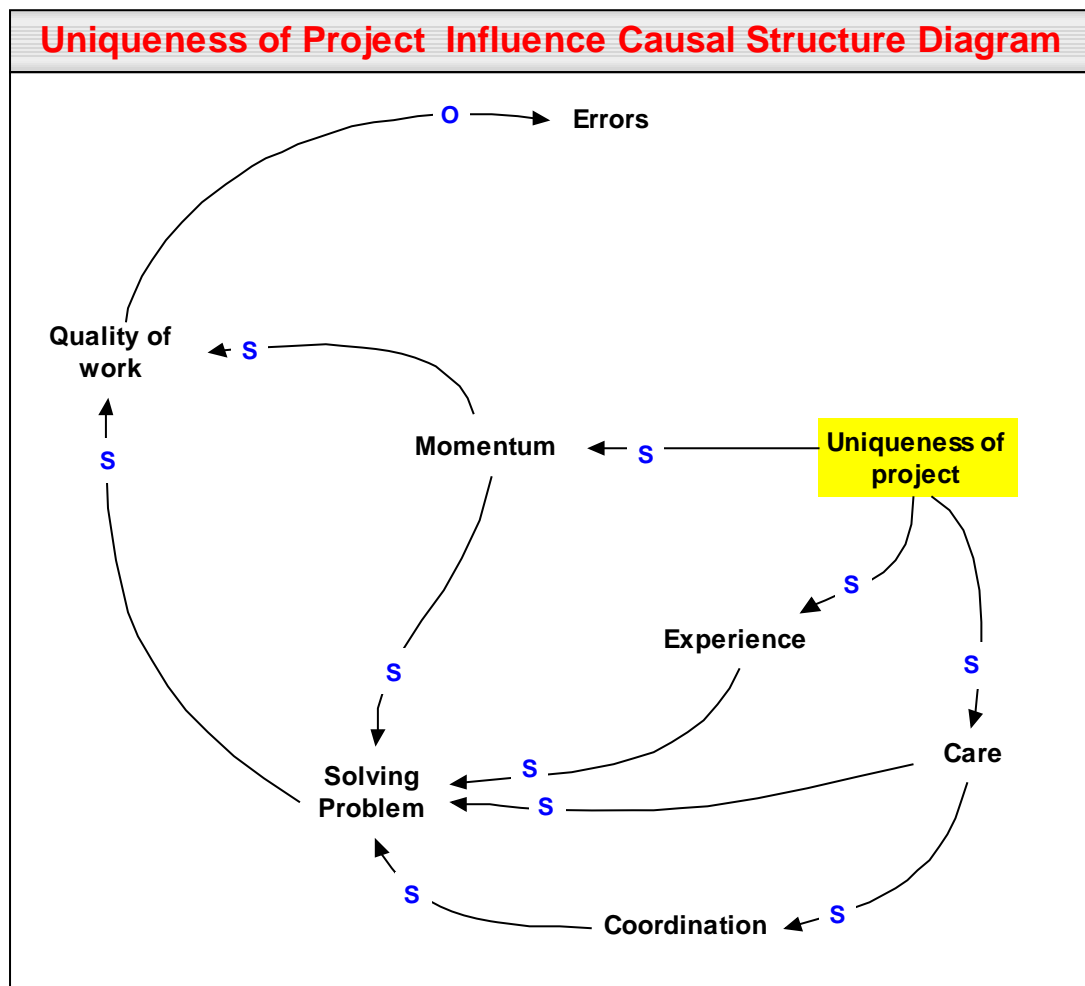
### 5.5.4 Project Characters

The project characters influence the number of errors generated in the construction documents, because they establish the size, budget, time frame for getting the construction documents. These factors are *de facto* of the project that the design team should be able to manage properly in order to minimize the number of errors generated in the construction documents.

#### 5.5.4.1 Uniqueness of the project

The uniqueness of the project reinforces the necessity of co-ordination and communication to achieve successful completion of the project.

There is some evidence that uniqueness of project will be result in a minimum number of errors as a result of the care taken during the design of the project.



**Figure 35 : Uniqueness of Project Causal Diagram**

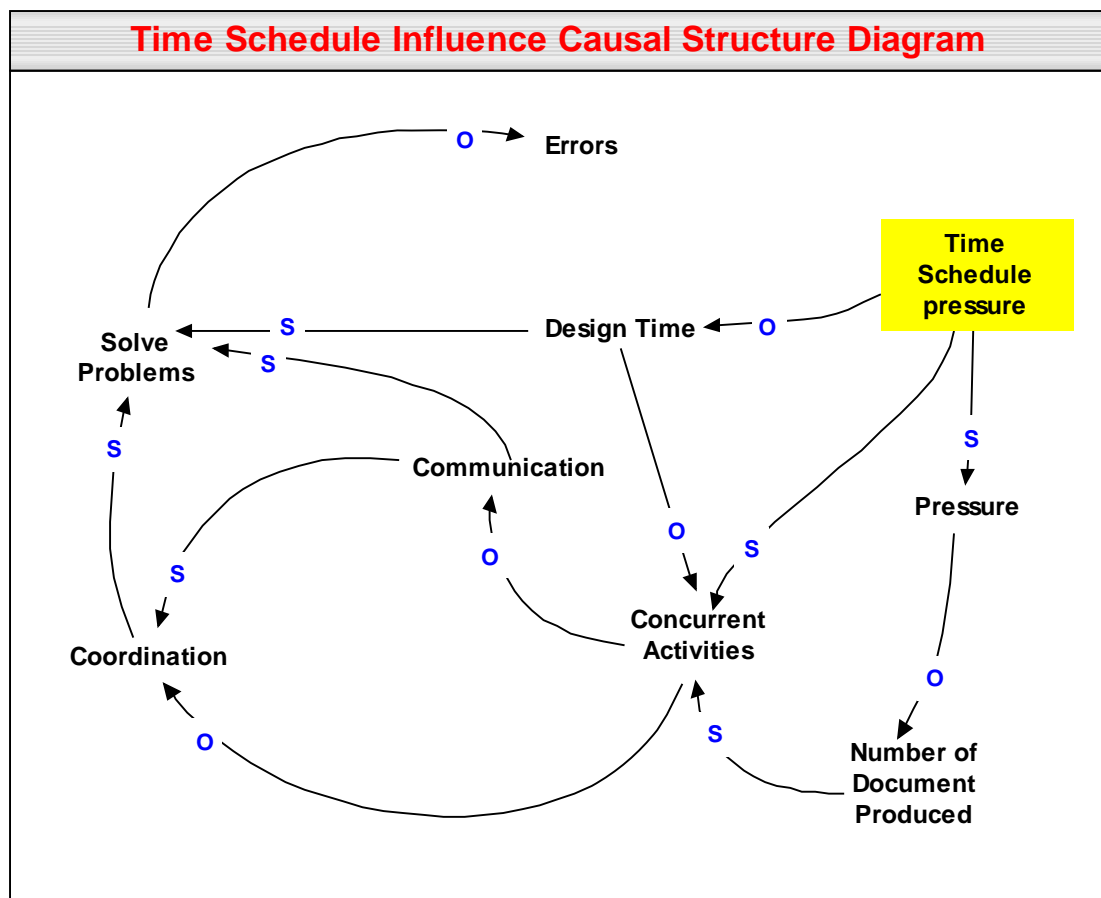
The chart indicates that the uniqueness of the project may increase the momentum, carefulness in working with the project and increase the need for experienced personnel to work on the project. An increase in momentum of the team members will

lead to an increase in the solving of problems and the quality of work which will reduce the number of errors in the construction documents. While an increase of care and experience will increase the solving of the problems as well as increasing again the quality of work.

#### 5.5.4.2 Time schedule pressure

The designers regarded insufficient design time as the most important issue influencing design document quality (Andi et al., 2003).

As shown in the influence of time earlier in this chapter, some projects force certain time schedule pressures which have to be met – for different reasons, or there is no need for the project. Such pressure will influence the procurement selected for the execution of the project. The construction documentation stage is the one most sacrificed, as the project will start on site without complete documents, enough study or coordination, etc.



**Figure 36 : Time Schedule Causal Diagram**

The chart indicates that time schedule pressure increases the pressure on the design team which reduces the number of documents produced. An increase in the number of

documents produced leads to an increase in the concurrent activities. An increase in the time schedule pressure also increases the concurrent activities. An increase in the time schedule pressure reduces the design time available for the production of the construction documents. An increase in the design time reduces the concurrent activities. An increase in concurrent activities will reduce the communication as well as the coordination. An increase in communication and coordination will increase the number of problems solved which will reduce the number of errors in the construction documents.

### 5.5.4.3 Project Budgeted cost

Rosemond (1984) and Rowland (1981) found that the errors rate increased when the winning bid was below the client estimate. A comparison was made by Charles et al. (1991, p550-51) between contracts with award amounts differing from the estimate. It was found that contracts with award amounts less than the estimate were more likely to have a cost overrun rate above 5%. This difference may indicate a lack of understanding between the owner and designer regarding the scope of work.

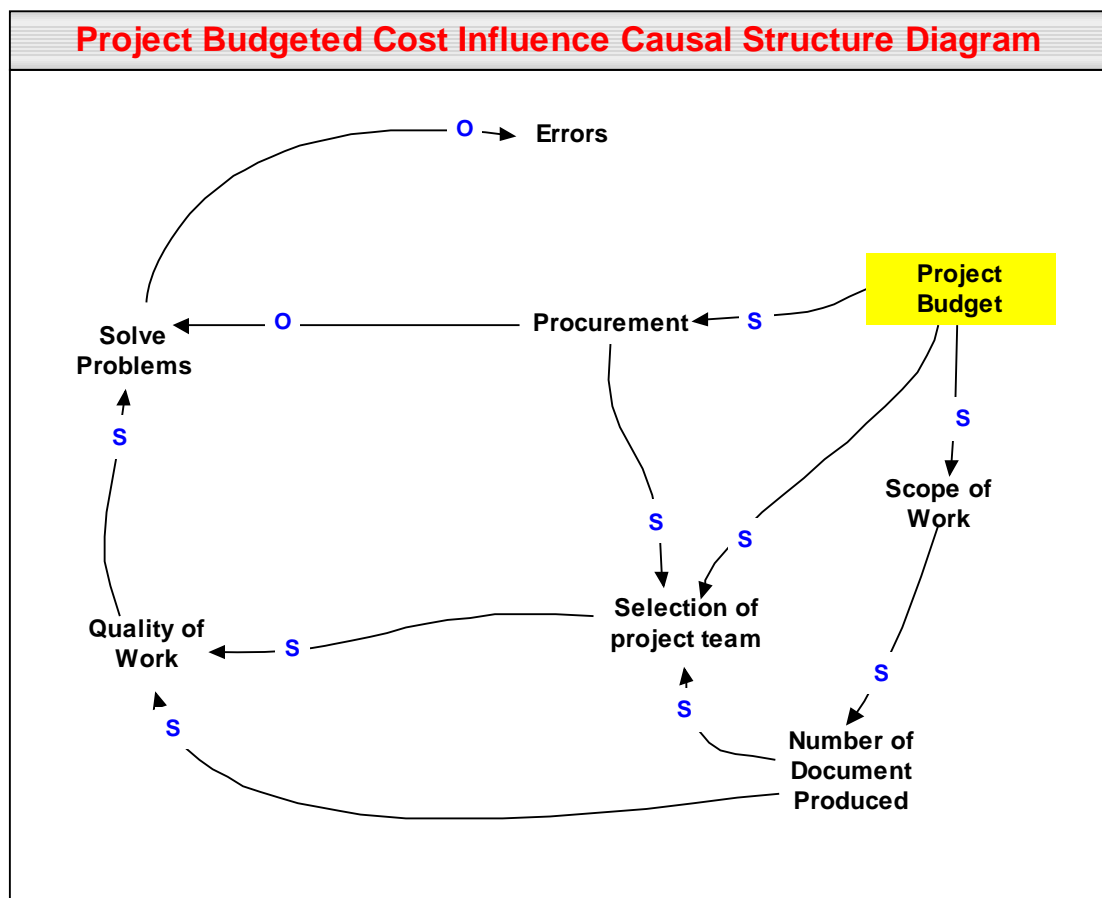


Figure 37 : Project Budgeted Cost Causal Diagram

The chart indicates that an increase in the project budget will increase the scope of work which will increase the number of documents produced. An increase in the number of documents produced will influence the selection of the project team that is capable of carrying out the job properly, which will increase the quality of work which will increase the number of problems solved. On the other hand, an increase in the project budget will increase the possibility of selecting of a proper project team directly which will increase the quality of work. An increase in the project budget will influence the selection of a procurement which best fits the project and will lead to more problem solving.

#### 5.5.4.4 Procurement

According to Brown and Beaton (1990), failures encountered with the procurement process can contribute to 30% of a project's cost being wasted as a result of problems of integration.

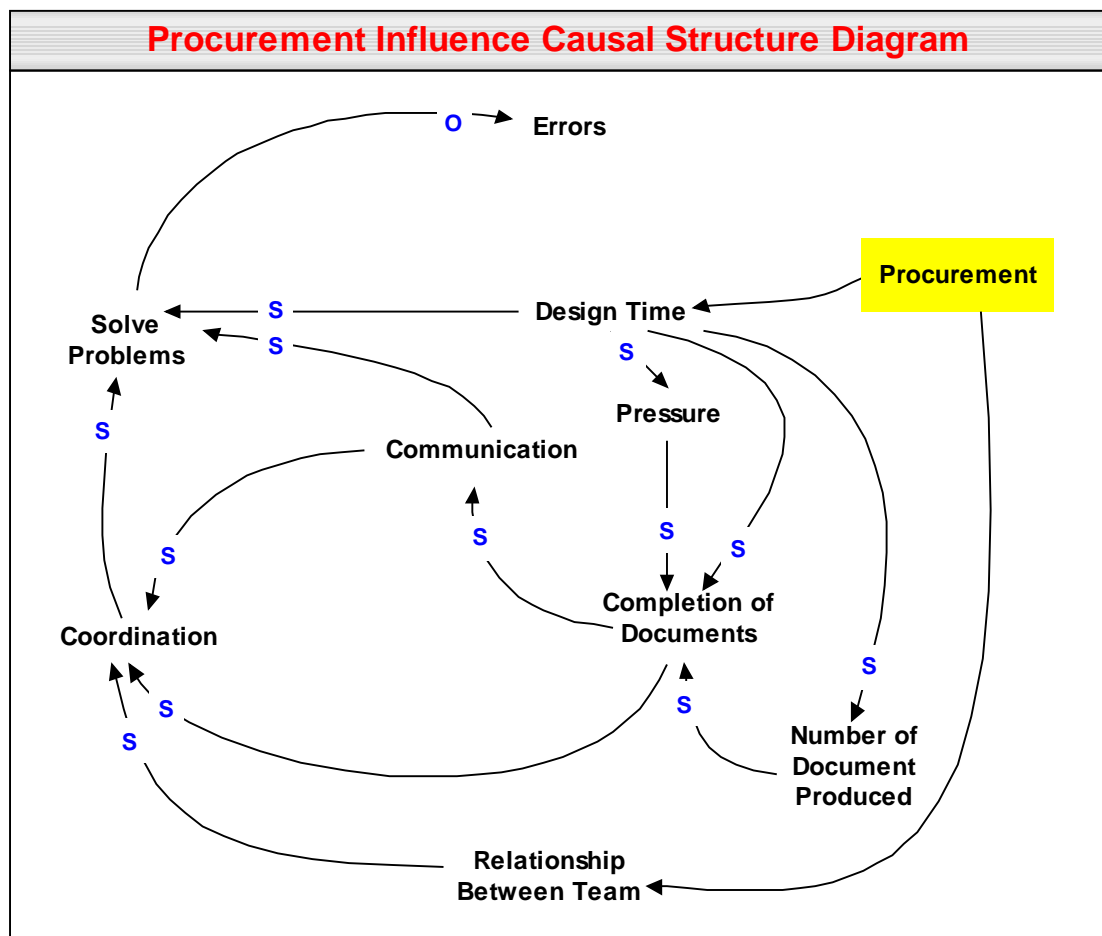


Figure 38 : Procurement Causal Diagram

The chart indicates that the procurement will influence the number of documents produced, the percentage of completion for the documentation and the available time for production of the construction documents. An increase in the number of documents to be completed will increase the amount of communication and coordination. An increase in communication and coordination will increase the number of problems solved and will reduce the number of errors in the construction documents.

On the other hand, selection of the project procurement will influence the time available for solving the problems and the time pressure on the design team.

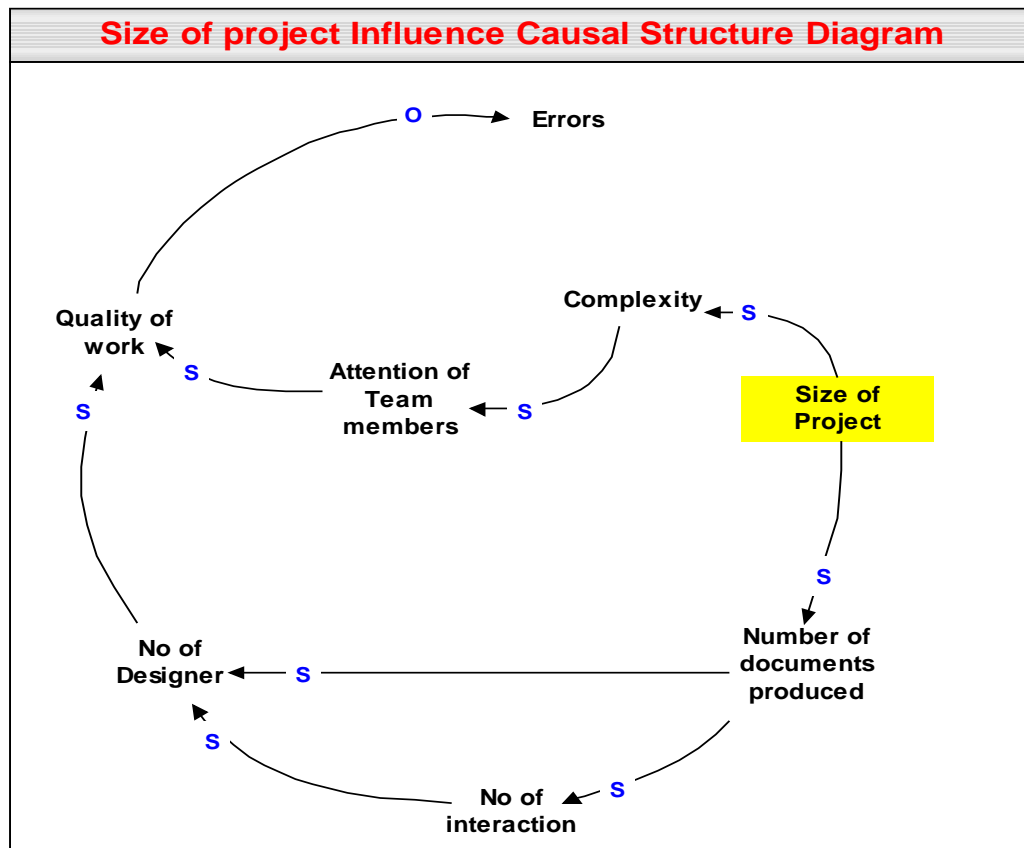
#### **5.5.4.5 Size**

Study (Rowland (1981) has shown that the project size influences the number of errors. Because the stakes are higher on larger projects, more care may be exercised in the bidding and planning process; thus, the cost overruns may be reduced. However, larger projects are generally more complex, and the complexity may increase the number of errors. The review of the literature indicates support for both conflicting views. Randolph et al. (1987) found that the number of errors decreased as the contract size increased, while Rowland (1981) found the errors rate increased as the project size increased.

The chart indicates that the increase in the size of the project will increase the number of documents produced, which will increase the amount of interaction required to complete the construction documents and will increase the number of designers. An increase in the number of designers will increase the quality of the work.

On the other hand, and increase in the size of the project will increase the complexity of the project which will increase the attention of team members which will increase again the quality of work.

An increase in the quality of work will reduce the number of errors generated in the construction documents.



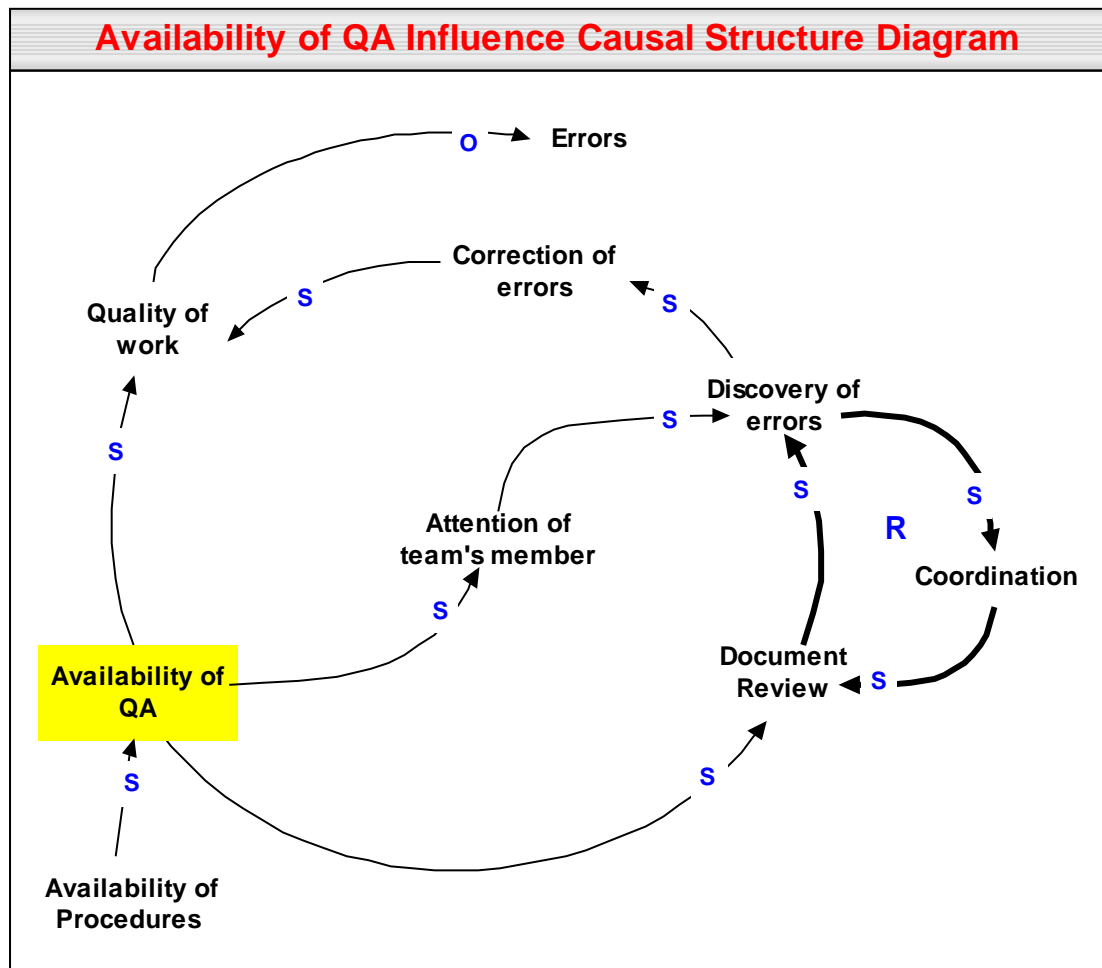
**Figure 39 : Size of Project Causal Diagram**

#### 5.5.4.6 Quality

The existence of a proper quality system in place owing to the nature of the project will minimize the number of errors generated in the construction documents and it will reduce the time spent redoing services caused by the consultant's mistakes (AIA-1994, p388).

The chart indicates that the availability of QA will influence the existence of errors in the construction documents in three ways. The first one is when it increases the document review. The increase in document review will lead to an increase in the discovery of errors. An increase in the discovery of errors will lead to an increase in the coordination which will increase the process of the document review. These processes create a reinforcing loop which leads to a reduction in the number of errors more and more. The second way is when the availability of QA leads to an increase in the attention of the team members to work. These increases in attention will lead to an increase in the discovery of errors. The third way is when the availability of QA will lead automatically to an increase in the quality of the work.





**Figure 40 : Availability of QA Causal Diagram**

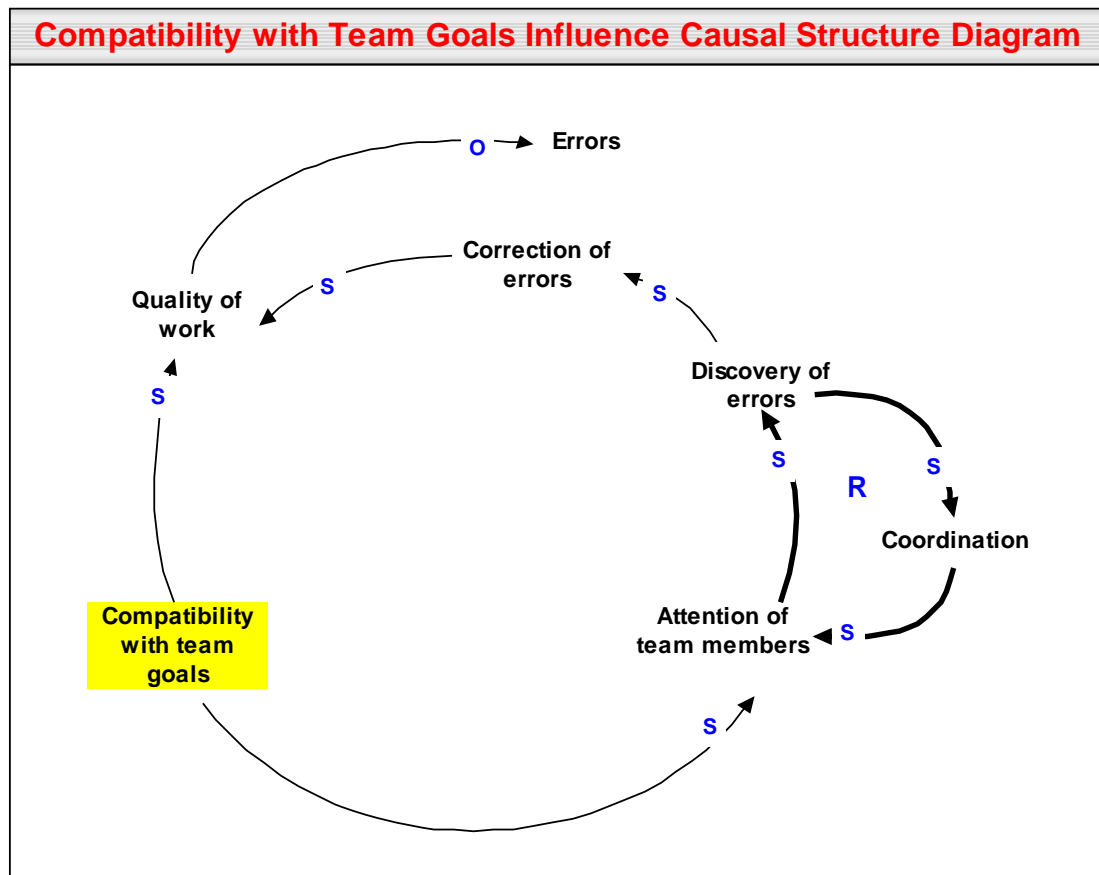
The discovery of more errors will lead to the correction of these errors. More discoveries of errors will lead to an increase in the quality of work which will lead finally to a reduction in the number of errors in the construction documents.

#### 5.5.4.7 Compatibility with designer goals

The degree of compatibility of the project with the overall designer goals and objectives, with its efforts to position itself relative to other firms, clients, and markets, has an influence on the number of errors generated in the construction documents (AIA 1994 p450).

#### Title capitalisation

The chart indicates the increase in the compatibility of team goals with those of the project, which will lead to an increase in the attention of the team members to the quality of the construction documents and an increase in the quality of work.

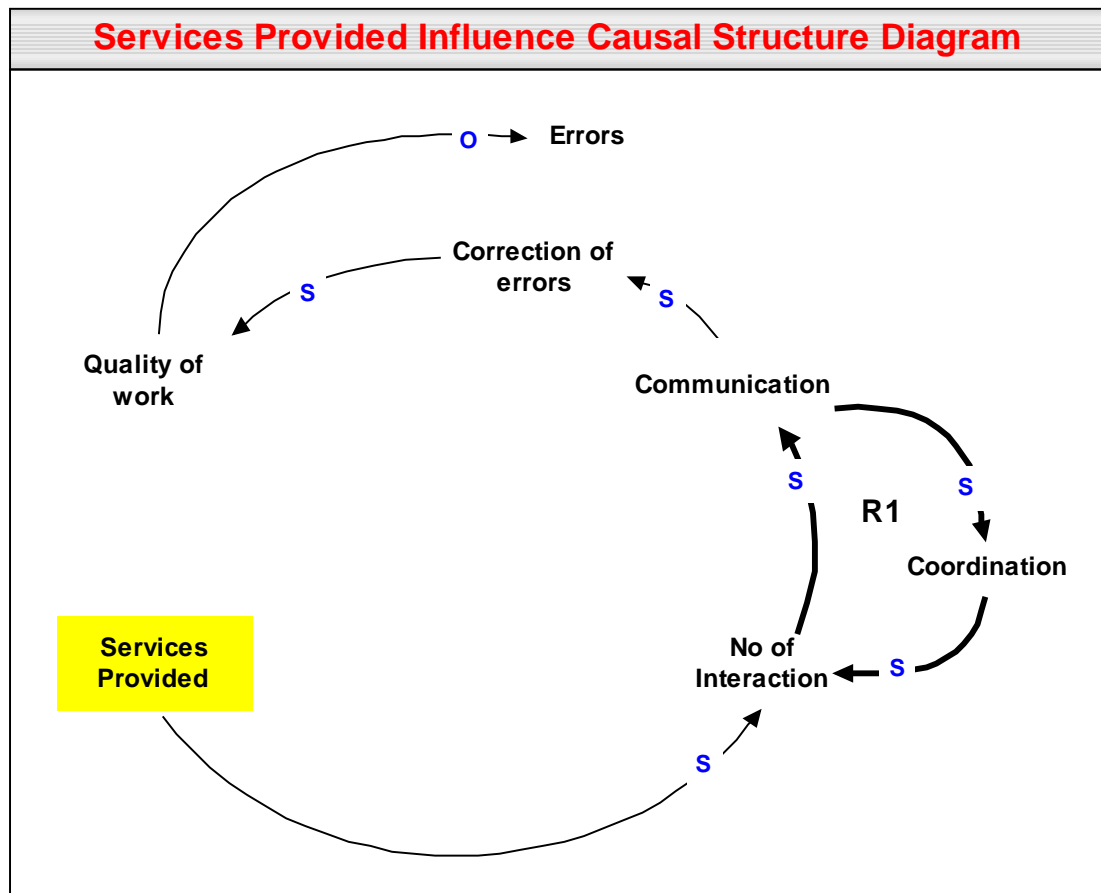


**Figure 41 : Compatibility with Team's Goals Causal Diagram**

An increase in the attention of the team members will lead to an increase in the discovery of errors which will lead to increase in the coordination and will lead again to an increase in the attention of the team members. These processes will create a reinforcing loop.

#### 5.5.4.8 Services provided

Today, engineering has many sub-disciplines, each with a set of experts looking at the same problem with a different approach, and no individual can master all the details of a project. These led the design offices to the subdivision of design project into separate services which are managed by different experts. The numbers of services to be provided for the project by the consultant have an influence on the number of errors generated in preparation of the construction documents (AIA 1994, p450). As the number of disciplines increases, more coordination and communication are required to avoid misunderstanding and misconceptions which lead to rework (Ana et al., 2004).



**Figure 42 : Services Provided Causal Diagram**

The chart indicates that an increase in the services provided will increase the amount of interaction. An increase in the amount of interaction will lead to an increase of communication which will lead to an increase in the coordination and will create more interaction among the project team members. These processes will create a reinforcing loop.

An increase in the communication will lead to the correction of errors which will lead to an increase in the quality of work which will lead finally to a reduction of errors in the construction documents.

#### **5.5.4.9 Authority Approval**

Regulatory constraints on design have increased steadily. Beginning with simple safety requirements and minimal land use and light and air zoning, building codes and regulations have grown into major force in design which regulate every aspect of design and construction (AIA , 1994, p632).

The most pernicious cases of lost time and cost resulted from amendments to design documents because of design errors and incompatibilities in design details with building regulations (NEDO, 1988). Many of this class of variations, unwanted by any of the design team, are unforeseen but not unavoidable.

Building design and construction are affected by a wide range of building codes and standards as well as planning, zoning, environmental protection, construction labour, and site safety laws and regulations.

In addition to these, the availability of proper authority approval has an influence on minimizing the number of errors, which are related to application of codes and standards.

On the other hand, a lengthy period to approve the project documents increases the number of errors caused by loss of interest in the project and change of the design team members.

The chart indicates that an increase in the authority approval will lead to an increase in the approval procedures that should be followed. An increase in these procedures will lead to an increase in the discovery of errors and in the period required to obtain authority approval on the project. An increase in the period of approval will lead to loss of interest on the team members' side which will lead to deterioration in the quality of work.

On the other hand, an increase in procedures will lead to an increase in the discovery of errors which will lead to an increase in the quality of work.

However; all these factors are interrelated and interact with each other and with other intermediate factors, as indicated in the following figure which shows how the factors influence each other in a dynamic and complex manner.

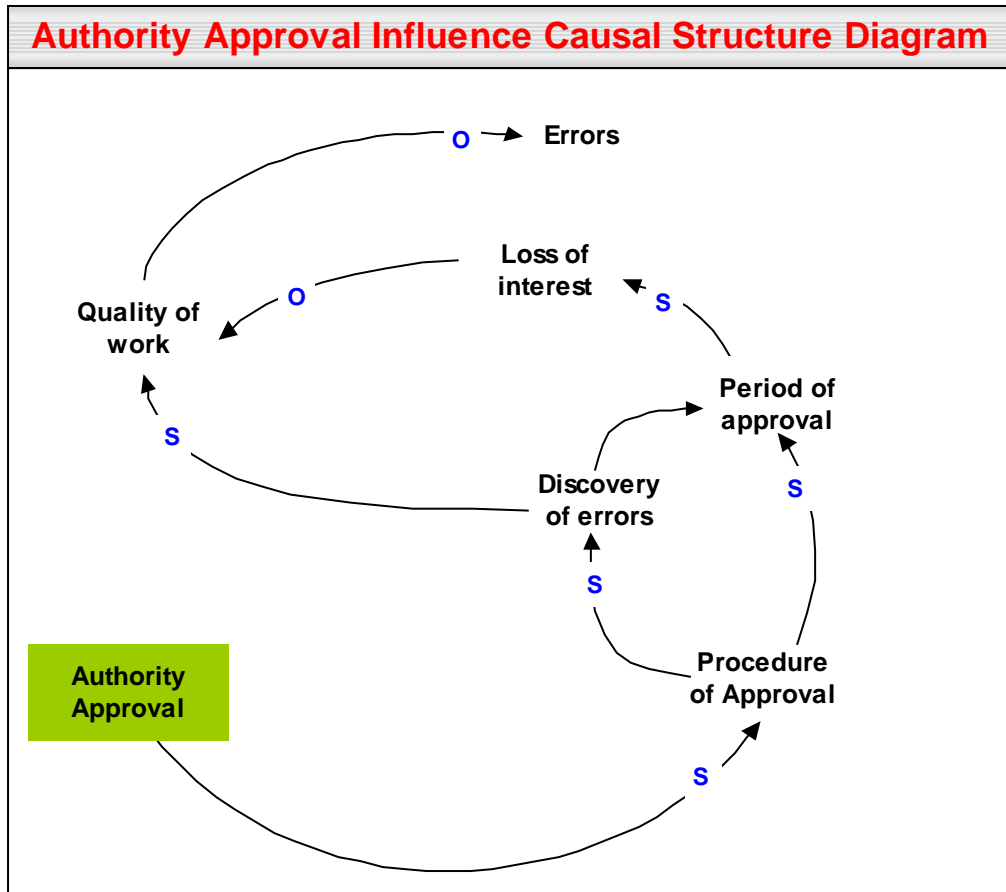


Figure 43 : Authority Approval Causal Diagram

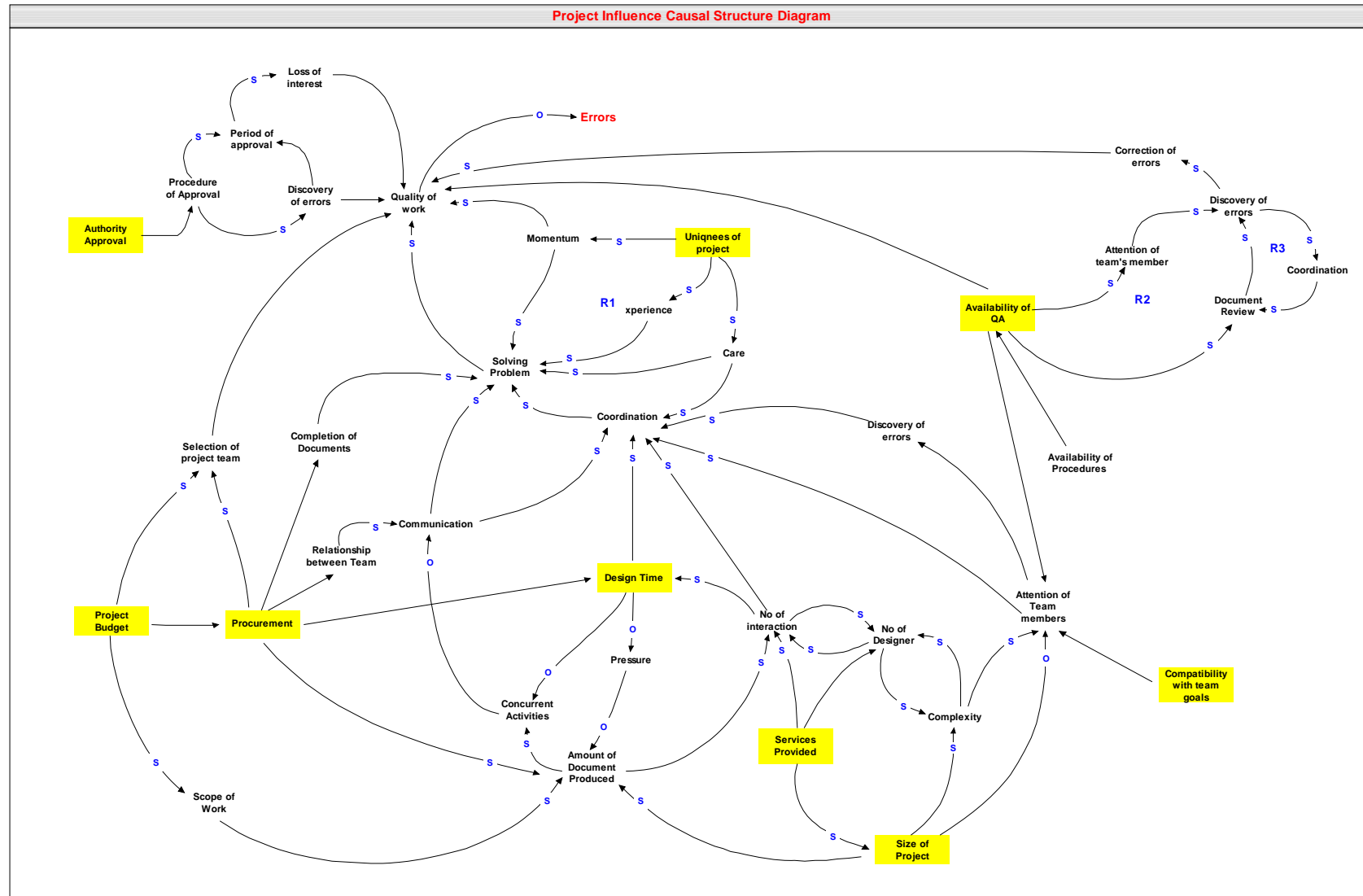


Figure 44 : Causal Diagram of Project on Occurrence of Errors in the Construction Documents

The following tables summarise the factors which stimulate the occurrence of errors in the construction documents.

<b>1 Management</b>
1.1 Management organizational structure
1.2 Project manager experience
1.3 Project brief
1.4 Change to key project personnel
1.5 Group organization
<b>2 Designer</b>
2.1 Design process
2.2 Design management experience
2.3 Designer professional education
2.4 Designer experience
2.5 Design fees
2.6 Design team efficiencies
2.7 Design time
2.8 Procedure for producing documents
2.9 Designer salary
2.10 Number of designer
2.11 Concurrent design activities
2.12 Amount of work with the designer
2.13 Reputation of designer
2.14 Availability of quality management
2.15 Effective design team
2.16 Communication
2.17 Availability of information
2.18 Transfer of knowledge and experience between designers
<b>3 Client</b>
3.1 Type of client
3.2 Client experience
3.3 Construction constraint time
3.4 Client point of contact
3.5 Planning the project
3.6 Identification of project risks
3.7 Attitude of client
<b>4 Project Characters</b>
4.1 Uniqueness of the project
4.2 Time schedule pressure
4.3 Project budget cost
4.4 Procurement
4.5 Size
4.6 Quality
4.7 Compatibility with consultant goals
4.8 Services provided
4.9 Authority approval

**Table 6 : Factors influencing the occurrence of errors in the pre-contract-stage**

### **5.6 Interaction between factors**

The design process, including the preparation of construction documents, develop out of collaboration between different actors entrusted with different duties, technical and compositional decision making, drafting, project and industrial monitoring work coordination, worker supervision, document review, etc. The "drafter" makes decisions, takes instruction from, and is supervised by the "project captain" who makes decisions and takes instructions from the "project architect", who makes decisions in collaboration with the "design architect", the "principal-in-charge", and other design consultants (Tombesi, P. 2000). This mix structure makes it difficult to isolate individual staff responsibilities clearly any time a mistake occurs, or to assign error percentages depending on any of the above factors.

There are interactions between the various influencing factors during different phases of the design process. Understanding such mechanisms in a particular situation of design work in a positive or negative way helps to develop suitable precautionary actions.

For example, experience plays an important role, in general, but important characteristics of a specific design team can influence the benefit of experience for the quality of analysis and decisions. Accordingly, the experience of a designer in a team will only be helpful, if not interceding with informal hierarchy or power. These sometimes complex constellations of interacting factors become evident in the "critical situations" (E. Frankenberger et al., 1998).

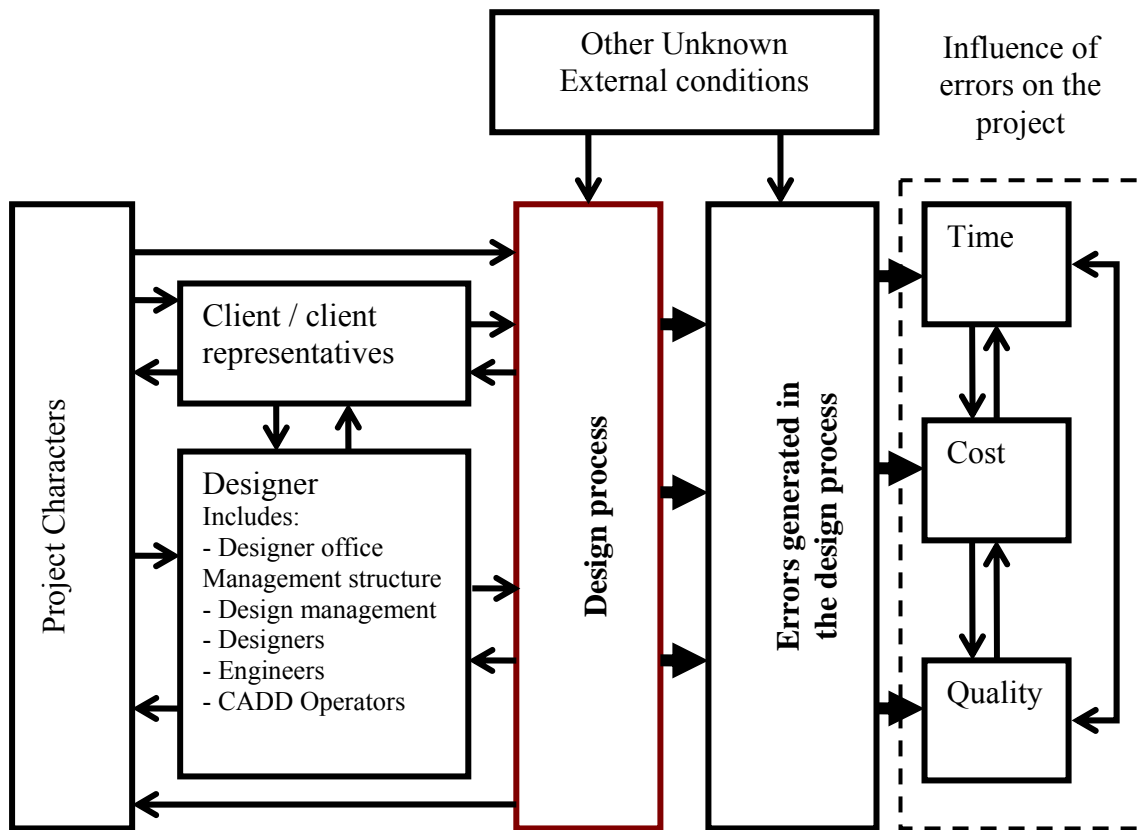
Another important factor is the reality that the production of construction documents is a complex system with tight coupling between various factors where incidents develop or evolve through a conjunction of several other factors. These incidents evolve through a series of interactions between the people responsible for system integrity (Figure 47). One factor acts, the other responds, which generates a response from the first and so forth. For these reasons, some factors are the result of other factors, i.e. they are not effective unless they are changed by other factors, and they are the consequence of other factors. For example, communication itself is not an original factor which could influence generation of errors, but it is the symptom of other factors, as shown in the causal diagrams.

In conclusion, as stated by Tombesi (Tombesi, P. 2000), the process of producing the construction documents is the result of a complex network of activities, which result in different artefacts with varying degrees of intellectual and craft complexity,



involving different types of quantitative and qualitative decisions, different types of knowledge, different types of uncertainty, and different production efforts.

For these reasons, the system adopted to analyse the factors should be able to study such interactive relationships between factors.



**Figure 45 : Interaction of Factors Affecting Occurrence of Error**

### **5.7 Assessing the fitness of the causal diagrams**

The above diagrams for each factor were drawn after careful analysis of all the factors affecting the generation of errors to capture the most significant insights of the objectives of the study, neatly and tidily with a minimum number of crossing lines. The diagrams were made clear by themselves with the least number of explanations needed.

Drawing the diagrams is not enough; one must know how to distinguish between a good diagram and a poor one. For this reason and to recognize the rightness of the diagrams, the following criteria have been used to study the fitness of the causal diagrams to fulfil the objectives of the study (adapted from Coyle, 1996-p46):

- The causal diagrams were validated by involving a group of experts in the field, as indicated at the beginning of this chapter.
- Have the purpose and the target audience for the diagram carefully chosen. The target shown in all diagrams is the generation of errors in the construction documents. The diagrams show the linkage between the factors up to the stage where it influences the number of errors generated.
- Are the factors which it includes consistent with the purpose? All the factors included in this chapter affect the generation of errors in the construction documents, which is the purpose of the study.
- The objective of system dynamics is policy analysis, so are the policies clearly shown in the diagram?

The objective of the causal diagrams shown in this chapter is to show how the factor influences the generation of errors in the construction document as a first step toward developing a complete model which will quantify these relationships.

- System dynamics also aims to produce policies which are robust against a range of circumstances, so are the exogenous factors which might present the system with setbacks or opportunities clearly identified? These exogenous factors were shown in the diagrams when applicable.
- Are the variables capable of being easily explained to the target audience, are they capable in principle of being measured and can they vary over time? Colour coding and symbols were used to explain the diagrams clearly.
- Has the diagram been constrained by too slavish an adherence to the conventions? The way the diagrams are shown is based mainly on trying to

understand how different factors influence the occurrence of errors in the construction documents.

### **5.8 Conclusions:**

The chapter has shown that every organization and individual may be influencing the quality of design documents directly or indirectly through the process of preparing the construction documents. Every participating organization and individual may affect the final quality of the construction documents and the generation of errors. The design activities can be linked as a chain which is only as strong as its weakest link. This weak links will result in errors. Using literature, case study projects and group of experts, the research has identified and classified the factors which are affecting the occurrence of errors in the construction documents. The classification of factors was based on individuals, as the project team consists mainly of individuals who cooperate with a specific aim. These factors include project management, designer, client, and project characters. However, these factors interact together in a highly dynamic way as the process of producing the construction documents is the result of a complex network of activities, which result in different artefacts with varying degrees of intellectual and craft complexity.

To clarify the causal relationship between the factors and occurrence of errors and as a step toward building the thesis model (conceptualization and formulation stages of system dynamic modelling (Figure 4 in Chapter 3), each factor has been concluded with a group validated causal analysis diagram which explains the relationship between the factors and the element(s) which have direct influence on the occurrence of errors in the construction documents using prior theoretical knowledge extracted from the literature, analysis case study projects and interviews.

In conclusion, in this chapter, all preparatory and background knowledge needed to develop the model is available to start and find the relationship between errors and their causes.

Therefore, in the following chapter the research model will be formulated, which explains how errors occur in the construction documents. This way the policy on how to minimize the number of errors generated in the construction documents under different scenarios will be understood.

6.1	Introduction.....	226
6.2	Approach to developing the model.....	226
6.3	Factors within the scope of the system dynamics model.....	228
6.4	Model assumptions .....	230
6.5	Model equations.....	231
6.6	Description of the model.....	234
6.6.1	Design process .....	239
6.6.2	Number of designers .....	241
6.6.3	Design management.....	243
6.6.4	Designer education and experience .....	244
6.6.5	Design fees.....	245
6.6.6	Design time .....	247
6.6.7	Procedure of producing documents .....	250
6.6.8	Designer salary.....	251
6.6.9	Concurrent design activities.....	252
6.6.10	Amount of work with the designer .....	252
6.6.11	Reputation of designer influence .....	254
6.6.12	Availability of quality assurance .....	255
6.6.13	Effective design team.....	257
6.6.14	Communication.....	258
6.6.15	Availability of information .....	259
6.6.16	Transfer of knowledge .....	261
6.7	The basic structure of the system.....	262
6.8	Conclusion .....	273

## **6.1 Introduction**

The objective of the research is to find the relationships between cause and effect and pinpoint the source of the problems. On the basis of this objective the research wants to answer questions such as ‘what are the main factors responsible for the occurrence of errors in construction documents?’ or ‘what are the mechanisms leading to minimal occurrence of errors (perhaps error-free) documents?’

In the previous chapter general assumptions about the behaviour of errors in a project system were identified using causal diagrams. These diagrams were built using the concept of system dynamics modelling to map and identify the major variables that influence the incidence of errors. They are qualitative models that provided an insight into the causal nature of error in a project system. These diagrams/models will be developed to integrate a conceptual causal loop model to determine the overall causal structure of error. They were the beginning for developing the hypothesis to account for the problematic behaviours that stimulate the occurrence of errors in the construction industry, and provide an explanation of the dynamics characterizing the problems and part of the learning process from both the modelling process and the real world. They guide modelling efforts by focusing the research on certain structures. This chapter is the remainder of the modelling formulation process that helps to test these hypotheses, both with the simulation model and by experiments and data collection in the real world.

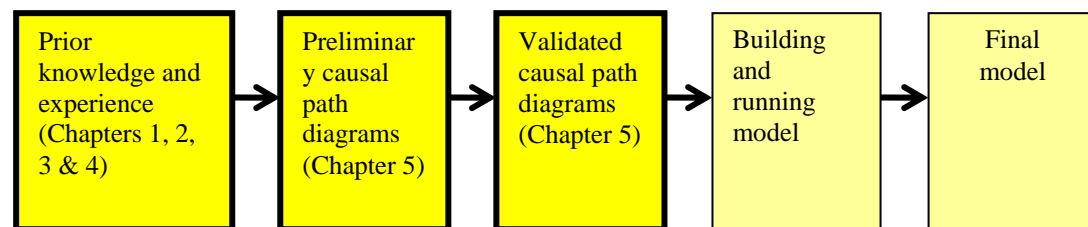
The objective of this chapter will then be to provide a full explanation of the proposed model that will explain the relationships which have been proposed between different factors and the occurrence of errors. The chapter will subsequently explain the methods used to quantify the variables and nature of the relationship among variables that determine the amount of errors in the construction documents.

## **6.2 Approach to developing the model**

Building design is a complex network of activities, which result in different artefacts with varying degrees of intellectual and craft complexity, involving different types of quantitative and qualitative decisions, knowledge, uncertainty, and different production efforts (Tombesi, 2000, p731). Furthermore, human decisions makers generally choose strategies that are relatively efficient in terms of effort and accuracy as task and context demands are varied (Payne et al., 1988, 1990). In developing standards by which to judge what are effective processes one must understand

problem solving in context, not in abstract. Effective problem-solving strategies are situation specific to some extent; what works well in one case will not necessarily be successful in another. Furthermore, appropriate strategies may change as an incident evolves; e.g. effective monitoring strategies to detect the initial occurrence of a fault (given normal operations as a background) may be very different from search strategies during a diagnostic phase. In understanding these tradeoffs relative to problem demands we can begin to see the idea that expertise and error spring from the same source (Woods et al., 1994, p94-95).

As the various bits and pieces of information have been gathered in the previous chapter (Figure 1) by using the casual path diagrams, they must be structured in a way that makes it possible to see how they are related.



**Figure 1 : Process of creating the model**

Therefore the next step is to decide what the model is going to look like by building the model itself, based on the analysis performed in the previous chapter. The model will be developed using the tools and techniques of the system dynamics software. Among other software (Section 3.5.1), Powersim Studio 2005 was selected for pragmatic reasons: easy to use, availability of training and build-in tools. The software will help the research by converting the structural qualitative model (casual diagram) into the mathematical quantitative model. The mental models of decision makers cannot process the variety and complexity of most of the systems experiencing problems. With the use of computers and System Dynamics software, however, it is possible to represent, combine, and formalize these models explicitly, and communicate their assumptions to laymen, students, colleagues, and policy designers who will subject them to constructive criticism. Simulation models, in particular, can be used to investigate the intimate relationship that exists between the structure and behaviour of dynamic systems. That is, how problematic behaviour arises from the underlying structure of a system and how this structure can be modified to alleviate the problems in a system.

Part of the process in developing the model will be to identify the variables that are going to be presented in the model and within the boundary setup of the model. It is necessary to identify which of the many factors identified in the previous chapters, is (are) crucial in order to solve the problem of the research (it will be discussed in Section 6.3). By eliminating the factors that are outside the scope of the given problem, the model will be easier to understand and develop. These limits will decide where and when the research should stop looking for cause-and-effect relationships. Then, when the first model is available, it will be the time to see how the model behaves. By running test simulations, the behaviour of key variables in the model can be plotted over time. By altering parameter values during these simulations, the effect of these parameters can be tested on the model structure. The important issue in this step is to verify that the model behaves reasonably, compared with the reference mode diagrams, and to identify problem behaviour and find fixes for them.

### **6.3 Factors within the scope of the system dynamics model**

For the purpose of building the model in system dynamics, three types of variables are sought: endogenous, exogenous, and excluded variables. The word "endogenous" means arising from within. An endogenous theory generates the dynamics of a system through the interaction of the variables and agents presented in the model. By specifying how the system works and the rules of interaction (the decision rule in the system), it is possible to explore the pattern of behaviour created by those rules and that structure, and also how the behaviour might change if the structure and rules are altered. In contrast, a theory relying on exogenous variables (those "arising from without" i.e. from outside of the boundary of the model) explains the dynamics of variables under study in terms of other variables whose behaviours are assumed (Sterman, 2000, p95).

In the previous chapter all the factors that have been identified by the literature, case study projects and interviews as causing occurrence of errors in construction documents were discussed and analysed. The purpose was to create a complete picture and a comprehensive list and analysis of all the factors that could cause errors. However, it is prudent not to include all of these identified factors in the actual system dynamics model, since the focus of system dynamics is on understanding the internal mechanism of the occurrence of the errors (endogenous explanation) to avoid placing blame in favour of finding the true, long-term solution to a problem.

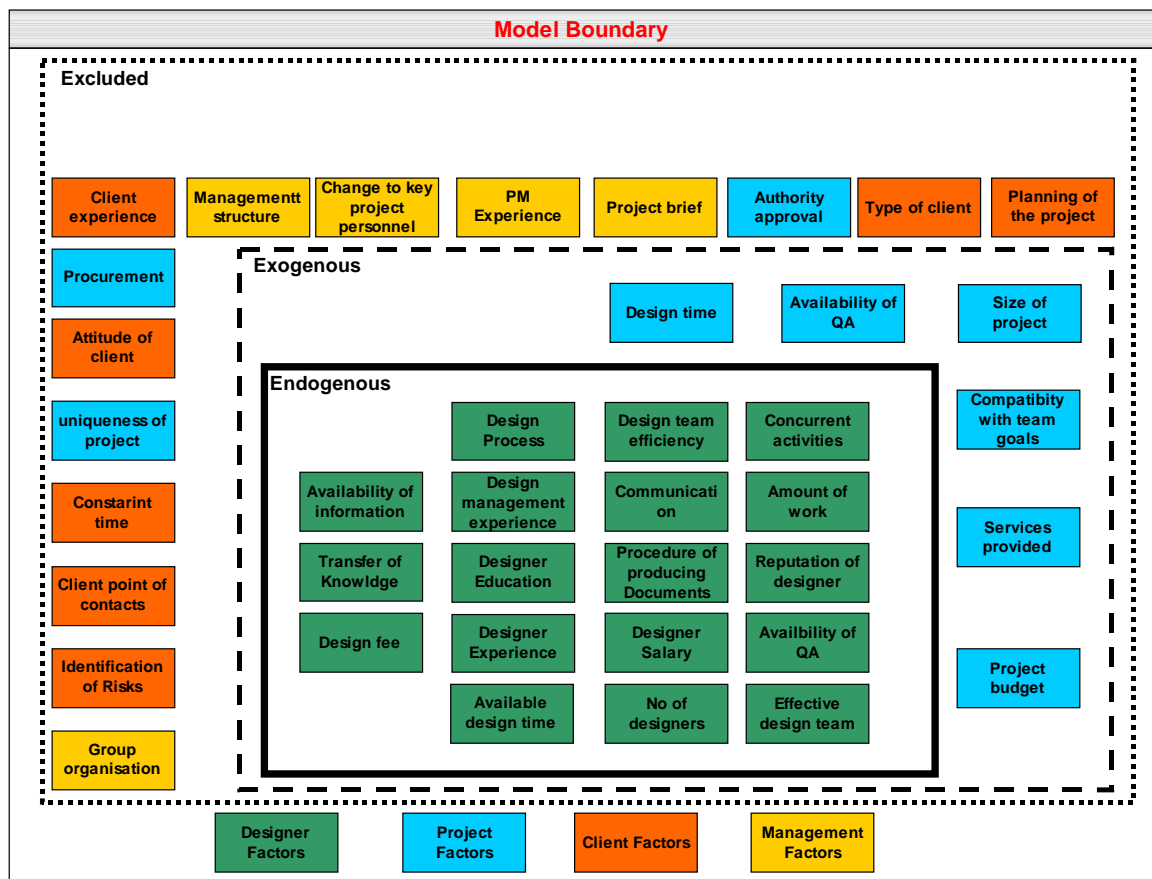
The focus of system dynamics on endogenous explanation does not mean excluding all the exogenous variables in the model. As stated earlier, a model is a simplification of reality and only some features of the real system are reflected in the model. Therefore, all explanatory variables that are not related to the purpose of the study but may affect the dependent and independent variables are termed an extraneous variable. But the amount of exogenous input should be small, and each exogenous input must be scrutinized to consider whether there is, in fact, any important feedback from the endogenous elements to these elements or not; if so the boundary of the model must be expanded and the variable must be modelled endogenously (Sterman, 2000, p95).

Based on the detail explanation and understanding of factors and causality relationships (Chapter 5), it will be logical and sensible to select the variables inside or outside the model's boundary. Furthermore, the construction documents are carried out for the most part by the designers, so it will be natural to include mainly the variables of the designers as endogenous, and a limited number of exogenous factors necessary to explain the system as reflected in the model boundary.

The above principles were discussed with the validation group (i.e. 11 experts, as discussed in the previous chapter). The output of the meeting was this classification (Figure 2). The figure summarises the model's boundary and the scope of the model by listing which key variables are included endogenously, exogenously and excluded.

As will be discussed later in the research (Chapter 8), the boundary of the model can be relaxed to include the excluded factors if deemed necessary by the researchers or professionals.





**Figure 2 : Factors within the scope of the model**

#### 6.4 Model assumptions

Sterman (Sterman, 2000, p98-99) in his defence of explicitly stating the model assumption underlying the model, stated: "Often, models are used not as tools of inquiry but as weapons in a war of advocacy. In such cases modellers seek to hide the assumptions of their models from potential critics. But even when the modeller's motives are benign, many feel uncomfortable listing what they've left out, see the omissions as flaws and prefer to stress the strengths of their model. While this tendency is natural, it undercuts the utility of the model and weakens the ability of people to learn from and improve the work. By explicitly listing the concepts chosen not to include, at least for now, the researcher provides a visible reminder of the caveats to the results and limitations of the model. Without a clear understanding of the boundary and assumptions, models constructed for one purpose are frequently used for another for which they are ill-suited, sometimes producing absurd results. All too often models with completely inappropriate and even bizarre assumptions about exogenous and excluded variables are used in policy making because the model users

are unable to examine the boundary of the models themselves and the modellers have not provided that information for them".

The first important assumption is the model's scope and focus, as reflected in the model boundary (Figure 2). This will focus the research on the inner working mechanism of errors within one project.

A second important boundary assumption is a stable environment, process and organization throughout the project life, e.g. the use of an exogenous constant to describe the average duration required to complete the development activities of construction documents. These values and functions do not change during the simulation.

The third assumption is the level of aggregation within the model boundary, as it focuses the research and model purpose. The level of aggregation assumption concerns the fundamental units which flow through projects. The research assumes these units are "task". Conceptually a "task" is an atomic unit of work. Examples of "task" might include producing a schedule, adding a level of detail to a drawing, solving a problem, coordination of an activity...etc.

Tasks are assumed to be uniform in size. Tasks are also assumed to be small enough to be flawed or correct but not partially flawed. This assumption becomes more accurate as task size becomes smaller.

As discussed earlier regarding the type of data, some of these variables are quantifiable and others not? The measurement of these variables will be varied from factual data to subjective response, based on the assessment of the strength, as will be discussed later in the chapter.

## **6.5 Model equations**

The equations of the model were estimated using the method employed by Ford and Sterman (1998) and Sterman (2000, p586). Generating reliable estimates of the functions in models requires methods to elicit qualitative information from individuals with firsthand experience in the system (Sterman, 2000, p585 and p867). Most of the information is tacit, residing only in the mental models of the experts. The parameter values have been estimated judgmentally using expert opinion gleaned from interviews (Section 3.8.4). The individuals (Section 5.3) who attended the validation meeting were interviewed individually or in small workshops (2-3 people); larger group sizes negatively affect the eliciting process (Vennix et al., 1992), to assess the value of the parameter, as the experts interviewed were aware of the research

problems and objectives, system dynamics and understanding of the causal diagrams developed in Chapter 5. Working with small groups is efficient and also helps build shared understanding among the members of the expert team (Sterman, 2000). A total of 12 small workshops were conducted for the purpose of establishing relationships.

The elicitation process (Sterman 2000) used to establish the equations of the model has three phases (Figure 3): positioning, description, and discussion. The positioning phase establishes the context and goals of the interview, and describes the model purpose and relationships to be estimated. This was straightforward as only individuals who had participated in the causal diagrams validation were interviewed. The description phase helps transform expert tacit knowledge into a usable form, using worksheets prepared for the experts. During the discussion phase, the expert explained the reasoning underlying their estimates of the relationship.

The important point to press here is that individuals did not arrive at a single, consistent set of results representing the group. Capturing the diverse views of a group is an important result of the elicitation process. The difference among experts provided the opportunity for testing and improvement in the discussion phase. The discussion led to an improved description of the relationship for use in the model.

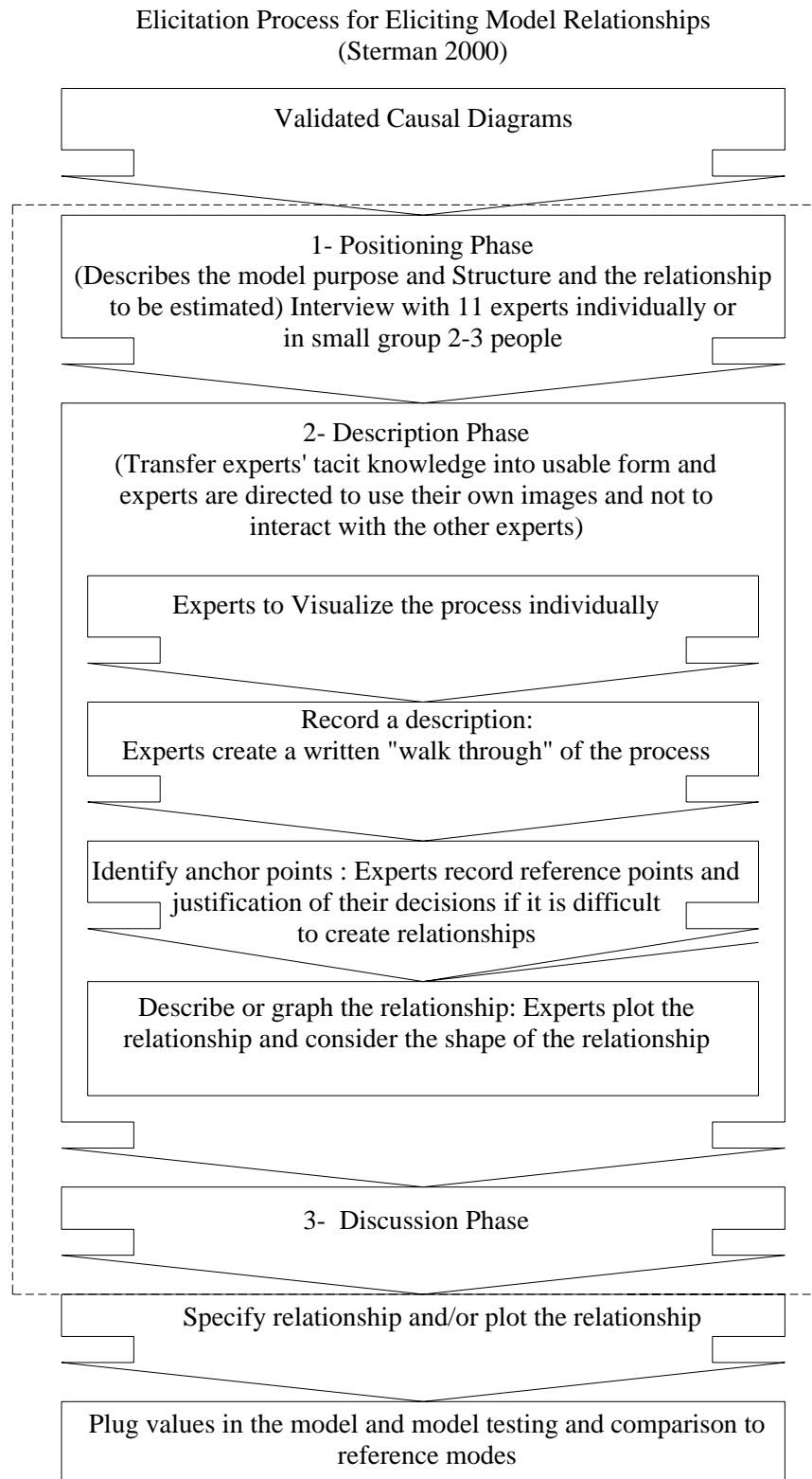
The research converted all these elicited views into equations that were plugged into the model. 52 iterations of the model were tested before reaching a reasonable model which behaved in manner that matched the reference mode diagrams created by the experts interviewed at the end of validation process (Section 5.3).

The expert knowledge gained from the above elicitation process was an important source of data for the specification of the variables relationships for use in the model. Numerical data to estimate important parameters and relationships are unavailable or cannot be developed in timely manner.

To recapitulate the process so far, the research postulated the variables to be included and the nature of the relationships between them on qualitative information that have been extracted from interviews and case studies. However, that is only relevant to the conceptualisation of the model and to verify that the relationships and variables specified within it are plausible.

The model itself is operationalised by estimating numerical values for the constant variables that are specified in it (Chapter 7 shows estimated values for different constant variables) and then using those values to generate outputs. The estimation of the remaining variables (i.e. non-constant variables) is performed by software based on the established relationships between variables elicited from 12 interviews. This

differentiates it from an empirical model that is built either on quantitative or qualitative data.



**Figure 3 : Elicitation of the relationships in the research model**

## 6.6 Description of the model

Chapter 2 contained a discussion of the different stages of producing the construction documents: the process of producing the construction documents entails going through important steps, especially at the end of the conceptual plans stage when the design is frozen and the preliminary authority approval has been gained. The actual start of producing the construction documents is after this stage, where in coordination with the client, the different materials and finishes and the different engineering design systems have been selected for the project (refer to figure 3 in Chapter 4). Any change in the material or design system will influence the production of the documents either in delays, cost overrun, or sacrificing the quality and inducing the occurrence of errors in the documents. At the end of the final detail design stage, all drawings and schedule are ready and the conditions of contracts and bills of quantity will be ready at the end of the contract documents stage. By then the package is ready to go for the tendering process, where the feedback will come from contractors about the adequacy of the documents for the intended purpose of the project; this may raise different types of errors, as discussed in Chapters 2 and 4. Then the contract documents will be frozen for the purpose of signing the contract with the successful contractors.

Based on the assumption that every task in the production of the document will be considered as a problem which may be an error unless it is solved by one or mixed effects of the factors that influence the production of the construction documents, the phases are linked in the following consequence (based on Ford, 1995):

- Workflows in early phases constrain progress in the latter phases.
- Errors inherited by later phases from early phases disturb the work of later work.
- Inherited errors that are discovered in later phases are corrected while forwarding the work to finish the deliverable item of the stage.
- Coordination with the client has to take place at least at the end of each phase; to make sure that his requirements and needs have been satisfied at the same time as the consultant contractual obligation has been protected.
- Completion and expected completion dates of phases influence the overall completion of the project. The project deadline in turn influences the deadline of the phase while setting the work programme.

- Poor schedule, quality, and cost performance in any phase increases the impacts of non conformance to the project targets. Those project level impacts influence individual phase targets.

However; the process of producing of the construction documents is divided into the following activities (Figure 5):

1. Base problems, as there is a possibility of error occurrence in every interaction that will take place while producing the construction documents; the initial amount of errors to be solved will be the number of interactions that will take place while producing the construction documents. This is represented in Figure 4 by "Initial errors" and "Potential errors".
2. Assumed correctly solved errors as a result of solving problem factors which are yet to be checked to ensure that the errors are solved correctly. This is represented in Figure 4 by "Assumed Error Solved".
3. Correctly solved errors as a result of checking the quality of the solution in the (assumed correctly solved errors) based on the (rate of correctly solving errors). This is represented in Figure 4 by "Correctly Solved error".
4. Erroneous solutions which have been discovered during checking the quality of the (assumed correctly solved errors) that there is a flaw in the solution which will go back again to the process for solving purpose. This is represented in Figure 4 by "Erroneous action".
5. (Skipped discovered errors) which are skipping the process of solving the errors but have been discovered by (the discovery of error factors) which will go back again to the process for solving purposes. This is represented in Figure 4 by "Discovered errors" and "Discovered skipped errors".
6. Skipped and erroneous solutions undiscovered errors which are skipping the process of solving the errors but have been undiscovered by (the discovery of error factors). This is represented in Figure 4 by "Undiscovered skipped errors" and "Undiscovered errors".

Figure 4 shows samples of four key loops: two balancing loops and two reinforcing loops (many loops can be identified in the figure). The first balancing loop (B1) indicates that "Potential errors" are solved which increase (denoted by S) "Assumed errors solved" which increases the number of "Correctly solved errors". As more

errors are solved, the number of potential errors decreases (denoted by O) and so on until "Potential errors" are processed completely.

The second balancing loop (B2) indicates that the number of "Correctly solved errors" is increasing the "Total error solved", which accordingly decrease the "Assumed errors solved" and so on.

The first reinforcing loop (R1) indicates that "Assumed error solved" increases "Erroneous action" that increases "Discovered errors" by delay of the start of quality assurance process. "Discovered errors" also increases "Potential errors" which increase "Assumed errors solved" and so on.

The second reinforcing loop (R2) indicates that the increase in "Potential errors" will increase the "skipped errors" which will increase through the delay of "Discovered skipped errors" and will also increase through the delay of "Potential errors" and so on.

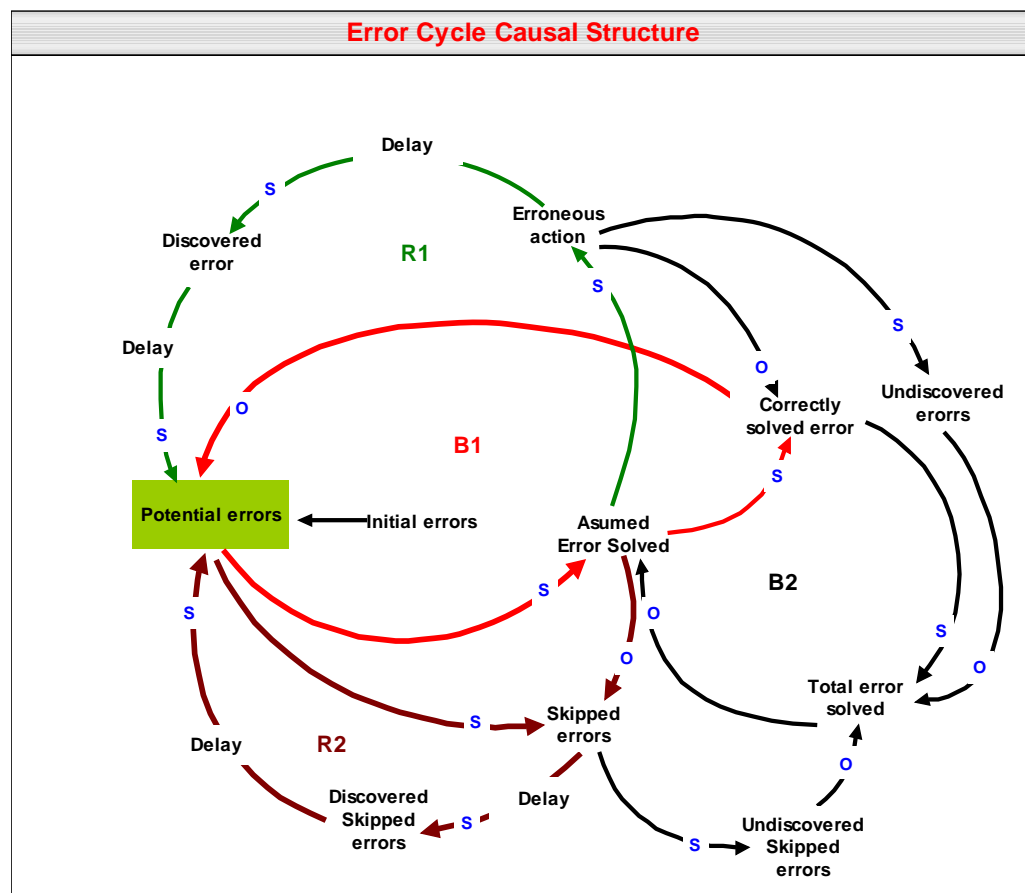


Figure 4 : Error development cycle in the process of producing construction documents

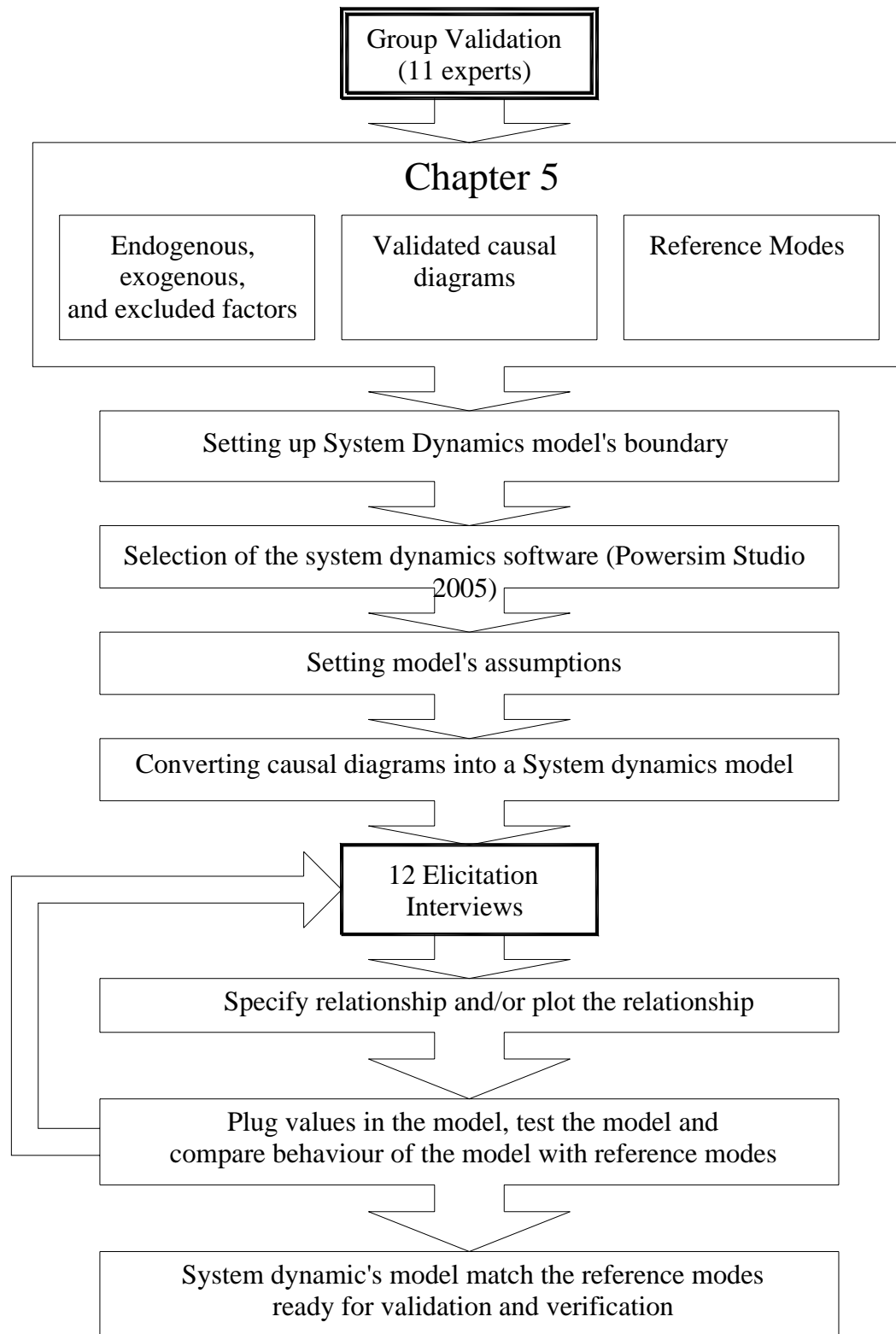
In spite of the fact that the causal relationships for the following system dynamic sub-models are generated from the validated causal diagrams, as discussed in Chapter 5, it is important to note that the appearance and arrangement of variables within the sub-models will differ from those shown in Chapter 5. This can be explained thus:

- Different symbols (i.e. levels, rates, auxiliary, and constants) will be used in this stage and they require a different logical arrangement.
- The variables are linked together by relationships that are governed by equations; therefore the variables should be shown together to be able to create the equations.
- The whole model and its variables are interactive in a very dynamic way, so its location within the model is not important. For clarity and a fluent description of the model, a small number of variables is shown together.

The following sections describe the model in detail. Although the processes are presented here as discrete components with well-defined interfaces for the purpose of explanation, in reality they overlap and interact in many ways. Each process can involve effort from one or more factors within the model, as can be seen in the equations of different factors. The full list of equations is grouped in Appendix A.

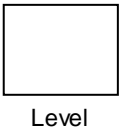

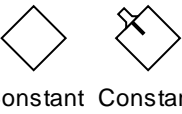

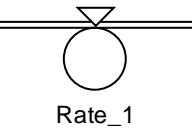


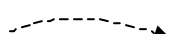

The approach adapted for converting causal diagrams into a system dynamics model is summarized in Figure 2.





**Figure 5 : Approach adapted for developing the system dynamics model**

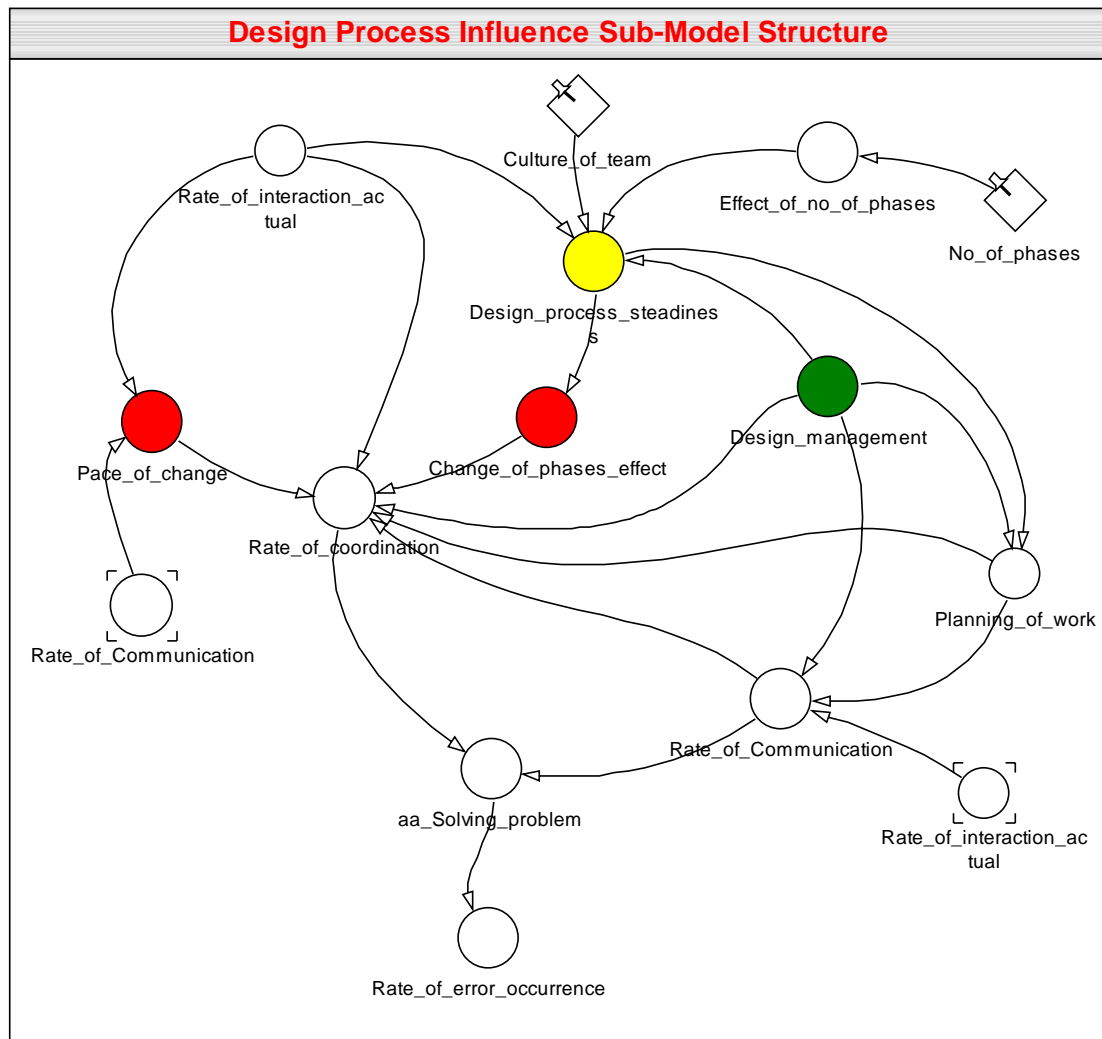
For clarity, (Table 1) summarizes the various symbols which appear in this chapter

Symbol	Name	Description
 Level	Level	A variable that accumulates changes. Influenced by flows.
 Auxiliary	Auxiliary	A variable that contains calculations based on other variables.
 Constant Constant	Constant	A variable that contains a fixed (initial) value. A pin in the corner indicates a permanent variable that keeps its value when the simulation is reset.
 Auxiliary	Snapshot	A variable symbol with an extra set of corners represents an alias for another variable on the same diagram. Snapshots are useful for linking variables located in different parts of a model.
 Rate_1	Continuous flow	A connector that influences levels. A flow is controlled by a variable connected by an information link (or attached directly) to the valve.
	Information link	A connector that provides information to auxiliaries about the value of other variables.
	Delayed link	A connector that provides delayed information to auxiliaries about the value of other variables at an earlier stage in the simulation.
	Initialization link	A connector that provides start-up (initial) information to variables (both auxiliaries and levels) about the value of other variables.
	Cloud	A symbol illustrating an undefined source or outlet for a flow to or from a level. The cloud symbol, also referred to as the source or sink or a flow, indicates the model's outer limits.

**Table 1 : Symbols used in the diagrams**

### 6.6.1 Design process

The first factor that will be considered is the influence of the "design process" on the generation of the errors. The conversion of the casual diagrams into a system dynamic model shows that design process steadiness is affected by the design management, culture of team, the rate of interaction between the team members, and the number of phases that the construction documents will go through.



**Figure 6 : Design process Sub-model**

The equation of the design process steadiness will be:

$$\begin{aligned}
 \text{Design process steadiness} = & \\
 & \left( \frac{\text{Rate\_of\_interaction\_actual}}{\text{Rate\_of\_interaction\_original}} \right) \\
 & * \text{Effect\_of\_no\_of\_phases} * \text{Design\_management} * \text{Culture\_of\_team}
 \end{aligned}$$

The first part of the equation compares the rate of actual interaction with rate of original interaction, which will indicate the steadiness of the design process. The rates of interaction and of communication will affect the rate of coordination.

$$\begin{aligned}
 \text{Effect\_of\_no\_of\_phases} = & \text{GRAPH}(\text{No\_of\_phases}, 1, 1, \\
 & \{1, 0.59, 0.34, 0.16, 0.08, 0.05, 0.1, 0.18, 0.57, 0.7, 0.73 // \text{Min:0;Max:1//}\})
 \end{aligned}$$

$$\text{Design\_management} = \text{Design\_office\_ingredient} * \text{Reputation\_of\_designer}$$

**Culture\_of\_team=1** When culture of team = 1 the culture of team is consistent  
 When culture of team = 0 the culture of team is inconsistent

$$\text{Pace\_of\_change} = (\text{Rate\_of\_interaction\_actual} / \text{Rate\_of\_interaction\_original})$$
$$* \text{GRAPH}(\text{Rate\_of\_Communication}, 0 \ll 1/\text{da} \gg, .02 \ll 1/\text{da} \gg, \{0, .2, .4, .6, .8, 1\} // \text{Min}:0; \text{Max}:1 // \})$$

The design process steadiness will influence the planning of the project

$$\text{Planning\_of\_work} = \text{Design\_management} + \text{Design\_process\_steadiness}$$

The planning of the work will influence the rate of coordination and the rate of communication, which will influence the solving of problem factors, as will be discussed later in the chapter.

### 6.6.2 Number of designers

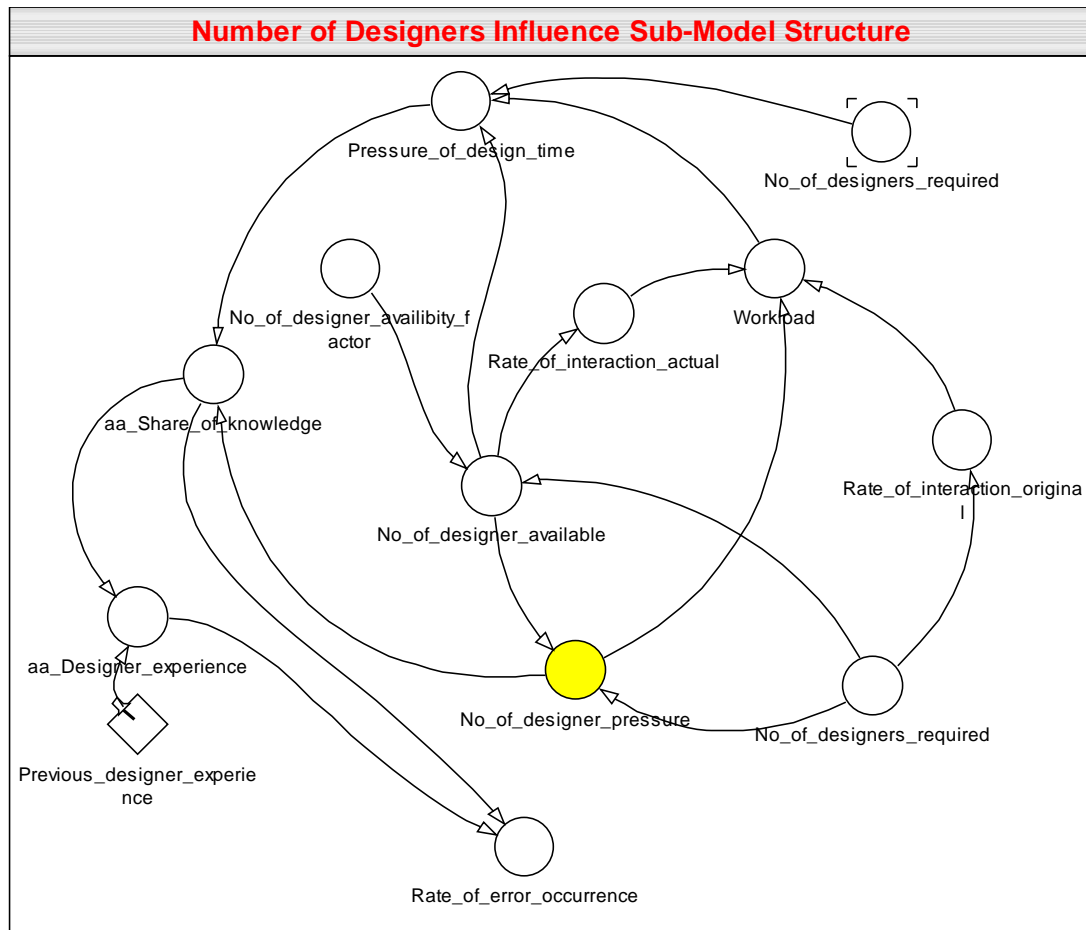
The number of designers available is the result of comparing the required number of designers with the available number of designers to do the job, so

$$\text{No\_of\_designer\_pressure} = \text{No\_of\_designer\_available} / \text{No\_of\_designers\_required}$$

Where

$$\text{No\_of\_designers\_required} = (\text{Required\_hours} * \text{Efficiency\_of\_production} / \text{Working\_hour\_per\_Week\_per\_designer}) / \text{Contractual\_design\_time}$$

$$\text{No\_of\_designer\_available} = \text{No\_of\_designer\_availability\_factor} * \text{No\_of\_designers\_required}$$



**Figure 7 : Number of designers sub-model**

The number of designer availability factor depends on the availability of all the resources in the organization to carry out the job and depend on the design fee factor and reputation of designer. A reputable designer will try to maintain his reputation by having the required resources for the job which will influence the design fee factor.

$$\text{No\_of\_designer\_availability\_factor} = \text{Design\_fee\_factor} * \text{Reputation\_of\_designer}$$

The number of designers with other factors will influence the share of information which will help in solving the problem.

$$\begin{aligned} \text{aa\_Share\_of\_knowledge} = & (\text{Knowledge} * \text{Transfer\_of\_knowledge}) * \\ & \text{Pressure\_of\_design\_time} * \text{No\_of\_designer\_pressure} * \\ & \text{Rate\_of\_Communication} * \text{Available\_design\_time} \end{aligned}$$

Sharing of information will help in sharing the experience and knowledge among the team members to substitute the lack of previous experience and distribute the available information.

$$aa\_Designer\_experience = Previous\_designer\_experience * aa\_Share\_of\_knowledge * Amount\_of\_information * Internal\_approval$$

If the designer has previous experience in the type of project in hand, the previous designer experience factor will be 1 and vice versa: if the teams do not have any similar experience in the past, the value will be 0.

These two factors (share of knowledge and designer experience) will help solving the potential errors while producing the construction documents, as will be discussed later in this chapter.

### 6.6.3 Design management

The design management will help in solving the errors while producing the construction document through planning the work and making clear the line of communication between the team members.

$$Design\_management = Design\_office\_ingredient * Reputation\_of\_designer$$

The design office ingredient is dependant on the education, experience, availability of information and the availability of quality assurance in the office. These factors help IN managing the design effort in a way that reduces the number of errors in the construction documents.

$$Design\_office\_ingredient = AVERAGE (Factor\_of\_designer\_education, Experienced\_designer, Previous\_designer\_experience, Availability\_of\_information, Availability\_of\_QA\_procedure)$$

The planning of work will affect the resource allocation and then technical knowledge availability through briefing to the team factor.

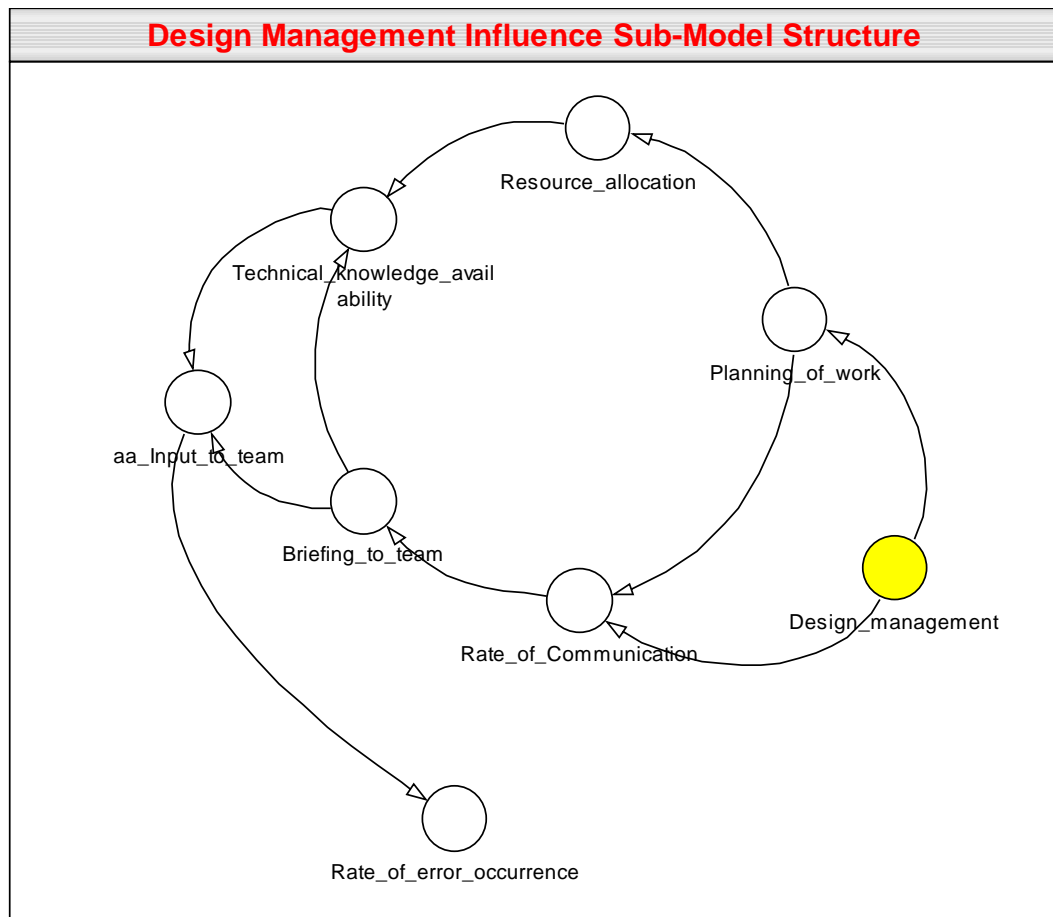
$$Resource\_allocation = Planning\_of\_work$$

$$Briefing\_to\_team = GRAPHLINAS (Rate\_of\_Communication, 0 << 1/da >>, 02 << 1/da >>, {0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 1 // Min: 0; Max: 1; Zoom //})$$

$$Technical\_knowledge\_availability = Briefing\_to\_team * Resource\_allocation$$

The technical knowledge availability and briefing to team will help reduce errors in the construction documents through input to the team factor.

$$aa\_Input\_to\_team = Briefing\_to\_team + Technical\_knowledge\_availability$$



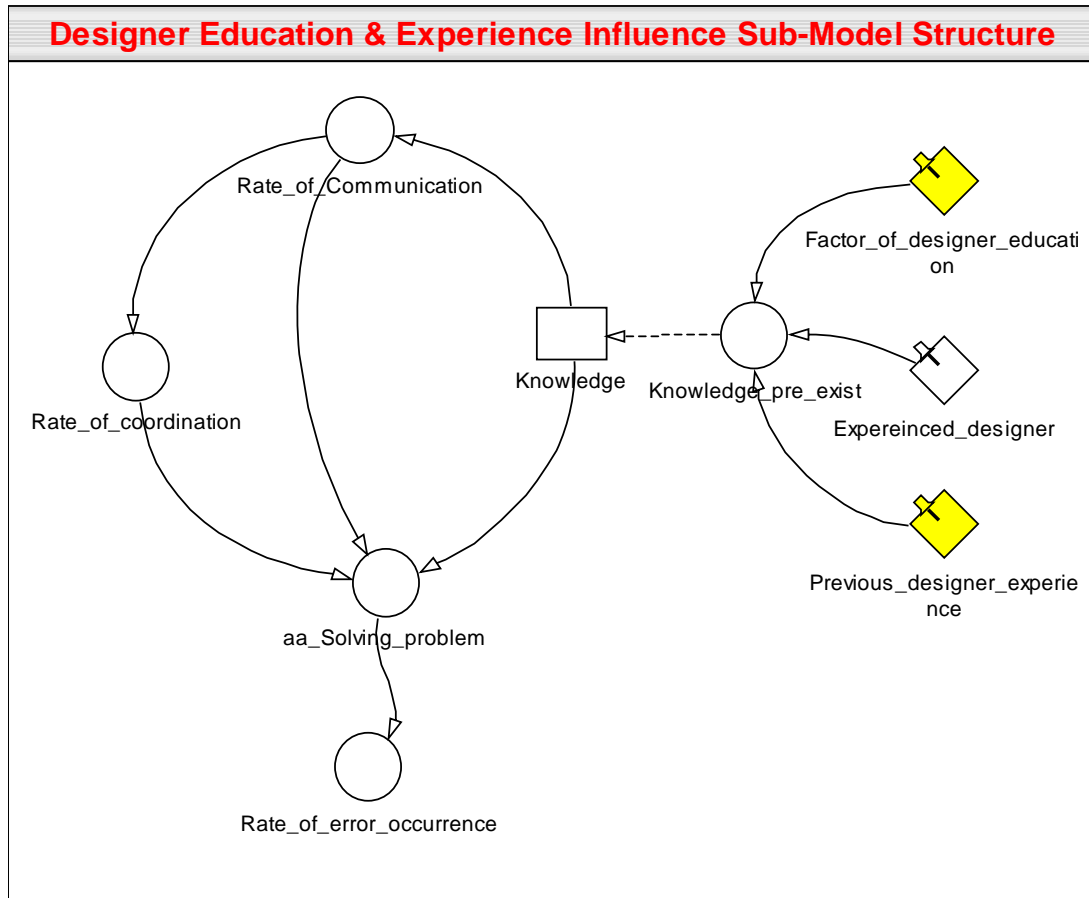
**Figure 8 : Design management sub-model**

#### 6.6.4 Designer education and experience

The education and experience factors influence the knowledge that pre-exist for the team of the project.

$$\begin{aligned}
 Knowledge\_pre\_exist = & AVERAGE (Factor\_of\_designer\_education , \\
 & Experience\_of\_designer\_with\_similar\_project , \\
 & Previous\_designer\_experience , Availability\_of\_information)
 \end{aligned}$$

This previous knowledge that pre exists will be the initial amount of knowledge that exists for the team members while preparing the construction documents. It consists mainly of the professional education that designers receive, the experience of the designers with similar projects, experience of the designer with projects and the availability of information regarding the project from other sources within the project.



**Figure 9 : Designer education & experience sub-model**

This knowledge that is transferred among team members will help solve the errors in the construction documents directly, will increase the rate of communication which increases the rate of coordination factors, as it will be discussed in the chapter.

$$\mathbf{Knowledge = Availability\_of\_information + Knowledge\_pre\_exist}$$

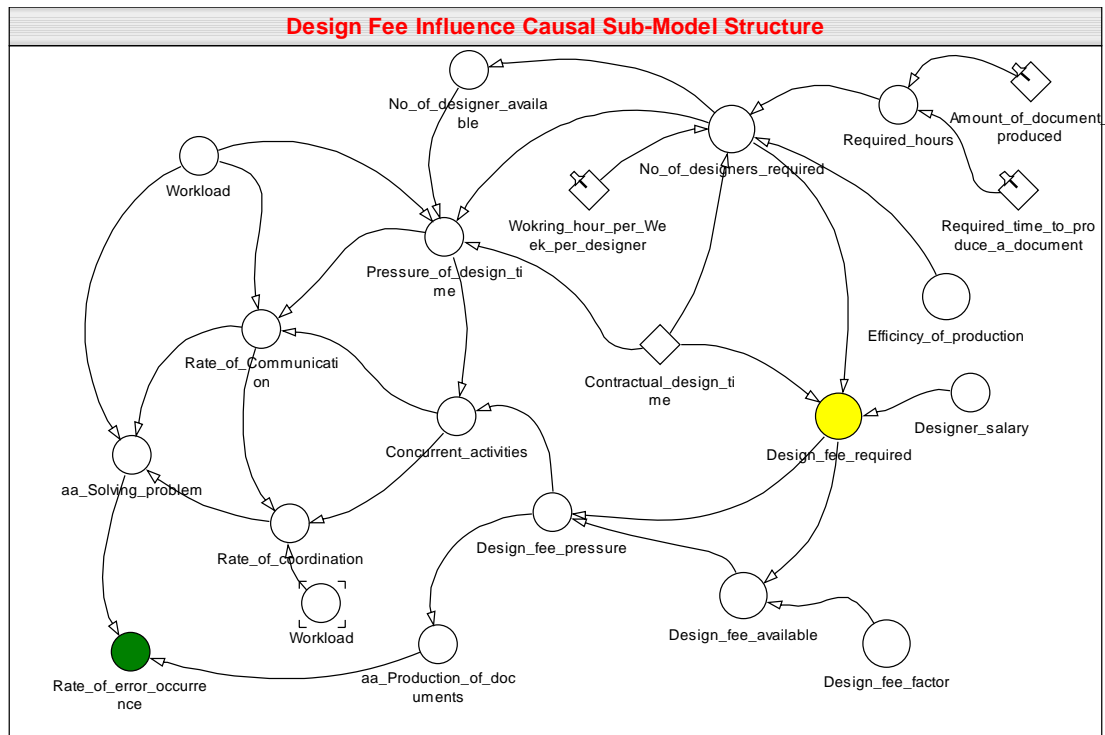
### 6.6.5 Design fees

Design fee pressure is the result of the pressure that occurs as a result of the difference between the required and available design fee.

So the design fee pressure equation will be

$$\mathbf{Design\_fee\_pressure = Design\_fee\_required / Design\_fee\_available}$$





**Figure 10 : Design fee sub-model**

Where

$$\begin{aligned} \text{Design\_fee\_required} &= \text{Contractual\_design\_time} * \text{Designer\_salary} * \\ &\quad \text{No\_of\_designers\_required} * ((\text{Amount\_of\_work\_with\_designer} + 1) \\ &\quad / \text{Amount\_of\_work\_with\_designer}) * \text{Reputation\_of\_designer} \end{aligned}$$

Where

*Contractual\_design\_time* is constant which is determined by the client

$$\begin{aligned} \text{Designer\_salary} &= \text{Salary\_standard} * \text{Factor\_of\_designer\_education} * \\ &\quad \text{Previous\_designer\_experience} \end{aligned}$$

$$\begin{aligned} \text{No\_of\_designers\_required} &= (\text{Required\_hours} * \text{Efficiency\_of\_production} \\ &\quad / \text{Working\_hour\_per\_week\_per\_designer}) / \text{Contractual\_design\_time} \end{aligned}$$

$$\begin{aligned} \text{Design\_fee\_available} &= (\text{Design\_fee\_factor} + (\text{Reputation\_of\_designer} - 1)) \\ &\quad * \text{Design\_fee\_required} \end{aligned}$$

Where

$$\text{Design\_fee\_factor} = \text{Reputation\_of\_designer}$$

So the main influence of the design fee results from pressure imposed on the design team to reduce the expenditure on the project. First, the design team tries to reduce the



$$*Probability\_of\_error / Factor\_of\_error\_resulting\_from\_interaction$$

And where

$$Time\_for\_extra\_activities = Extra\_activities * Time\_to\_do\_an\_interaction$$

$$Extra\_activities = (Total\_no\_of\_errors * Probability\_of\_error / Factor\_of\_error\_resulting\_from\_interaction) - Total\_amount\_of\_interaction)$$

Where time to do an interaction is the time spent to solve an interaction in the process of producing the construction documents.

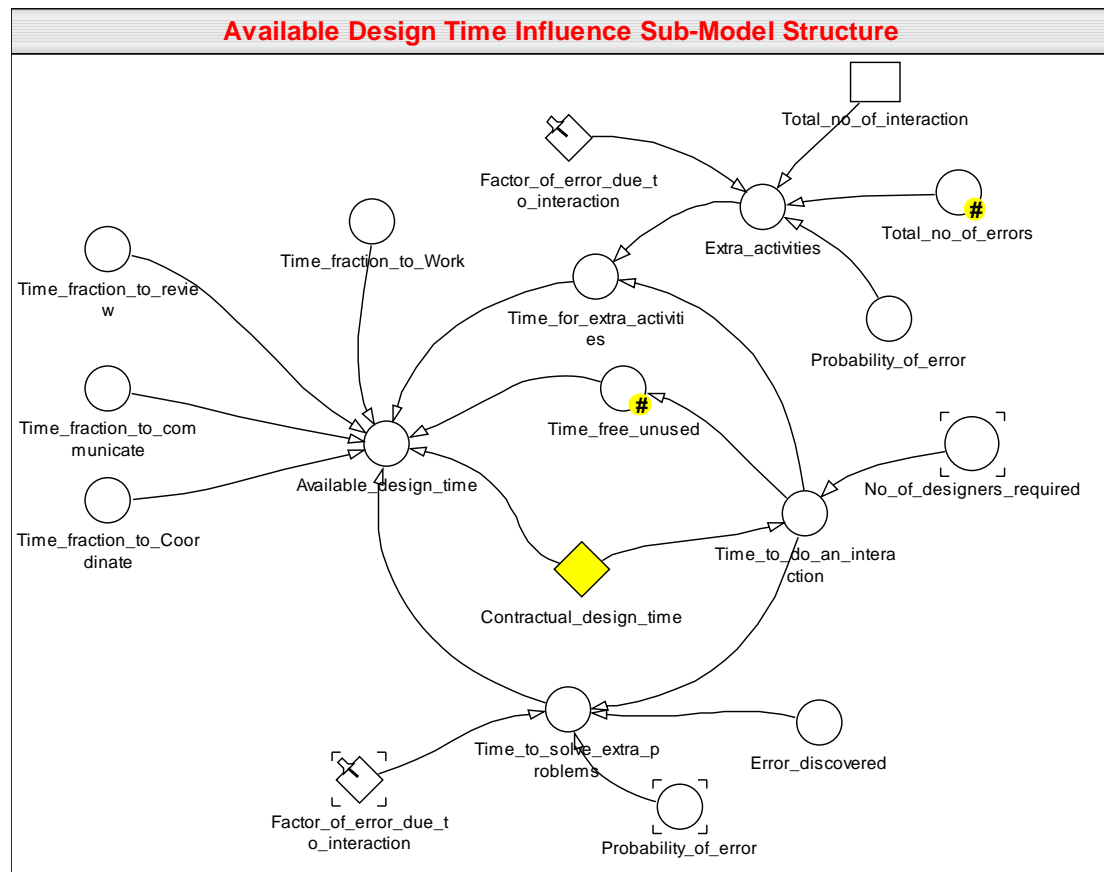
$$Time\_to\_do\_an\_interaction = Contractual\_design\_time / (Number\_of\_documents\_produced * No\_of\_designers\_required * No\_of\_disciplines)$$

The available design time creates the pressure on the design time which affects the concurrent activities and rate of communication, which influence the rate of coordination and rate of solving problems and conclude with the creation of errors in the construction documents. The equations were discussed in the previous section.

The available design time is associated with this model. It is related to the actual time available to the design team to solve the problems, as more errors discovered the available design time will be reduced as a result of the time spent solving the errors discovered.

$$Available\_design\_time = (Contractual\_design\_time - Time\_to\_solve\_extra\_problems + Time\_free\_unused - Time\_for\_extra\_activities) * AVERAGE(Time\_fraction\_to\_communicate, Time\_fraction\_to\_Coordinate, Time\_fraction\_to\_review, Time\_fraction\_to\_Work)$$

$$Time\_to\_solve\_extra\_problems = Error\_discovered * Time\_to\_do\_an\_interaction * Probability\_of\_error / Factor\_of\_error\_caused\_by\_interaction$$



**Figure 12 : Available design time sub-model**

These is the time saved from the contractual time

$$\begin{aligned} \text{Time\_free\_unused} = & (\text{No\_of\_free\_interaction} * \text{Time\_to\_do\_an\_interaction}) \\ & + \text{Time\_free\_from\_skipped\_errors} \end{aligned}$$

*Where*

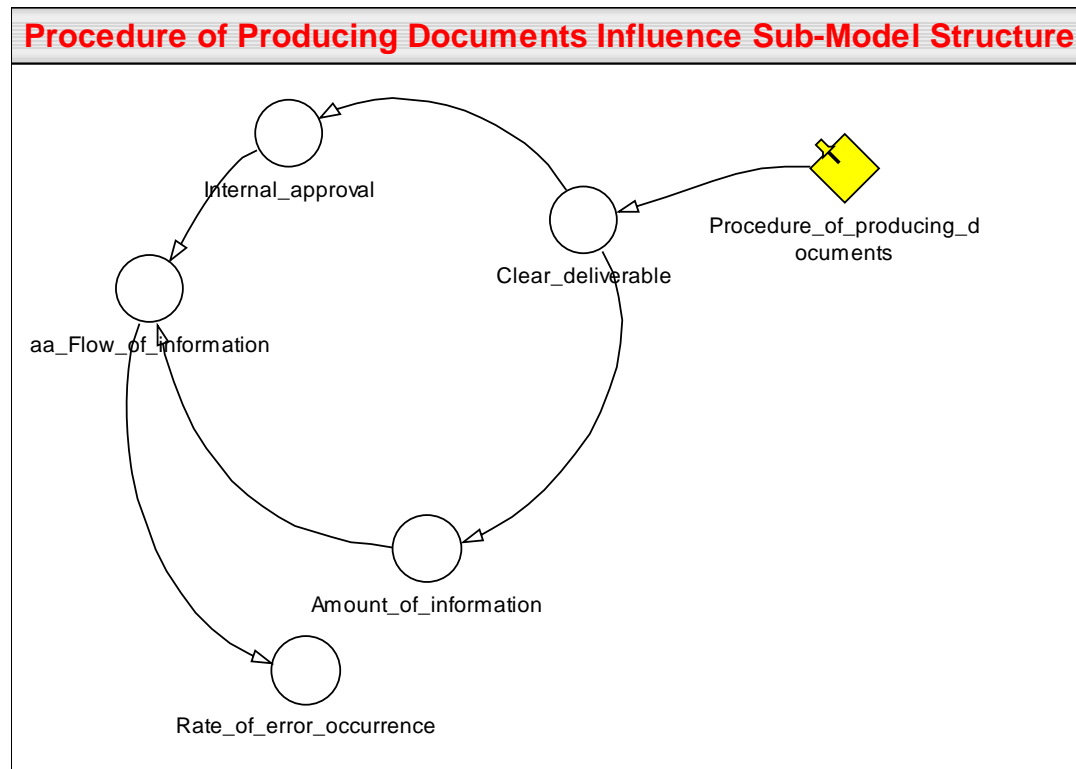
$$\begin{aligned} \text{No\_of\_free\_interaction} = & (\text{Total\_amount\_of\_interaction} / \text{Probability\_of\_error}) \\ & - (\text{Total\_no\_of\_errors} / \text{Factor\_of\_error\_caused\_by\_interaction}) \\ & ) * \text{Probability\_of\_error} \end{aligned}$$

$$\text{Time\_for\_extra\_activities} = \text{Extra\_activities} * \text{Time\_to\_do\_an\_interaction}$$

Where

$$\begin{aligned} \text{Extra\_activities} = & ((\text{Total\_no\_of\_errors} * \text{Probability\_of\_error} / \\ & \text{Factor\_of\_error\_caused\_by\_interaction}) - \text{Total\_amount\_of\_interaction}) \end{aligned}$$

### 6.6.7 Procedure of producing documents



**Figure 13 : Procedure of producing documents sub-model**

The availability of procedures to produce the construction documents influences the clarity of deliverables.

*Clear\_deliverable*= *GRAPH*(*Procedure\_of\_producing\_documents*,0,1,  
{0,1,2,3,4,5,6,7,8,9,1//Min:0;Max:1//})

*Internal\_approval*=*GRAPH*(*Clear\_deliverable*,0,1,{0,1,2,3,4,5,6,7,8,9,1//Min:0  
;Max:1//})

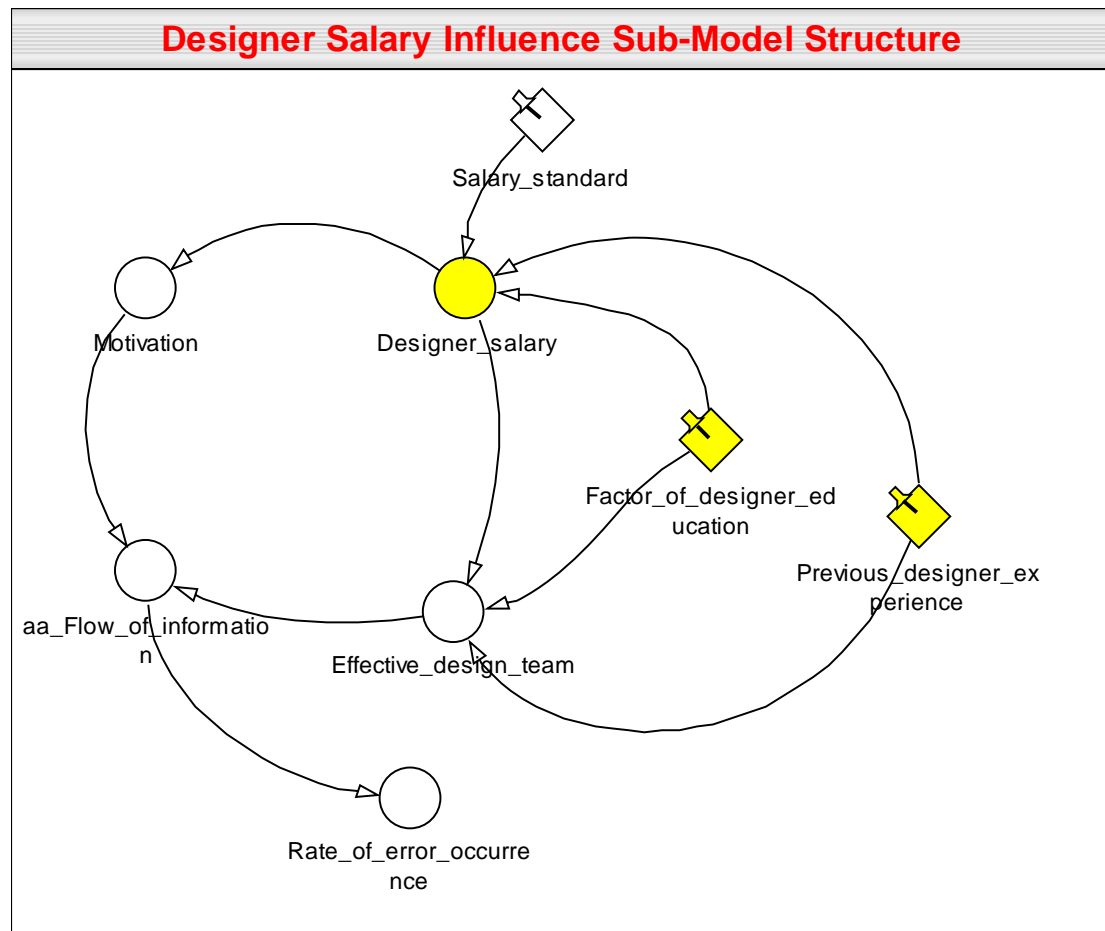
*Amount\_of\_information*=  
*GRAPH*(*Clear\_deliverable*,0,1,{0,1,2,3,4,5,6,7,8,9,1//Min:0;Max:1//})

*aa\_Flow\_of\_information*= *AVERAGE*(*Amount\_of\_information*  
,*Effective\_design\_team* , *Internal\_approval*, *Motivation*)

The main influence of the procedures is on the flow of information which ultimately influences the amount of information generated in the construction documents.

### 6.6.8 Designer salary

Designer salary is a function of the standard salary in the organization, a factor of designer education and previous designer experience.



**Figure 14 : Designer salary sub-model**

$$\text{Designer\_salary} = \text{Salary\_standard} * \text{Factor\_of\_designer\_education} * \text{Previous\_designer\_experience}$$

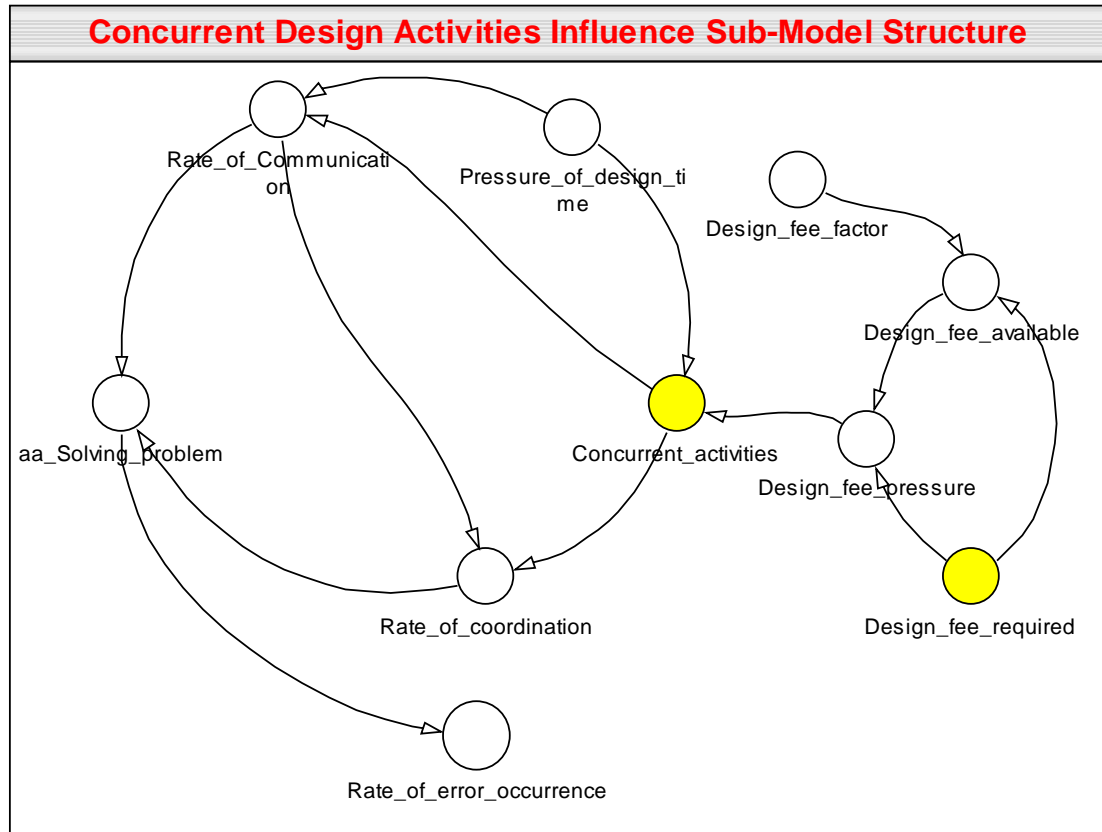
The designer salary accordingly influences, along with other factors, the motivation and effectiveness of the design team.

$$\text{Motivation} = \text{GRAPH}(\text{Designer\_salary}, 0 \ll \text{USD/person/mo} \gg, 1 \ll \text{USD/person/mo} \gg, \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 1 // \text{Min:0;Max:1} // \})$$

$$\text{Effective\_design\_team} = \text{AVERAGE}(\text{GRAPH}(\text{Designer\_salary}, 0 \ll \text{USD/person/mo} \gg, 1 \ll \text{USD/person/mo} \gg, \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 1 // \text{Min:0;Max:1} // \}), \text{Factor\_of\_designer\_education}, \text{Previous\_designer\_experience}, \text{Match\_of\_goals}, \text{Procedure\_of\_producing\_documents})$$

The motivation and effectiveness of the design team influence the flow of information, and as a result the number of errors generated while producing the construction documents (refer to the equation of the previous section).

### 6.6.9 Concurrent design activities

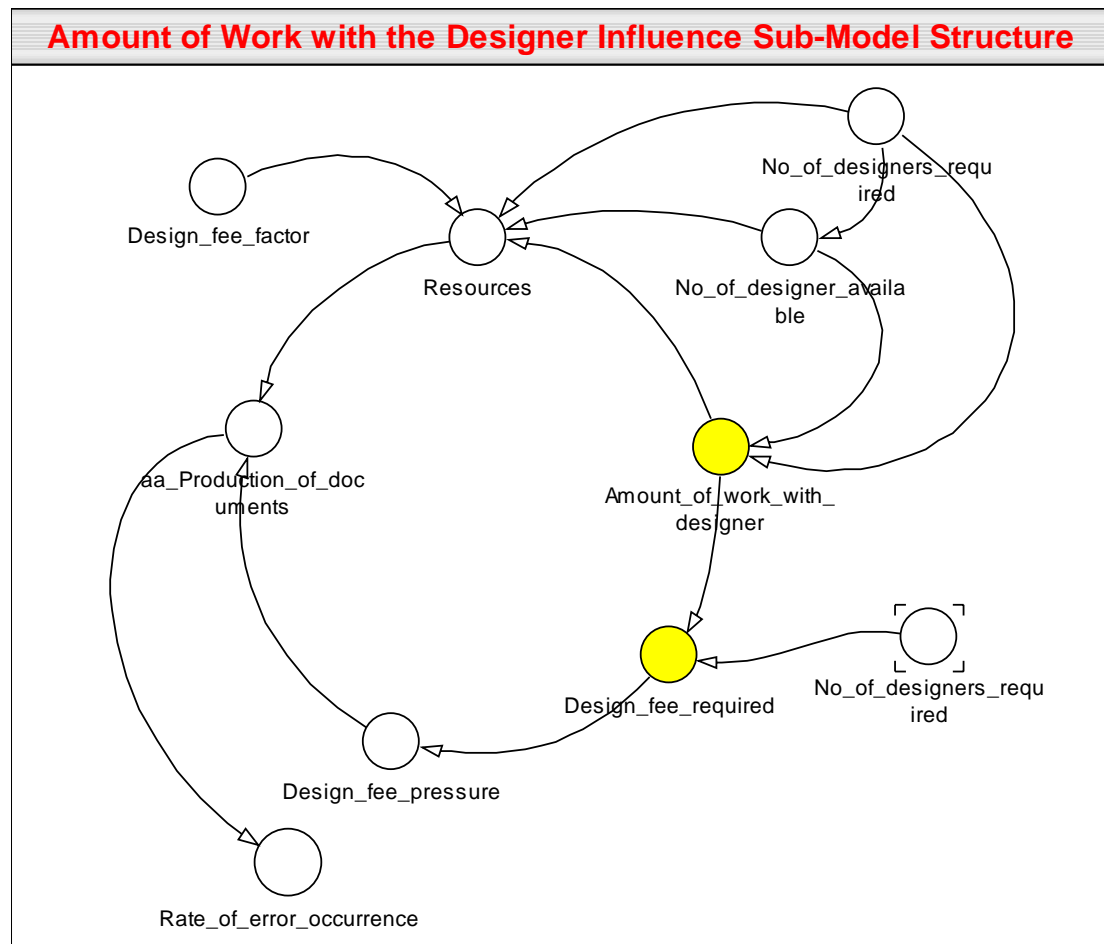


**Figure 15 : Concurrent design activities sub-model**

As discussed previously, the concurrent design activities are influenced by the pressure of the number of designer available, design time and the design fees. Doing tasks concurrently influences the rate of coordination and rate of communication which influence the rate of solving problems, and as the result the rate of errors generated in the construction documents.

$$\text{Concurrent\_activities} = \frac{\text{No\_of\_designer\_pressure} * \text{Pressure\_of\_design\_time}}{\text{Design\_fee\_pressure}}$$

### 6.6.10 Amount of work with the designer



**Figure 16 : Amount of work with designer sub-model**

The amount of work with the designer is influenced by the available of number of designers.

$$\text{Amount\_of\_work\_with\_designer} = \text{No\_of\_designers\_available} / \text{No\_of\_designers\_required}$$

The amount of work influences the resources available to carry out the job and the design fee to carry out the job

$$\text{Resources} = \text{Amount\_of\_work\_with\_designer} * \text{Design\_fee\_factor} * \text{No\_of\_designers\_required} / \text{No\_of\_designers\_available}$$

$$\text{Design\_fee\_required} = \text{Contractual\_design\_time} * \text{Designer\_salary} * \text{No\_of\_designers\_required} * ((\text{Amount\_of\_work\_with\_designer} + 1) / \text{Amount\_of\_work\_with\_designer}) * \text{Reputation\_of\_designer}$$

While

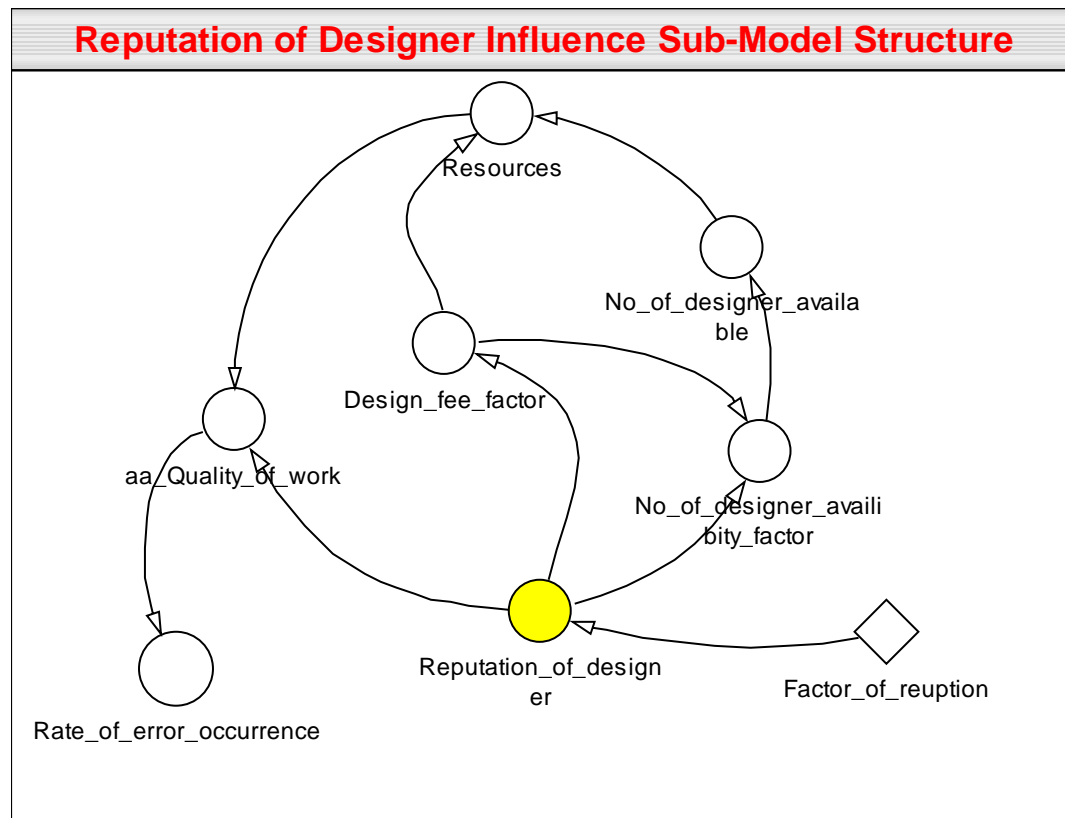
$$\text{Design\_fee\_pressure} = \text{Design\_fee\_required} / \text{Design\_fee\_available}$$

Finally

$$\text{aa\_Production\_of\_documents} = \text{Resources} * \text{Design\_fee\_pressure}$$



### 6.6.11 Reputation of designer influence



**Figure 17 : Reputation of designer sub-model**

The reputation of the design team is the function of the designer's education, experience, previous similar experience and reputation from other factors.

$$\text{Reputation\_of\_designer} = \text{AVERAGE}(\text{Factor\_of\_designer\_education}, \text{Experienced\_designer}, \text{Previous\_designer\_experience}, \text{Factor\_of\_reputation})$$

The reputation of the design team influences the design fee, the quality of the work and the number of designers available to carry out the work.

As the number of designers available depends on the design fee and the reputation of design,

$$\text{No\_of\_designer\_availability\_factor} = \text{Design\_fee\_factor} * \text{Reputation\_of\_designer}$$

As the fees are an output of the reputation of the designer in education. experience, previous experience, etc.

$$\text{Design\_fee\_factor} = \text{Reputation\_of\_designer}$$

The quality of work will then be the function of the design office ingredient, rate of communication, availability of QA procedure, coordination, share of understanding, reputation of the designer, knowledge available to the design team about the project and resources available to carry out the work.

$$aa\_Quality\_of\_work=(Design\_office\_ingredient*Rate\_of\_Communication)+(Availability\_of\_QA\_procedure*Coordination * Share\_of\_understanding * Resources * Reputation\_of\_designer * Knowledge)$$

The result of such interaction and functions will influence the number of errors generated while producing the construction documents.

#### **6.6.12 Availability of quality assurance**

The availability of quality assurance (QA) influences the document review, the ingredient of the design office and the quality of work. The document review attempts to protect design documents from defects produced during production activities. Holes in the system defences are the result of failure by document reviews to detect and correct a few residual problems that come to light during later stages.

$$Document\_review=Design\_office\_ingredient+DELAYINF(Availability\_of\_QA\_procedure,QA\_start\_date) *(1+Difference\_of\_interaction)$$

$$Design\_office\_ingredient=AVERAGE( Factor\_of\_designer\_education,Experienced\_designer,Previous\_designer\_experience,Availabilty\_of\_information,Availability\_of\_QA\_procedure)$$

$$aa\_Quality\_of\_work=(Design\_office\_ingredient*Rate\_of\_Communication)+(Availability\_of\_QA\_procedure*Coordination*Share\_of\_understanding*Resources*Reputation\_of\_designer*Knowledge)$$

The document review influences the rate of coordination which influences the rate of solving problems which influences the rate of errors in the construction documents. Also, the document review influences the rate of discovery of errors which affects the rate of problems solved.

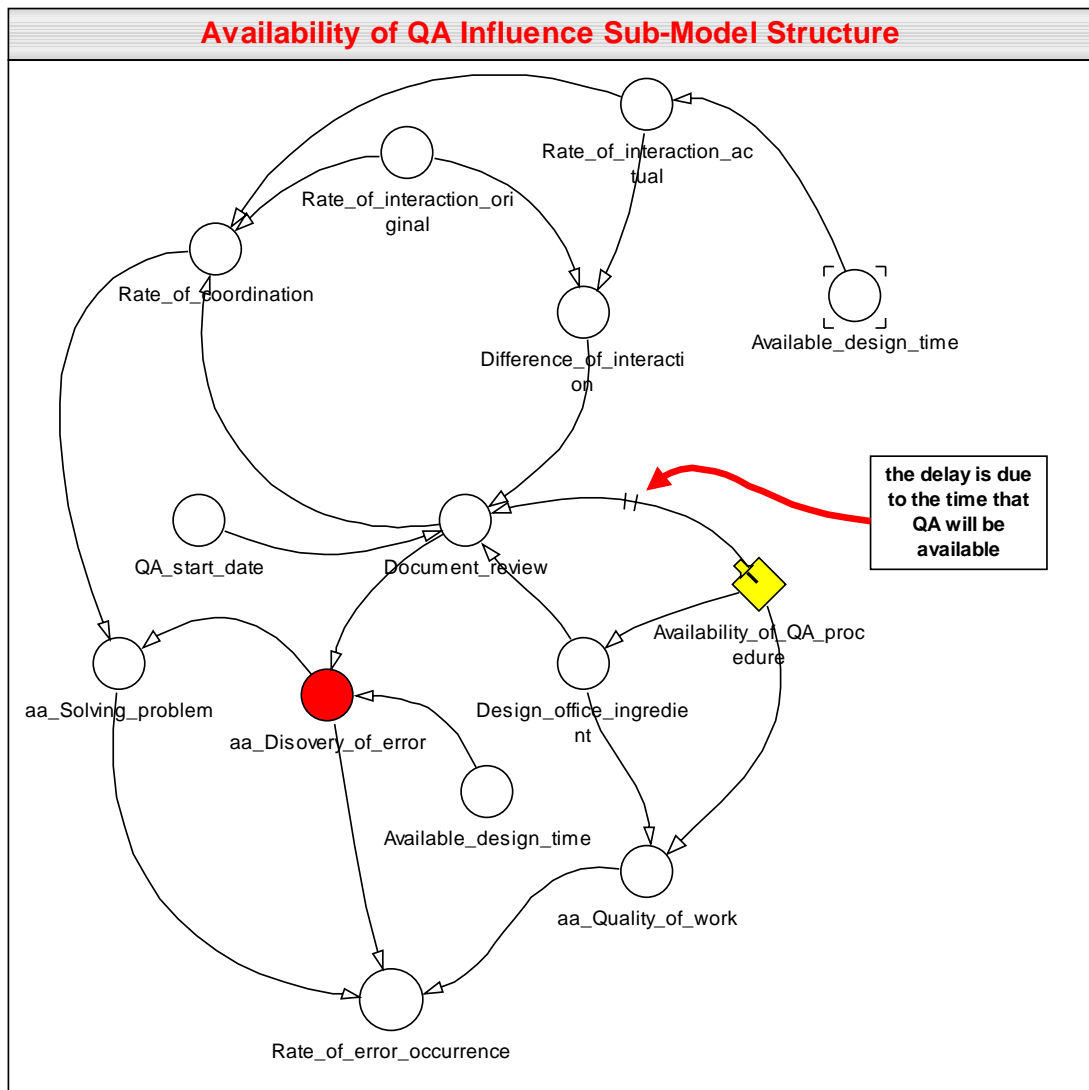


Figure 18 : Availability of quality assurance sub-model

## 6.6.13 Effective design team

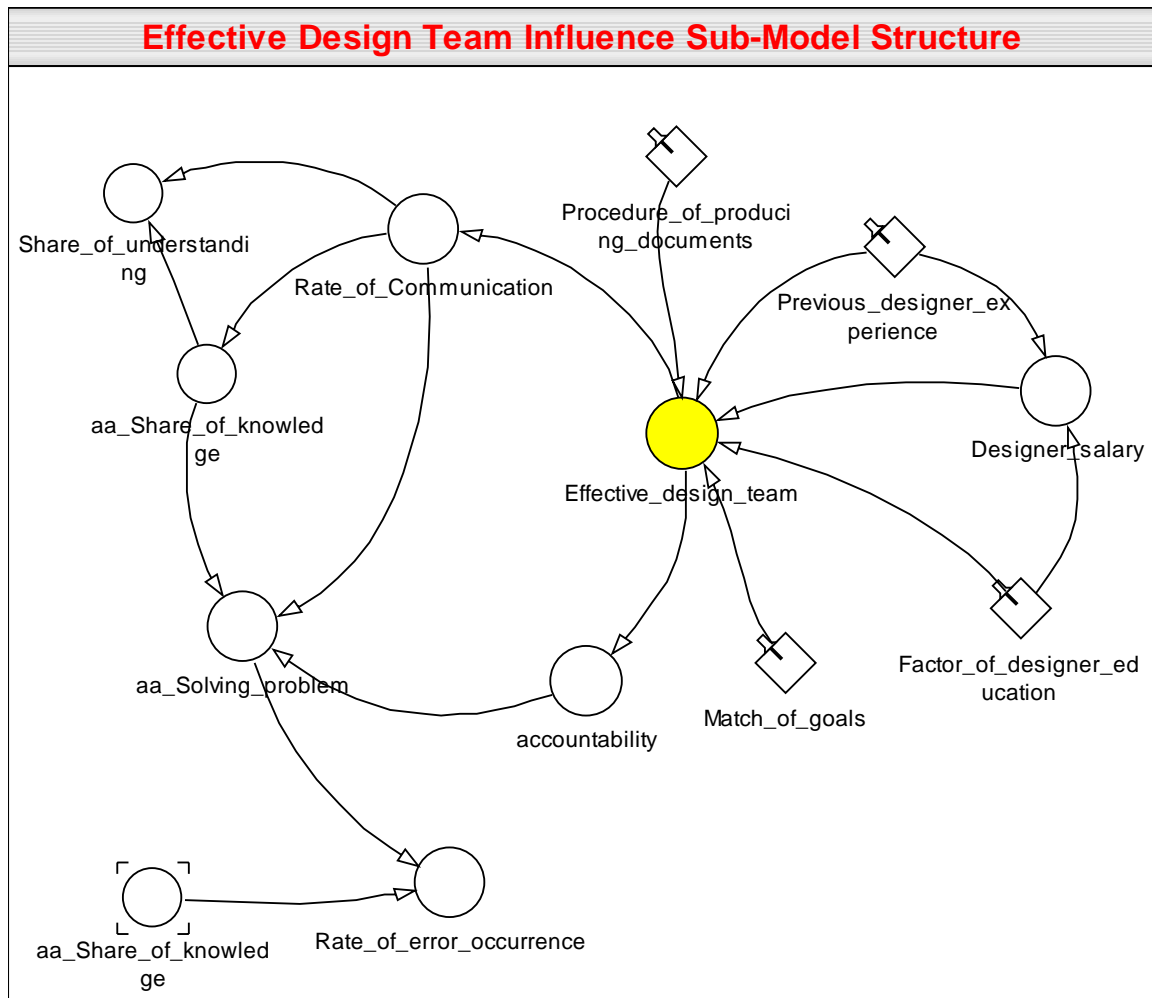


Figure 19 : Effective design team sub-model

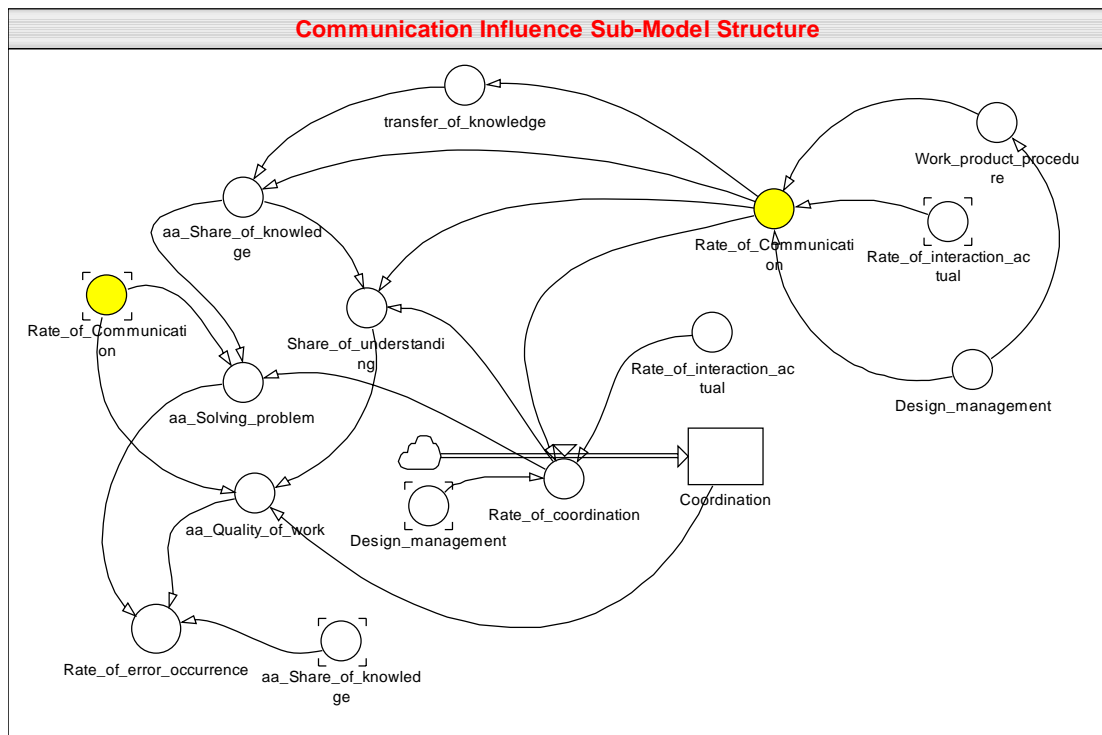
The effective design team is the function of previous designer experience, designer salary, designer education and the match of goals of the designer with the objective of the client.

*Effective\_design\_team=AVERAGE(GRAPH(Designer\_salary,0<<USD/person/mo>>, 0.1<<USD/person/mo>>, {0,.1,.2,.3,.4,.5,.6,.7,.8,.9,1//Min:0;Max:1//}) ,Factor\_of\_designer\_education ,Previous\_designer\_experience ,Match\_of\_goals ,Procedure\_of\_producing\_documents )*

The effective design team affects the rate of communication and the accountability of the design team. The rate of communication will affect the share of knowledge and solving the problems, and the rate of error generation, while the accountability will influence the rate of solving problems.

*Accountability=GRAPH(Effective\_design\_team,0,.2,{0,.2,.4,.6,.8,1//Min:0;Max:1//})*

### 6.6.14 Communication



**Figure 20 : Communication sub-model**

The rate of communication, as discussed in the previous sections, is the function of the rate of interaction, knowledge available for the design team, pressure of design time, the design management, planning of work, workload for the designer, the design procedure available, concurrently of the interactions and efficiencies of the design team to carry out the work.

$$\begin{aligned}
 & \textit{Rate\_of\_Communication} \\
 & = (\textit{Rate\_of\_interaction\_actual} / \textit{Rate\_of\_interaction\_original}) \\
 & * \textit{aa\_Discovery\_of\_error} * \textit{Knowledge} * \textit{Pressure\_of\_design\_time} \\
 & * \textit{Design\_management} * \textit{Planning\_of\_work} * \textit{Workload} * \textit{Work\_product\_procedure} \\
 & * \textit{group\_organisation} * \textit{Concurrent\_activities} * \textit{Effective\_design\_team}
 \end{aligned}$$

The rate of communication influences the rate of coordination, transfer of knowledge, and the share of understanding. These factors influence the share of knowledge, solving problems and the quality of work which finally influences the rate of error occurrence in the construction document.

$$\begin{aligned}
 & \textit{Rate\_of\_coordination} = \textit{Design\_management} * \\
 & (\textit{Workload} * \textit{Rate\_of\_interaction\_actual} / \textit{Rate\_of\_interaction\_original}) \\
 & * \textit{Pace\_of\_change} * \textit{Change\_of\_phases\_effect} * \textit{Concurrent\_activities} * \\
 & \textit{Document\_review} * \textit{Rate\_of\_Communication} * \textit{Planning\_of\_work}
 \end{aligned}$$

$$\text{Share\_of\_understanding} = \text{aa\_Share\_of\_knowledge} * \text{Rate\_of\_coordination} / \text{Rate\_of\_Communication}$$

$$\text{aa\_Quality\_of\_work} = (\text{Design\_office\_ingredient} * \text{Rate\_of\_Communication}) + (\text{Availability\_of\_QA\_procedure} * \text{Coordination} * \text{Share\_of\_understanding} * \text{Resources} * \text{Reputation\_of\_designer} * \text{Knowledge})$$

### 6.6.15 Availability of information

The availability of information will influence the knowledge available to the design team

$$\text{Knowledge} = \text{Availability\_of\_information} + \text{Knowledge\_pre\_exist}$$

$$\text{Knowledge\_pre\_exist} = \text{AVERAGE}(\text{Factor\_of\_designer\_education}, \text{Experienced\_designer}, \text{Previous\_designer\_experience}, \text{availability\_of\_information})$$

The previous equation will take the knowledge gained from education, experience and the previous designer experience.

However, the knowledge will not be useful without proper ways to transfer it.

$$\text{Transfer\_of\_knowledge} = \text{Rate\_of\_Communication} / \text{Knowledge}$$

The availability of knowledge and proper ways of transferring it will share the knowledge between the design team based on the pressure of design time and the number of the designers in the team.

$$\text{aa\_Share\_of\_knowledge} = (\text{Knowledge} * \text{Transfer\_of\_knowledge}) * \text{Pressure\_of\_design\_time} * \text{No\_of\_designer\_pressure} * \text{Rate\_of\_Communication} * \text{Available\_design\_time}$$

Existence of knowledge with proper ways of sharing and proper analysis will influence the way the problem is solved which will affect the number of errors generated in the construction documents.

$$\text{aa\_Solving\_problem} = (\text{Knowledge} * \text{aa\_Share\_of\_knowledge} / \text{Rate\_of\_Communication}) * \text{Workload} * \text{aa\_Discovery\_of\_error} * \text{Proper\_analysis} * \text{Accountability} + \text{Rate\_of\_coordination}$$

$$\text{Proper\_analysis} = \text{AVERAGE}(\text{Factor\_of\_designer\_education}, \text{Knowledge}, \text{Previous\_designer\_experience})$$

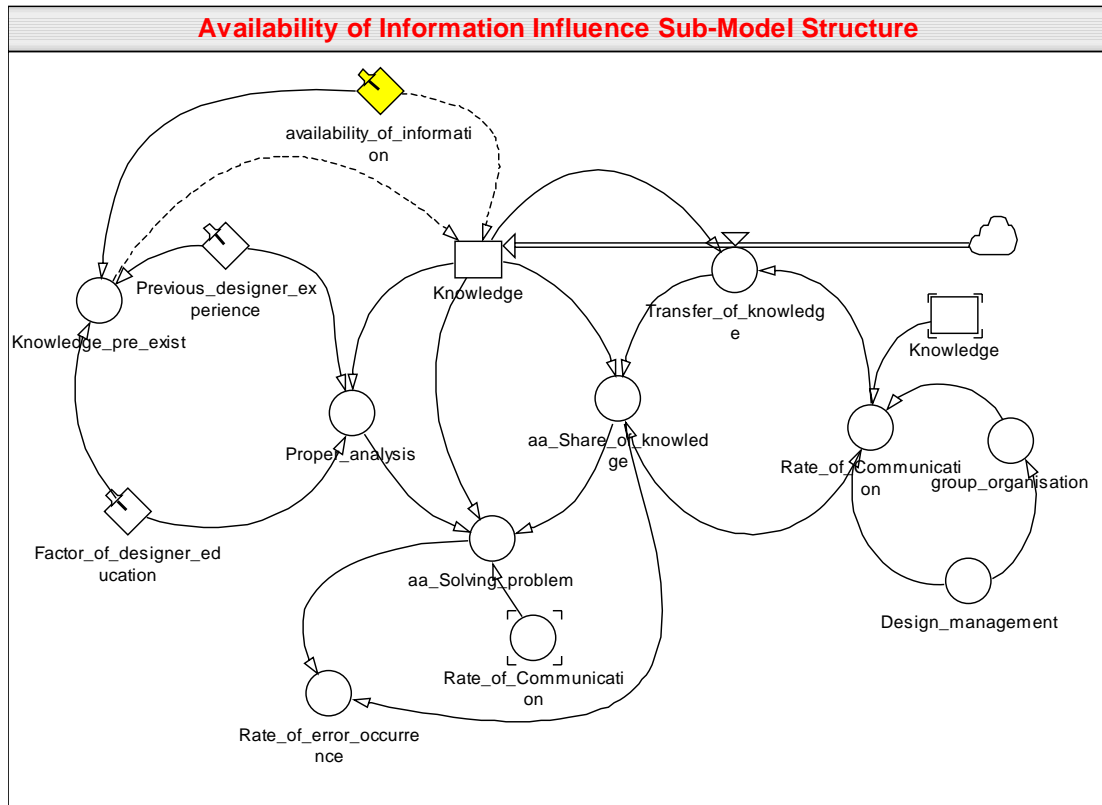
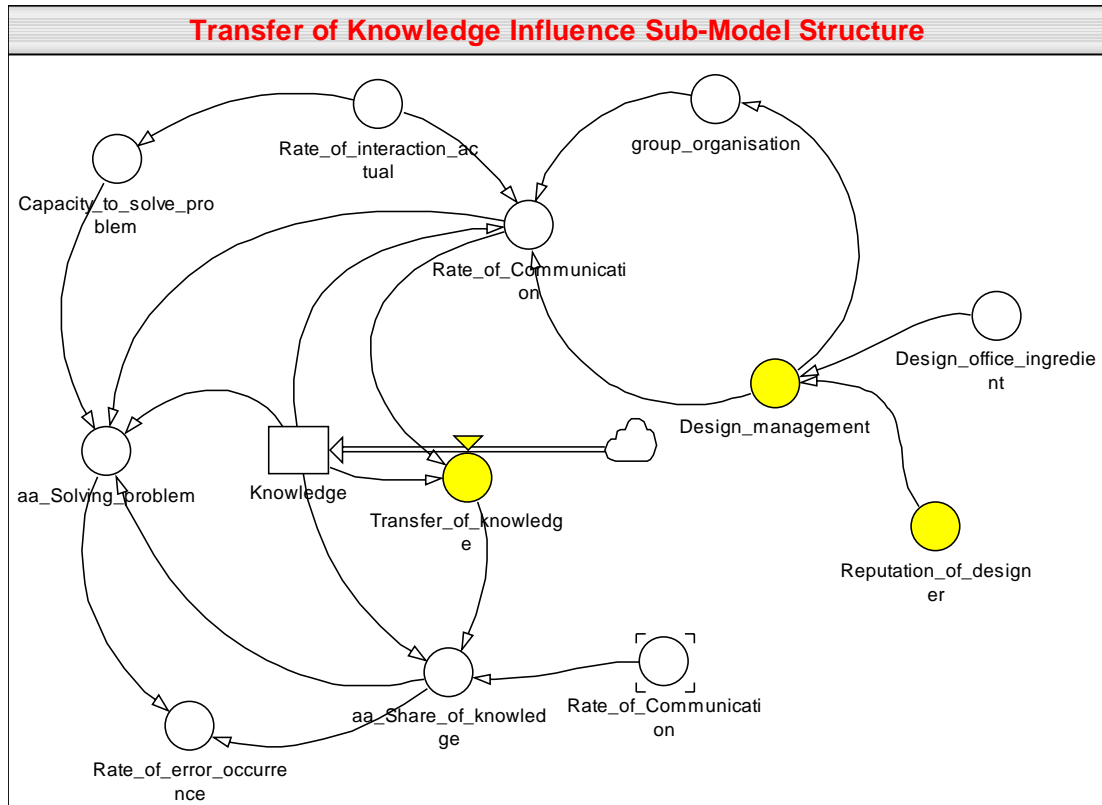


Figure 21 : Availability of information sub-model

### 6.6.16 Transfer of knowledge



**Figure 22 : Transfer of knowledge sub-model**

Transfer of knowledge will influence the amount of knowledge distributed among the team members which will influence the rate of solving problems, rate of communication and the rate of sharing knowledge.

$$Knowledge = dt(\text{transfer\_of\_knowledge}) + \text{availability\_of\_information} + Knowledge\_pre\_exist$$

$$aa\_Share\_of\_knowledge = (\text{Knowledge} * \text{Transfer\_of\_knowledge}) * \text{Pressure\_of\_design\_time} * \text{Amount\_of\_designer\_pressure} * \text{Rate\_of\_Communication} * \text{Available\_design\_time}$$



## 6.7 The basic structure of the system

The basic structure of the system explains the whole system and the main interaction of different components together and how the model describes error development process while producing the construction documents.

Any task in the model flow (Figure 22) into and through the following state:

1. Initial Tasks
2. Tasks gone through solving processes.
3. Tasks skipped during the solving processes
4. Tasks assumed to be correct.
5. Tasks assumed to be correct but flaws are discovered and have to be reprocessed once again;
6. Tasks assumed to be correct but flaws are discovered and have to be reprocessed once again;
7. Tasks assumed to be correct but flaws are undiscovered and they will be skipped
8. Tasks skipped the solving process but were discovered and had to be reprocessed once again;
9. Tasks skipped the solving process and undiscovered

The initial numbers of tasks are accumulating in the stock of potential errors. Tasks are solved for the first time through the performance of the solving activity flows. They accumulate in the stock of assumed solved errors. Then they pass through the quality of work assurance process and accumulate in the stock of correctly solved errors. If the tasks which are defective are discovered through erroneous action flow they will accumulate in the erroneous tasks stock. Then these erroneous tasks go through the discovery of errors flow and accumulate in the discovered erroneous task stock. These discovered erroneous tasks go again through the solving activity flows and go through the processes again. Some of potential erroneous tasks will skip the process of the problem solving flow and they will accumulate in the skipped errors stock through the skipped action flow. Some of the skipped errors will be discovered through the discovery of errors flow and will accumulate in the discovered skipped errors stock. These discovered skipped errors will go through the solving activity flow and will go through the processes.

As shown in figure (Figure 22) the causal loop depicts the reduction in the number of task available as potential errors as the work is completed correctly. In this loop the basework rate is based on the tasks available for basework and the minimum basework duration. The potential rate of tasks increases as the numbers of tasks with flaws are discovered.

The process raises the question: "How fast on average can a task be completed if everything needed is available?" The answer to the question will lead to the development of the first parameter, the Average Time for Each Interaction (ATEI). ATEI is the average time required to complete a task if all required information, materials and resources are available and no defects are generated.

$$\text{Average\_time\_for\_each\_interaction} = \frac{\text{Contractual\_design\_time}}{\text{Total\_amount\_of\_interaction}}$$

$$\text{Total\_no\_of\_interaction} = \text{Rate\_of\_interaction}$$

$$\text{Rate\_of\_interaction\_actual} = \frac{\text{Amount\_of\_document\_produced} * \text{No\_of\_disciplines} * \text{No\_of\_designer\_available}}{\text{Available\_design\_time}}$$

As every action in the process of developing the construction documents can lead to the generation of an error, there is the possibility of an error in every interaction that will take place between every person for every document and this is related to the reputation of the designer (Figure 21).

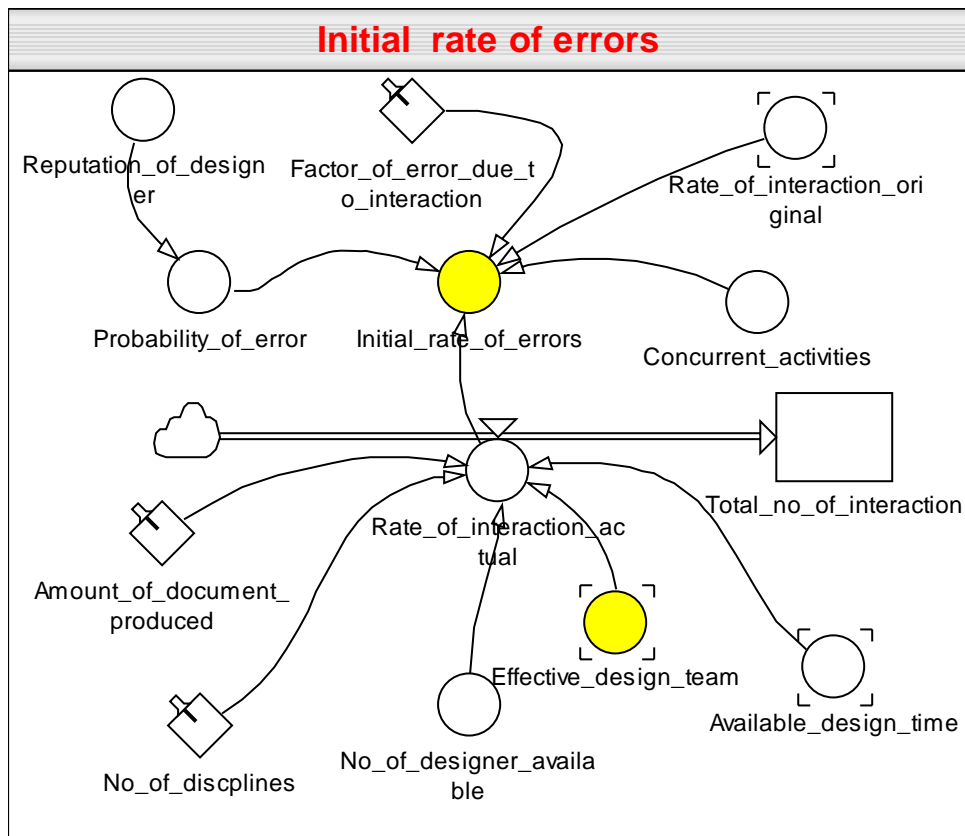
$$\text{Probability\_of\_error} = 1 \llcorner \text{person} * \text{doc} \gg * \text{Reputation\_of\_designer}$$

$$\text{Reputation\_of\_designer} = \text{AVERAGE} (\text{Factor\_of\_designer\_education}, \text{Experienced\_designer}, \text{Previous\_designer\_experience}, \text{Factor\_of\_reputation})$$

$$\text{Factor\_of\_error\_as\_a\_result\_of\_interaction} = 1 \llcorner \text{error} \gg$$

So these lead to an initial rate of errors

$$\text{Initial\_rate\_of\_errors} = \frac{(\text{Rate\_of\_interaction\_actual} - (\text{Rate\_of\_interaction\_actual} * (\text{Concurrent\_activities} - 1))) * \text{Factor\_of\_error\_caused\_by\_interaction}}{\text{Probability\_of\_error}}$$



**Figure 23 : Initial rate of errors**

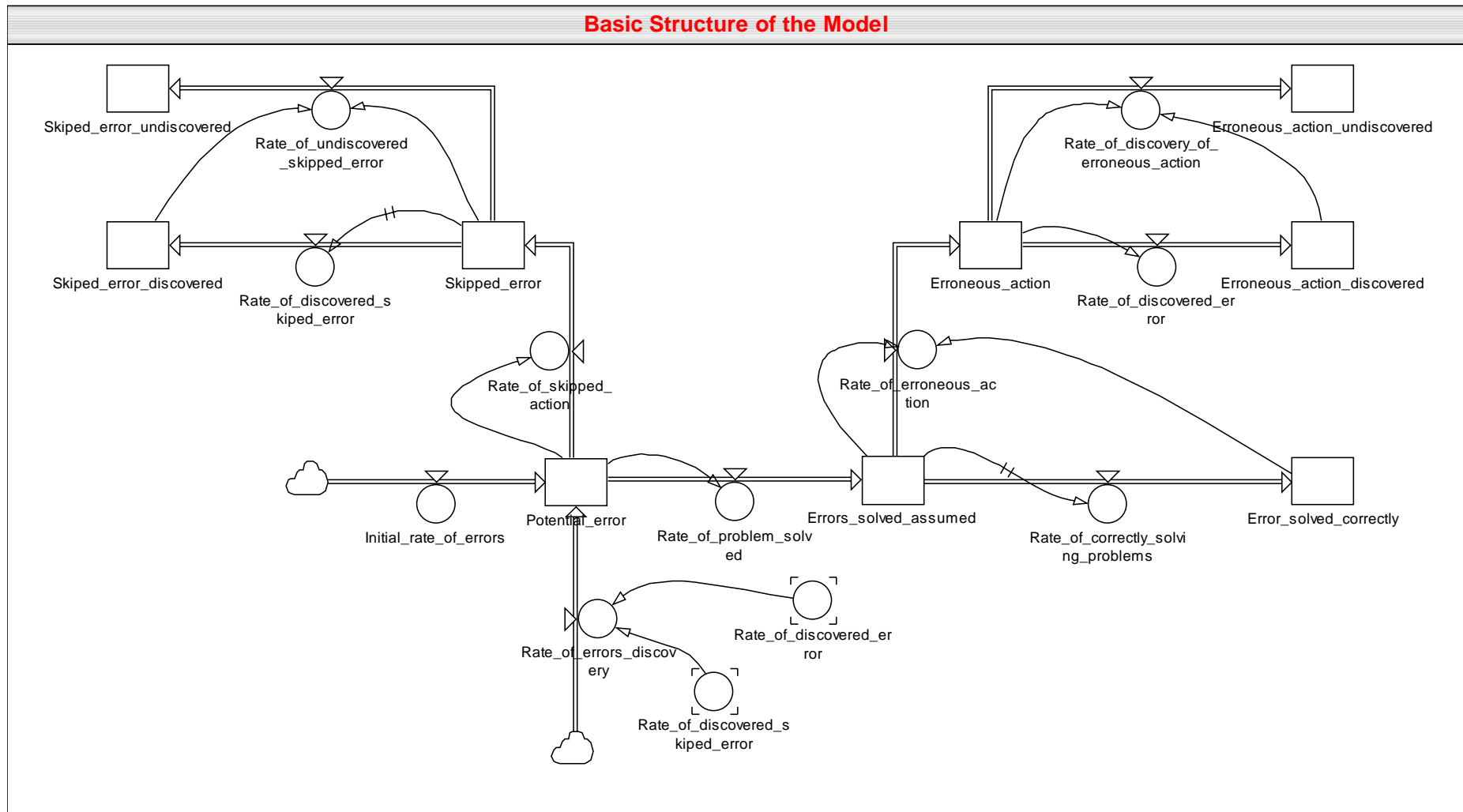
The initial rate of errors feeds the system with the initial number of potential errors while producing the construction documents, as shown in the basic structure of the model (Figure 22). These initial numbers of errors accumulate in the potential error stock ready for processing to transfer to the assumed solved error stock through the rate of problems solved, or they will be skipped to the skipped error stock through the rate of skipped interactions.

$$\text{Potential\_error} = dt(\text{Initial\_rate\_of\_errors}) - dt(\text{Rate\_of\_problem\_solved}) - dt(\text{Rate\_of\_skipped\_action})$$

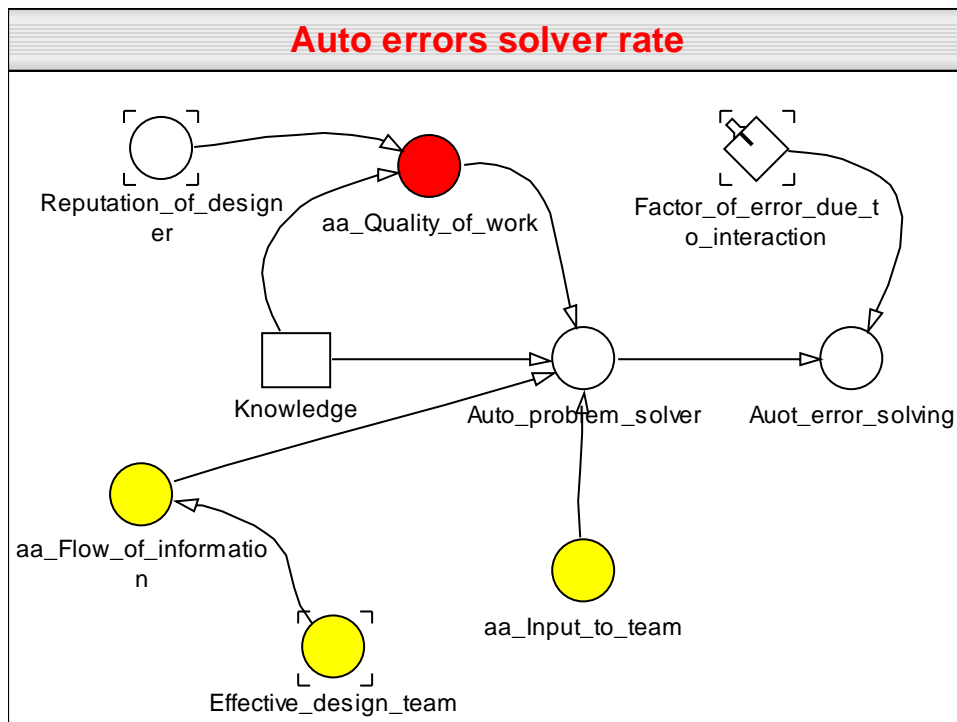
$$\text{Rate\_of\_problem\_solved} = (\text{Potential\_error}) * aa\_Solving\_problem$$

$$\text{Total\_amount\_of\_interaction} = dt(\text{Rate\_of\_interaction\_actual})$$

However, some of these errors will be solved automatically through auto-error solving factors as a result of the factors related to the flow of information, input to team, the knowledge and quality of work, as shown in (Figure 23).



**Figure 24 : Basic structure of the model**



**Figure 25 : Auto error solver rate**

$$\text{Auto\_problem\_solver} = (\text{aa\_Flow\_of\_information} + \text{aa\_Input\_to\_team} + \text{Knowledge}) * \text{aa\_Quality\_of\_work}$$

If the factor of errors caused by interaction is considered with the auto problem solver, then the auto error solving factor will automatically solve part of the potential error.

$$\text{Auto\_error\_solving} = \text{Auto\_problem\_solver} * \text{Factor\_of\_error\_caused\_by\_interaction}$$

So the rate of problems solved will be rewritten to include the auto problem solver factor

$$\text{Rate\_of\_problem\_solved} = (\text{Potential\_error}) * \text{aa\_Solving\_problem} + \text{Auto\_error\_solving} * (\text{Rate\_of\_interaction\_actual} / \text{Rate\_of\_interaction\_original})$$

As discussed before, that part of the potential errors will skip the rate of problems solved to the skipped error stock through the rate of skipped action by finding the ratio of the original interaction and the actual rate of interaction.

$$\text{Rate\_of\_interaction\_original} = \text{Number\_of\_documents\_produced} \quad *$$

*No\_of\_disciplines*

$$* \text{No\_of\_designers\_required} / \text{Contractual\_design\_time}$$

$$\text{Rate\_of\_interaction\_actual} = \text{Number\_of\_documents\_produced} * \text{No\_of\_disciplines}$$

$$* \text{No\_of\_designers\_available} / \text{Available\_design\_time}$$

where the differences will be in the availability of the required designers and the available free time from the contractual design time.

So the rate of skipped action will be as follows:

$$\text{Rate\_of\_skipped\_action} = \text{Potential\_error} *$$

$$(\text{Rate\_of\_interaction\_actual} / \text{Rate\_of\_interaction\_original})$$

$$/ \text{Available\_design\_time}$$

The assumed solved errors will go through the rate of correctly solved problems to make sure that the errors are solved correctly.

$$\text{Rate\_of\_correctly\_solved\_problems} = \text{DELAYINF}(\text{aa\_Quality\_of\_work} \quad *$$

$$\text{Errors\_solved\_assumed}, \text{QA\_start\_date})$$

The delay function is designed to indicate the period when the quality assurance process starts to check the documents produced.

While the some of skipped errors will be discovered through the rate of discovered skipped errors and will be accumulated in the skipped error discovered stock for later reprocessing in the system through the rate of errors discovery

$$\text{Rate\_of\_discovered\_skipped\_error} = \text{DELAYINF}(\text{Skipped\_error}$$

$$* \text{aa\_Discovery\_of\_error}, \text{QA\_start\_date})$$

The delay function is designed to indicate the period when the quality assurance process starts to check the document produced while the remaining skipped errors will skip the process through the rate of undiscovered skipped errors and will be part of the number of errors that the system failed to solve.

$$\text{Rate\_of\_undiscovered\_skipped\_error} = (\text{Skipped\_error} - \text{Skipped\_error\_discovered}) / \text{Available\_design\_time}$$

Part of the assumed solved errors will skip with flaws through the rate of erroneous action, so all errors will be accumulated in the erroneous action stocks.

$$\text{Rate\_of\_erroneous\_action} = (\text{Errors\_solved\_assumed} - \text{Error\_solved\_correctly}) / \text{Available\_design\_time}$$

Part of these erroneous actions will be discovered through the rate of discovered errors and all the erroneous discovered actions will accumulate in the erroneous action discovered stock for later reprocess through the rate of errors discovery.

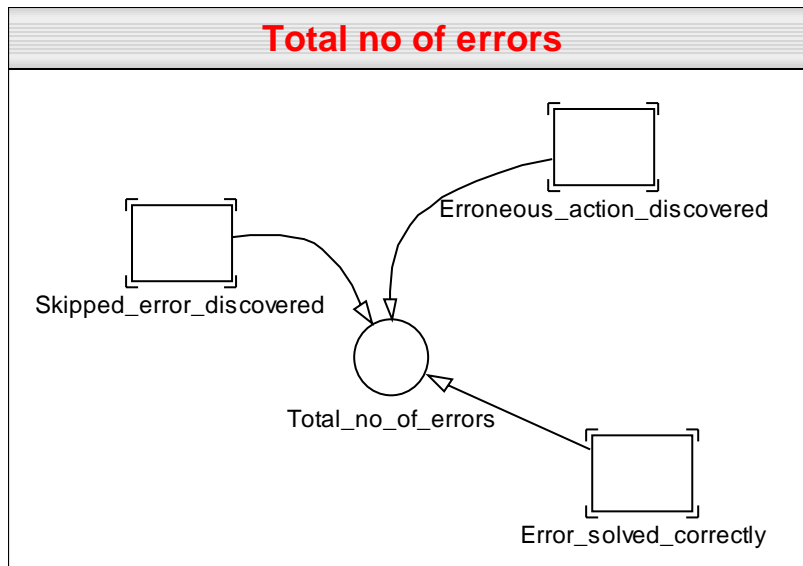
$$\text{Rate\_of\_discovered\_error} = \text{aa\_Discovery\_of\_error} * \text{Erroneous\_action}$$

while the remaining erroneous action will skip the process through the rate of discovery of erroneous action and will be part of the erroneous action that the process failed to solve.

$$\text{Rate\_of\_discovery\_of\_erroneous\_action} = (\text{Erroneous\_action} - \text{Erroneous\_action\_discovered}) / \text{Available\_design\_time}$$





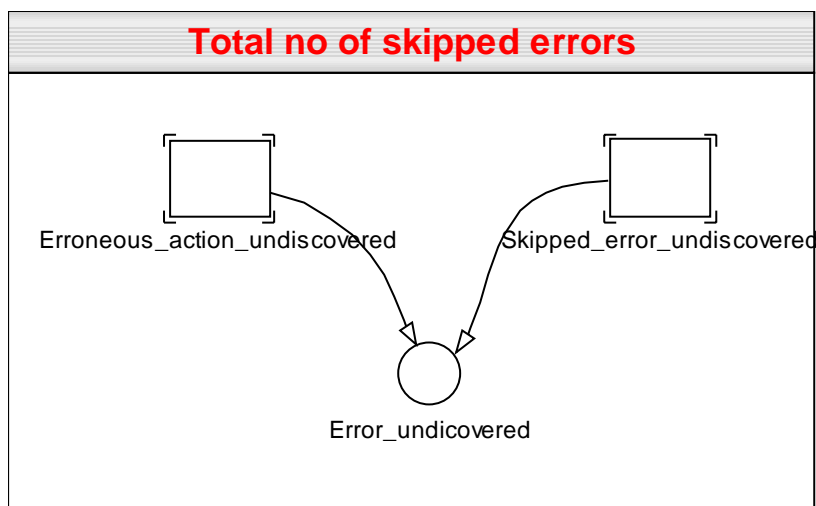


**Figure 27 : Total number of errors**

The diagram (Figure 28) indicates the total number of errors solved or processed during the project where all these interactions went through the solving process.

$$\text{Total\_no\_of\_errors} = \text{Errors\_solved\_correctly} + \text{Skipped\_errors\_discovered} + \text{Erroneous\_actions\_discovered}$$

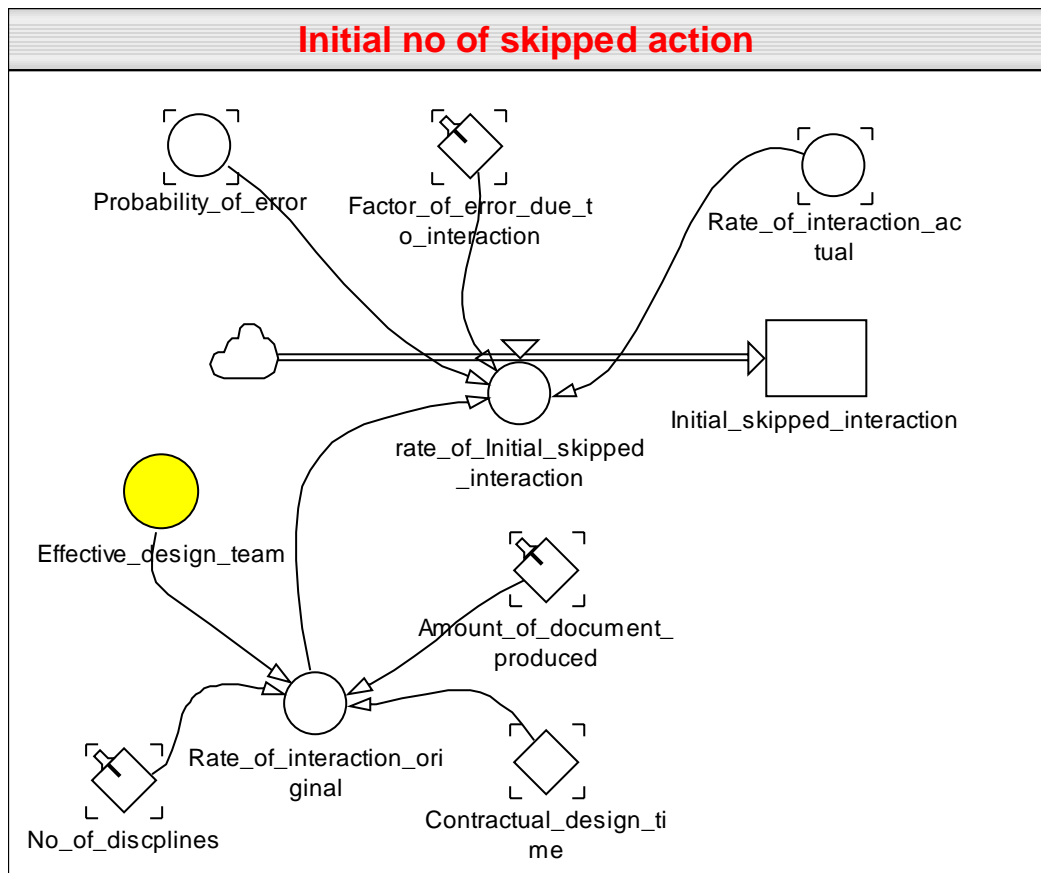
while (Figure 29) indicates the total number of errors that skipped the system and went without solution or without an approved solution.



**Figure 28 : Total number of skipped errors**

*Error\_undiscovered=*

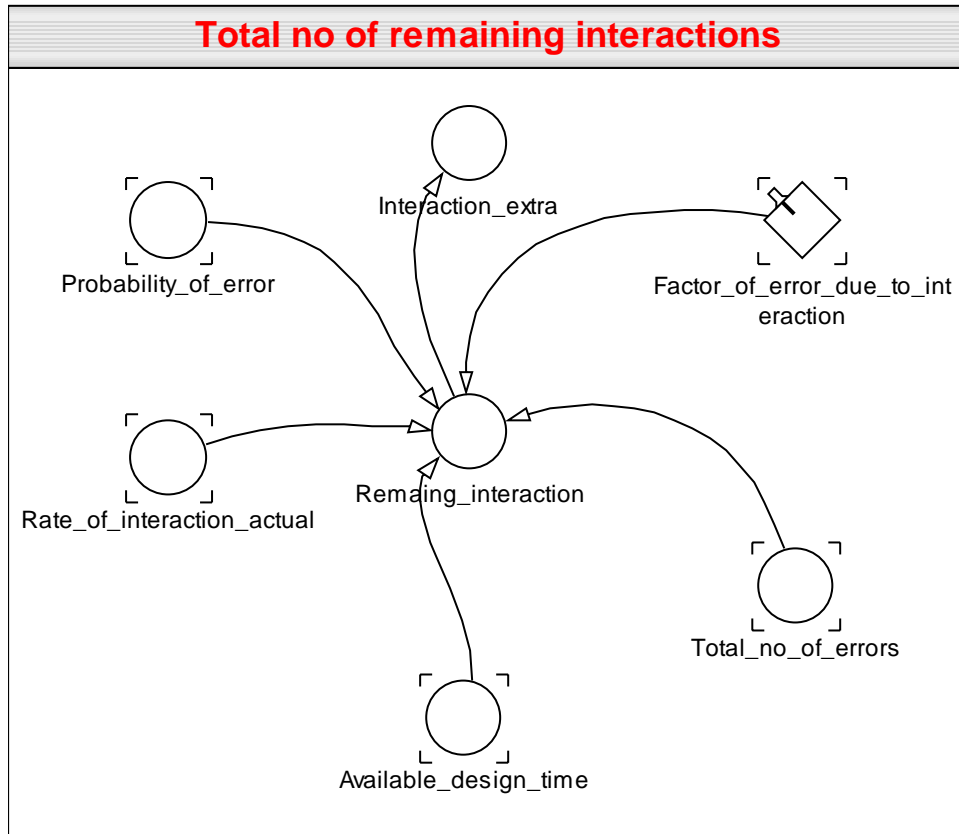
*Erroneous\_action\_undiscovered+Skipped\_errors\_undiscovered*



**Figure 29 : Initial no of skipped action**

Figure 30 indicates the initial number of interactions skipped, which results in the difference between the original interaction and the actual interaction.

*Rate\_of\_Initial\_skipped\_interaction =(Rate\_of\_interaction\_original-  
Rate\_of\_interaction\_actual)\*Factor\_of\_error\_caused\_by\_interaction  
/Probability\_of\_error*



**Figure 30 : Remaining interactions**

The remaining interaction without any process is shown in the following figure (Figure 31).

$$\begin{aligned}
 \text{Remaining\_interaction} = & (\text{Rate\_of\_interaction\_actual} * \text{Available\_design\_time} / \\
 & \text{Probability\_of\_error} * \text{Factor\_of\_error\_caused\_by\_interaction}) - \\
 & \text{Total\_no\_of\_errors}
 \end{aligned}$$

## **6.8 Conclusion**

Based on the suggested modelling technique proposed in the research methodology chapter (Chapter 3) and the proposed causal diagrams discussed and validated in Chapter 5, the research model was developed and described in this chapter. Even though the model was explained in a linear fashion, the creation was rather in iteration mode where one step was advanced, then took some steps back and re-evaluated everything already done so far. However, finally the simulation model system, using system dynamic software (Powersim 2005), was created, which apparently describes the system of error in the construction document within the set boundary and assumptions. The model has 142 factors: 16 levels, 17 constant factors and 108 auxiliary factors. By using the proposed model of the research, the occurrence of errors was simulated while producing the construction documents when the system is stable.

The model can be used to determine the major variables that influence errors. It can provide richer understanding of the interdependence between a project's subsystems and the management challenges associated with identifying effective error prevention strategies. The model also encourages a paradigm shift on how a project system should be viewed: away from the traditional mechanistic view to a holistic viewpoint. If errors are to be reduced or eliminated, the focus must be on the whole system rather than on individual parts.

In the next chapter, the model will be validated using tests suggested by the researchers in system dynamics.

7.1	Introduction.....	276
7.2	Validation and verification of the model .....	276
7.3	Validation of the research model .....	278
7.4	Behavioural validation of the model.....	283
7.4.1	Total number of interactions and number of problems solved .....	284
7.4.2	Types of error occurring while producing the construction documents .. .....	285
7.4.3	Remaining number of interaction and number of errors solved. ....	287
7.4.4	Quality of work.....	288
7.4.5	Discovery of errors .....	289
7.4.6	Flow of information .....	290
7.4.7	Production of documents .....	291
7.4.8	Share of knowledge and design experience .....	292
7.4.9	Input to team .....	293
7.4.10	Solving problems .....	294
7.5	Structure oriented behaviour validation using sensitivity analysis.....	295
7.5.1	Factor of errors due to interaction.....	299
7.5.2	Working hours per week per designer .....	301
7.5.3	Salary standard.....	303
7.5.4	Time required to produce a document .....	305
7.5.5	Number of disciplines .....	307
7.5.6	Number of phases .....	309
7.5.7	Procedure to produce documents .....	311
7.5.8	Previous designer experience.....	313
7.5.9	Number of documents produced.....	315
7.5.10	Availability of information .....	317
7.5.11	Availability of quality assurance procedure .....	319
7.5.12	Culture of the team.....	321
7.5.13	Experience of the designers .....	323
7.5.14	Designer Education.....	325
7.5.15	Reputation of the designer .....	327
7.5.16	Match of the goals.....	329
7.5.17	Contractual Design Time .....	331
7.6	Behaviour of factors affecting the generation of errors in the construction documents .....	336
7.6.1	Category 1: factors with deviation less than 10% between high and low value.....	339
7.6.2	Category 2: factors with deviation between 10%-15% for high and low value.....	340
7.6.3	Category 3: factors with deviation between 15%-20% for high and low value.....	341
7.6.4	Category 4: factors with deviation between 20%-25% for high and low value.....	342
7.6.5	Category 5: factors with deviation between 25%-30% for high and low value.....	343
7.6.6	Category 6: factors with deviation between 25%-30% for high and low value.....	344
7.6.7	Category 7: factors with deviation between 30%-35% for high and low value.....	345
7.7	Classification of sensitivity of the factors:.....	346

7.8	Validating the findings of the research model for the most sensitive factors..	349
	.....	349
7.8.1	Lack of professional education .....	349
7.8.2	Lack of experience .....	351
7.8.3	Lack of good reputation of the design office .....	353
7.8.4	Lack of experience with similar projects .....	355
7.9	Summary .....	358

## 7.1 Introduction

It is necessary to establish confidence in the usefulness of a model with respect to its purpose. Validation of the model structure and behaviour are important parts of the simulation validation in general and system dynamics model validation in particular. Validity of the results of a given study is crucially dependent on the validity of the model.

After placing faith in the usefulness of the model, it is important to know how sensitive the model is to changes in parameter values and apparently how much each factor can be dropped while maintaining a reasonable drop in the number of correctly solved problems. The rest of this chapter will discuss and analyse how sensitive the research model is to variations in the factors identified as the root cause of the problem. Also, it is important to know what factors have the greatest influence on the model, and to validate these findings by using case study projects.

## 7.2 Validation and verification of the model

Model validation is an important aspect of any model-based methodology in general and system dynamics in particular. Validity of the results of a given study is crucially dependent on the validity of the model.

Validation continues to be a challenging issue for both the study and the practice of model building in management and social sciences (Arthur et al., 2005). The challenge stems from critiques of the published model in academic settings and the requirements to demonstrate quality assured products and processes in commercial and practitioner modelling projects.

Many modellers speak of model "validation", or claim to have "verified" a model. In fact, validation and verification of models is impossible (Sterman, 2000). The word "verify" derives from the Latin *verus* - truth; Webster's dictionary defines "verify" as "to establish the truth, accuracy, or reality of". "Valid" is defined as "having a conclusion correctly derived from premises". Valid implies being supported by objective truth".

By these definitions, no model can ever be verified or validated. As described in Chapter 3 "research methodology", all models are limited, simplified representations of the real world. They differ from reality in ways large and small, infinite in number. This view was widely shared by modellers (Sterman, 2000, p846). "No

model has ever been or ever will be thoroughly validated... "Useful" , "Illuminating", "convincing" or "inspiring confidence" are more apt descriptors applying to models than "valid" (Greenberger, et al., 1976).

Moreover, Coyle and Exelby (2000) have emphasized that there is no such thing as absolute, only a degree of confidence which becomes greater as more and more tests are performed. They have stressed that validation means ensuring that the model's structure meets the purpose for which it is intended, and verification means ensuring that its equations are technically correct. According to the traditional reductionist /logical empiricist philosophy, a valid model is an objective representation of a real system. According to this philosophy, validity is seen as a matter of accuracy, rather than its usefulness (Santanu et al., 2000). Barlas and Carpenter (1990), in supporting this viewpoint, have suggested that model validation cannot be entirely objective, quantitative and formal. Since validity means usefulness with respect to a purpose, model validation has to have subjective, informal and qualitative components. Furthermore Oreskes et al. (1994, p644) wrote "Models are representations, useful for guiding further study but not susceptible to proof".

The impossibility of validation and verification is not limited to computer models. Any theory that refers to the world relies on imperfectly measured data, abstraction, aggregations, and simplifications, whether the theory is embodied in a large-scale computer model, consists of the simplest equations, or is entirely literary. The difference between analytic theories and computer simulations is difference of degree only (Serman, 2000, p847).

Modellers should focus on tests that can reveal the limitations of our current models, mental and formal. Oreskes et al. (1994) write: "We must admit that a model may confirm our biases and support incorrect intuitions. Therefore, models are most useful when they are used to challenge existing formulations, rather than to validate or verify them. Any scientist who is asked to use a model to verify or validate a predetermined result should be suspicious."

However, despite the fact that validation is impossible and it is difficult to say that the model is "correct" or even finished, it is important to recognize that models are used to make important decisions. The choice is never whether to use a model but only which model to use. Our responsibility is to use the best model available for the purpose at hand despite its inevitable limitations. The decision to delay action in the



vain quest for a perfect model is itself a decision, with its own set of consequences (Sterman, 2000, p850).

The model validation definition that will be used for this research will be "establishing confidence in the usefulness of a model with respect to its purpose" (Barlas, 1996). According to Coyle (1996), a valid model means "well suited to a purpose and soundly constructed".

It is important to recognize also that the goal is to help construction industry professionals make better decisions, decisions informed by the best available model. Instead of seeking a single test of validity models - either pass or fail -, multiple points of contact should be sought between the model and reality by drawing on many sources of data and a wide range of tests. Instead of viewing validation as a testing step after a model is completed, it is recognized that theory building and theory testing are intimately intertwined in an iterative loop.

### **7.3 Validation of the research model**

Model validity and validation have long been recognized as being among the main issues in the system dynamics field (Forrester, 1968; Forrester et al., 1974; Sterman 1984; Barlas 1989; Barlas et al., 1990). Richardson (1996) identifies "Confidence and validation" as one of the eight key problems for the future dynamics discipline. Yet there has been little active research devoted to the development of concrete methods and tools suitable for system dynamics validation. Barlas (1996) states that only three of all the articles published in the System Dynamics Review (between 1985 and 1995) deal with model validity / validation. Furthermore, there is no clear evidence of consistent and widespread use of even the established validity tools (Peterson et al., 1994).

Validity of the causal-descriptive model is critically different from that of a mere correlation (purely data driven) (Barlas, 1990, 1996 and 1999). In purely correlation modelling, since there is no claim for causality in structure, the model is assessed as being valid, if its output behaviour matches the real output within some specified range of accuracy, without any questioning of the validity of the relationship that constitutes the model. Models that are built primarily for forecasting purposes (such as time-series or regression models) belong to this category. On the other hand, causal-descriptive models are statements about how real systems actually operate in

certain aspects. In this case, what is crucial is the validity of the internal structure of the model. The model, being about the real system, must not only reproduce/predict its behaviour, but also explain how the behaviour is generated, and suggest possible ways of changing the existing behaviour. System dynamics models fall into this category. In short, the system dynamics model must generate the right output behaviour for the right reasons (ibid).

Validation of a system dynamics model thus consists of two broad components: structure validation and behaviour validation (ibid).

- Structure validation means establishing that the relationships used in the model are an adequate representation of the real relationships, with respect to the purpose of the study.
- Behaviour validation consists of demonstrating that the behaviour of the model is close enough to the observed real behaviour.

In system dynamics validation, there is no point in testing the behaviour validity until the model demonstrates some acceptable level of structure validity.

Although structure validity is crucial, the majority of technical research in model validation literature deals only with behaviour validation, for two main reasons (Barlas et al., 1999). The first one stems from a lack of recognition of the philosophical importance of structure validity in causal-descriptive modelling. The second reason is concerned with the technical difficulty of designing formal/statistical tools that address structural validity.

A simulation model can be validated using a combination of tests such as boundary adequacy, structure assessment, dimensional consistency, (Forrester and Senge, 1980; Sterman, 2000). The boundary adequacy test involves drawing the model boundary, that is, deciding which variables will be included in the model. The structure assessment test is conducted by ensuring that the system structure is consistent with the knowledge of the system (both physically and mentally). The dimensional test simply means testing the consistency in units of all the variables and relationships.

A simulation model can be tested or verified with tests, such as behaviour reproduction, behaviour anomaly and family members and sensitivity analysis (Forrester and Senge, 1980; Sterman, 2000). In behaviour reproduction tests, past behaviours of some of the variables in the model are replicated and evaluated. The behaviour anomaly test is based on evaluating the importance of some relationships

when they are removed from the model. A model will pass the family member test if it can be applied to similar systems with new sets of parameters. The sensitivity analysis test will be conducted to ensure that the important but uncertain parameters may affect the behaviours of system dynamics models in an acceptable range.

System dynamics simulation models can be validated with the same validation techniques in statistical and econometric models: using a different data set (from those on which the models were built) to validate the models. Since system dynamics models are often built largely on mental data (Forrester, 1994), system dynamics models are very often validated against the so-called reference mode that is extracted from people's mental models. Reference mode refers to a set of graphs that characterize the dynamic behaviour pattern of the problem over time which shows how the problem arose and how it might evolve in the future (Sterman, 2000). Reference mode is often referred to during the modelling process to help the modeller and clients break out of the short-term event-oriented world views. The building up of these reference modes was part of the validation process discussed in Chapter 5.

In the end, no simulation models can be validated in the sense of a perfect model, since all models are simplified representations of the real world (Kleijnen, 1995; Sterman, 2000). The validity of a model should be judged by its purpose or usefulness (Forrester, 1961; Kleijnen, 1995) and validation of a model is a process of building confidence in a model's soundness and usefulness as a policy tool (Forrester and Senge, 1980). The most common way to gain confidence in the model is to have users participate in the modelling process (Forrester and Senge, 1980) and this is the approach that will be used here. The modelling process, as mentioned before, used the expert knowledge of 11 experts in building up the causal diagrams and estimating the relationship between parameters (see figure 1).

Confidence is believed to be the proper criterion because there can be no proof of the absolute correctness with which a model represents reality. There is no method for proving a model to be correct. The model is validated if it is an accurate representation of the system under study and particular purpose. What is, therefore, of importance to note here is that the notion of a model as an aid to learning about the behaviour of complex, non-linear management systems is a valid one; models cannot be devised which will provide "answers" to what can be quite opaque "issues" at the strategic level ( Morecroft, 1992; deGeus, 1992).

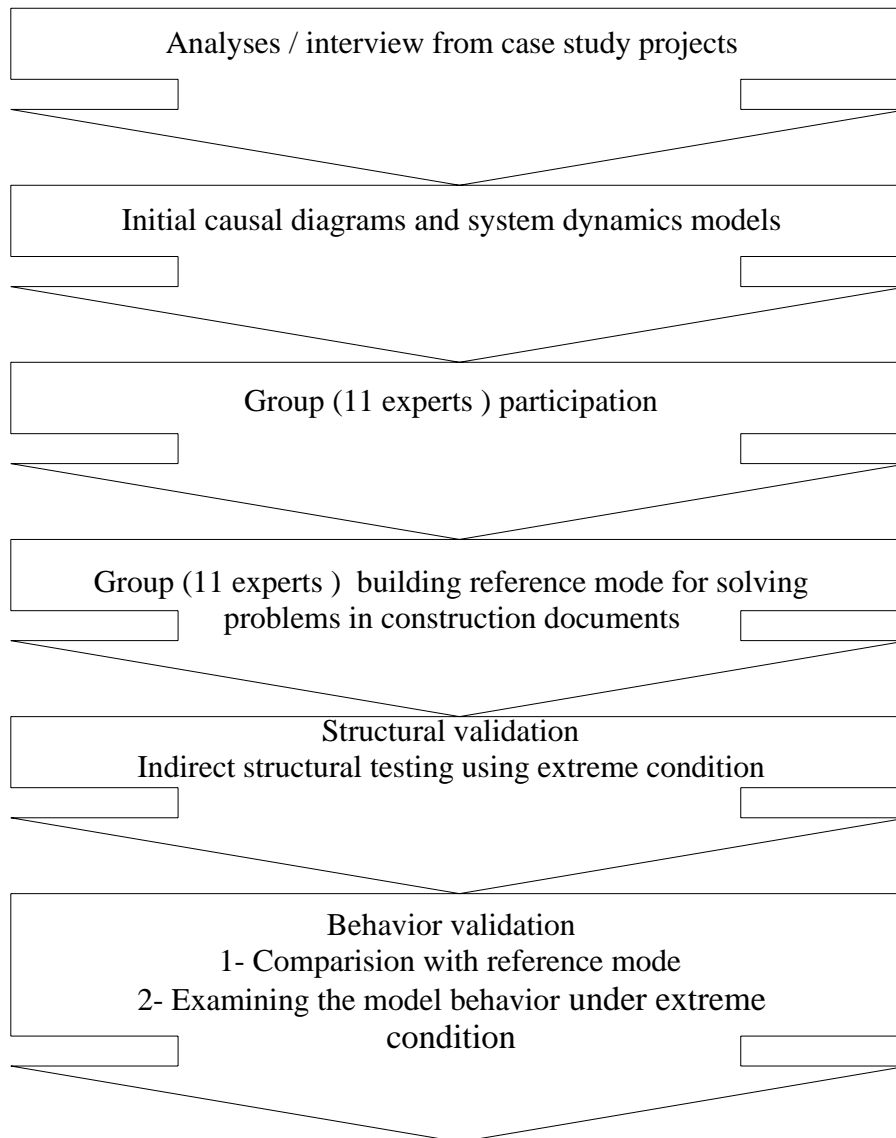
Barlas (1986, 1989, 1996, and 1999) and Coyle (1977, 1996) suggested the following tests for the validation of the system dynamics models (Figure 1:

- Structural validation consists of two parts:
  - o Direct Structural testing: Direct structure tests assess the validity of the model structure, by direct comparison with knowledge about real system. These tests are achieved in two parts:
    - By comparing the model equations with the real system relationships (empirical structural validation)
    - By comparing the model equations with the available theory (theoretical structural validation)
  - o Indirect structural testing: indirect structure or (structure-oriented behaviour) tests assess the validity of the structure indirectly, by applying certain behaviour tests on model-generated behaviour patterns.
  
- Behavioural validation consists of two parts:
  - o Tests for behavioural pattern predication: these tests try to determine whether the behaviour patterns generated by the model are close enough to the major patters exhibited by the real system
  - o Behaviour tests that are structurally oriented: by examining the model's behaviour under different conditions, these tests try to determine whether there is a major error in the structure of the model.

Barlas (1996) submits that structure-oriented behaviour testing (indirect structural testing) is the most promising direction for research on model's structural validation; therefore this approach will be used to validate the structure of the research model. The indirect test suggested by Barlas (1999) and Coyle (1977, 1996) is the extreme condition. The extreme condition test involves assigning extreme values to selected parameters and comparing the model-generated behaviour with the anticipated or observed behaviour of the real system under the same extreme conditions. In extreme condition tests, the modeller wants to make sure that the model's behaviour in extreme conditions still makes sense. Structure-oriented behaviour tests are strong behaviour tests that can provide information on potential structure flaws. Their main

advantage over direct structure tests is that they are much more suitable for formalizing and quantifying.

In addition to the structural validation of the model, the behaviour of the model will be validated using the above mentioned behaviour tests.



**Figure 1 : Process of the Validation of the research model**

#### 7.4 Behavioural validation of the model

Usually, a model development process will require the modelling loop to be repeated several times before the model satisfies the needs of the problem and matches the reference mode created with the help of the experts. This is not a disadvantage, however, as it allows the researcher to make sure that the simulation will actually help solve the problem it was created to solve. Once the behaviour is acceptable, the simulation can be used to solve the problem itself.

Sterman (2000, p751) is of the opinion that the replication of the past experience is not the only test for the model. It is generally quite easy to tune a model to fit a given set of data. Building confidence in a model involves a much broader series of tests, both of the structure and its response to a wide range of circumstances, and not only the limited range of historical experience.

The behaviour of the model in first place was compared and validated towards the reference mode diagrams that were created with the group observations (expert knowledge). This will prevent us from building a model that starts to deviate from the original plans and that may not shed light over the problem it was originally intended to do. A model can be validated on several criteria. The behaviour of the model should be evaluated to see whether it is acceptable in a satisfactory manner or not (within reasonable limits).

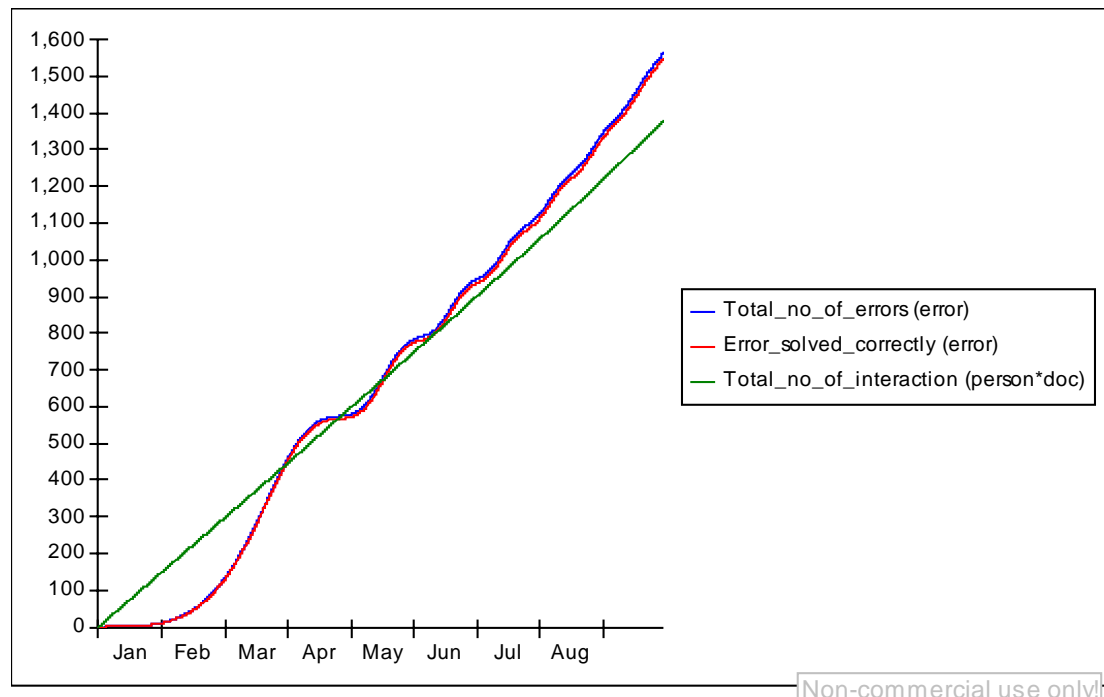
However, the following charts show the behaviour of the model under steady conditions (perfect conditions as indicated in the value of constant factors) that influence the generation of errors in the construction documents (Table 1).

**For clarity of the charts, X axis represents the total time allocated for the design and production of the construction documents in months, and Y axis represents the total number of errors.**

Factors	Value
Factors of error due to interaction	1
Working hour per week per designer	208<<hr/mo/person>>
Salary Standard	1<<USD/person/mo>>
Required time to produce a document	50<<hr/doc>>
No of disciplines	8
No of phases	5
Procedure to produce documents	1
Previous designer experience	1
Amount of document produced	100<<doc>>
Availability of information	1
Availability of quality assurance procedure	1
Culture of team	1
Experience of the designers	1
Designer education	1
Reputation of the designer	1
Match of the goals	1
Contractual Design time	200<<da>>

**Table 1 : Values used for steady condition of the model**

#### 7.4.1 Total number of interactions and number of problems solved

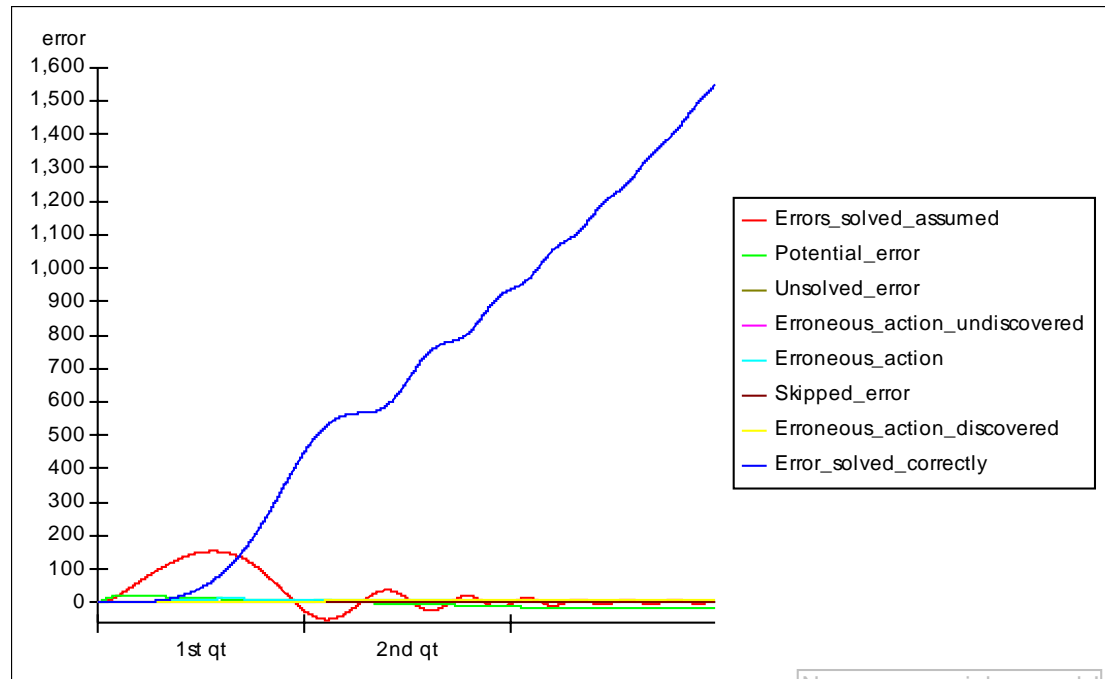


**Figure 2 : Total number of interactions and number of problems solved**

The graph shows that the interactions that take place in the model are fed to the model as the work is progressing, while the errors that are solved are equal to the total number of problems that took place while producing the construction documents. The

extra problems solved correctly in the model shown in the graph toward the end of the project are caused by the rework of the interactions that were discovered with flaws in the process of preparing the construction documents.

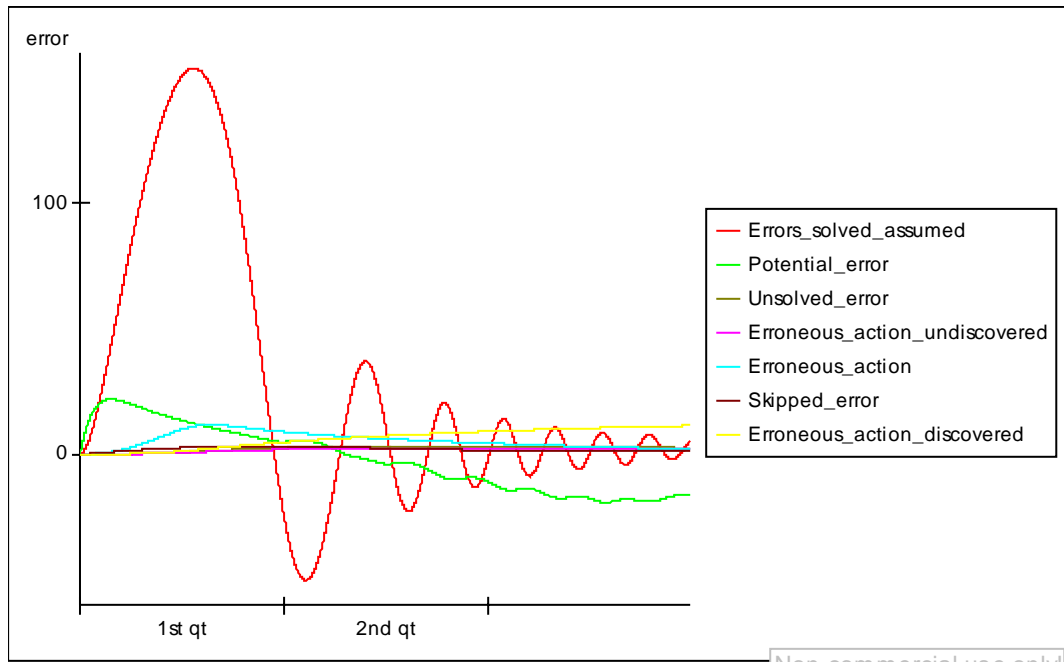
#### 7.4.2 Types of error occurring while producing the construction documents



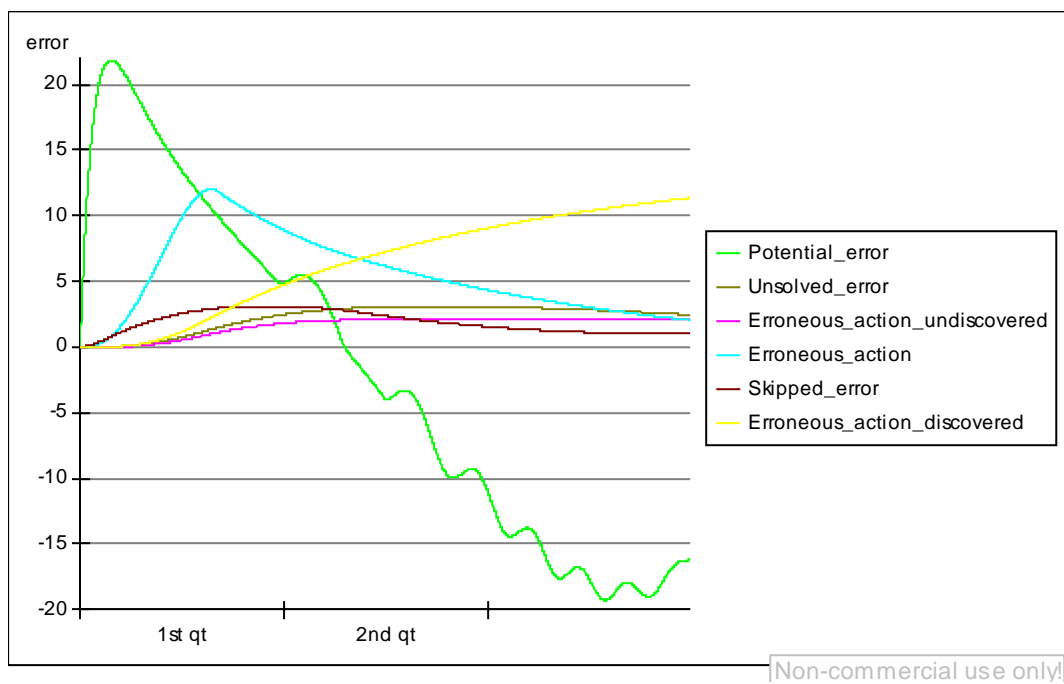
**Figure 3 : Type of errors occurring in the construction documents**

This graph shows the different number of errors that occur while producing the construction documents. It indicates that the number of errors solved correctly is increasing while progressing in the construction documents, with a delay at the beginning because of the start of the quality assurance process which ensures the correctness of solving the interaction; then it escalates with a steep move with a delay afterward and escalating again toward the end of the project. It indicates also that the number of assumed errors is escalating at the beginning of the project before the start of the quality assurance procedure, and the range of escalation is vanishing toward the end of the project (Figure 4). It indicates also that the erroneous actions are minimal if all procedures and factors are adequate while producing the construction documents (Figure 5).

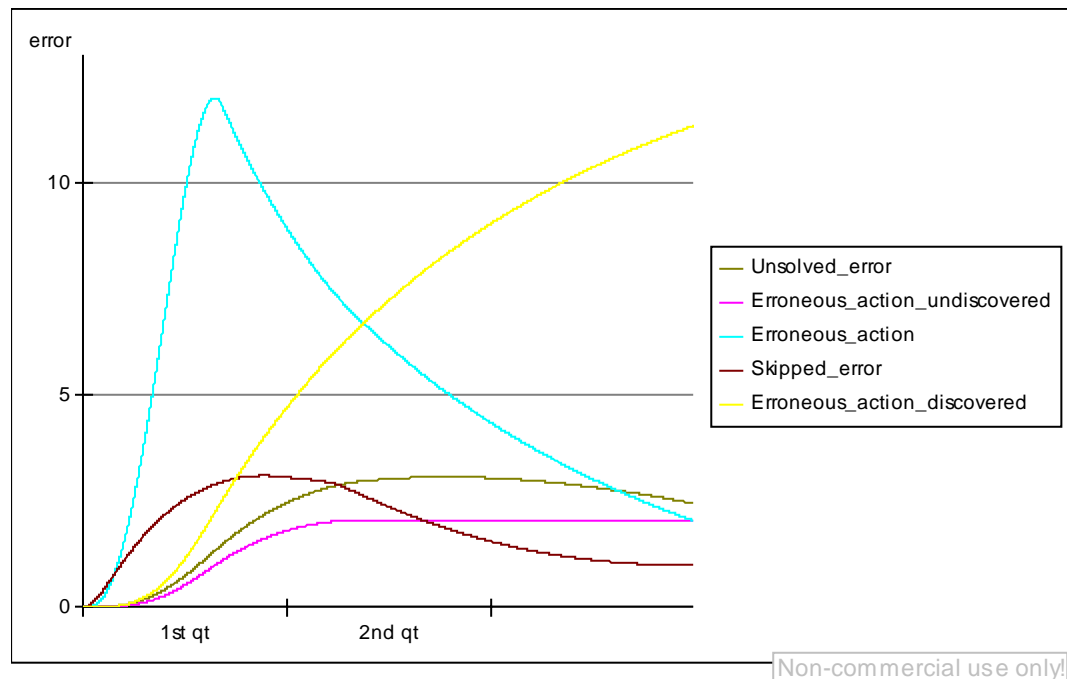




**Figure 4 : Type of errors occurring compared with assumed errors.**



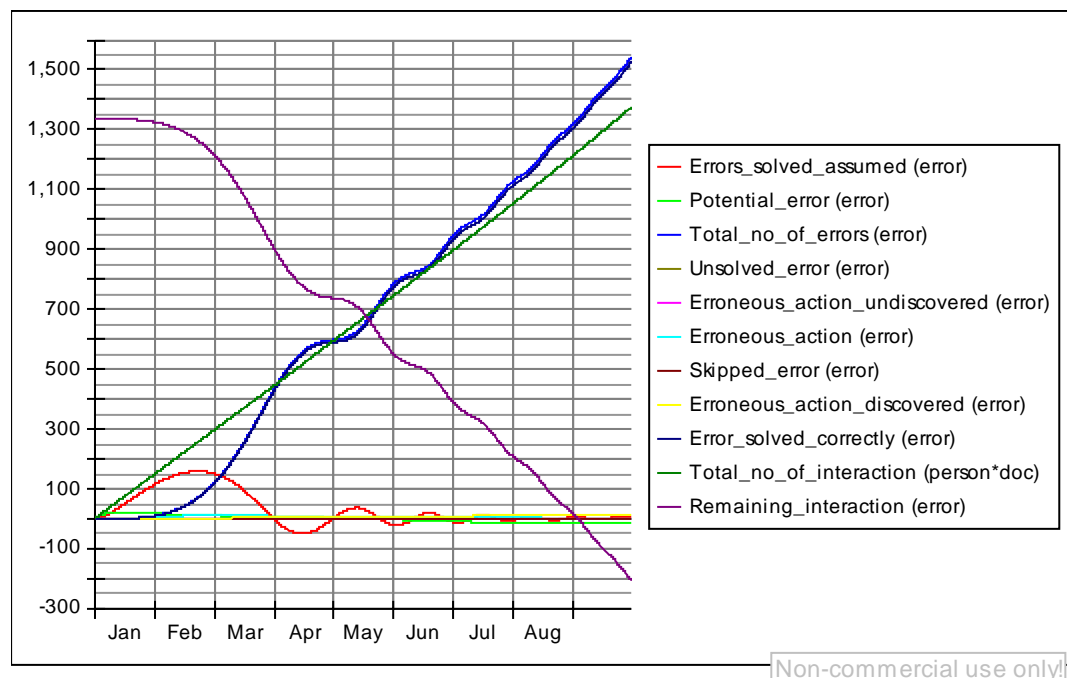
**Figure 5 : Types of errors occurring compared with potential errors**



**Figure 6 : Erroneous problem**

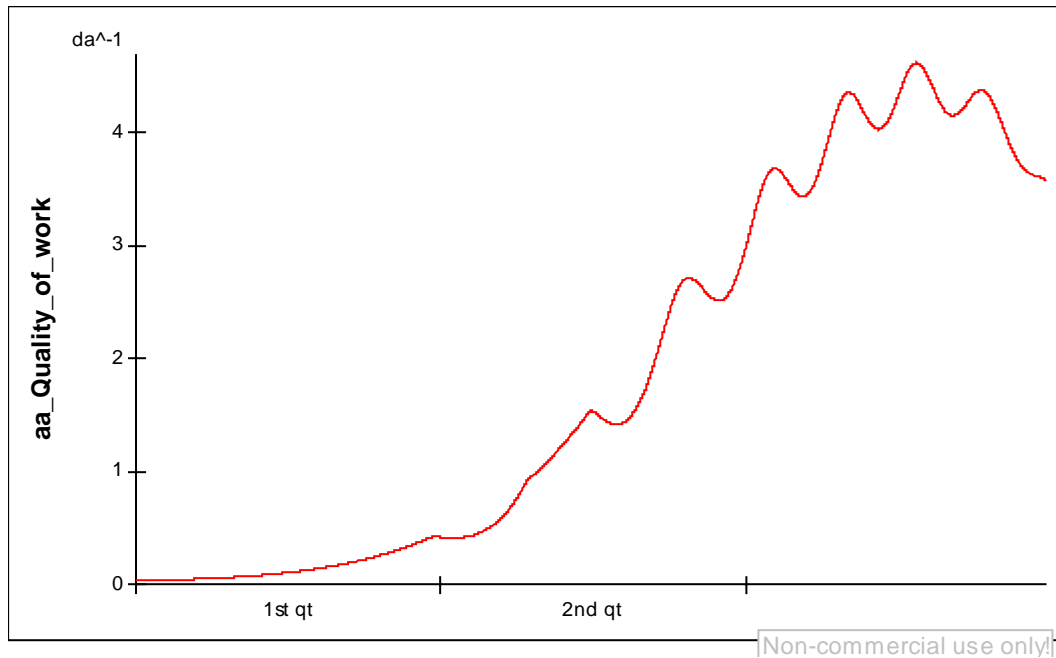
**7.4.3 Remaining number of interaction and number of errors solved.**

The graph shows all types of errors occurring while producing the documents and illustrates that the amount of remaining interaction are reducing when reaching the end of the project. The negative amount of remaining interaction is the result of the extra problems solved when flaws were discovered by the quality assurance process.



**Figure 7 : Remaining no of interaction and number of errors solved**

### 7.4.4 Quality of work

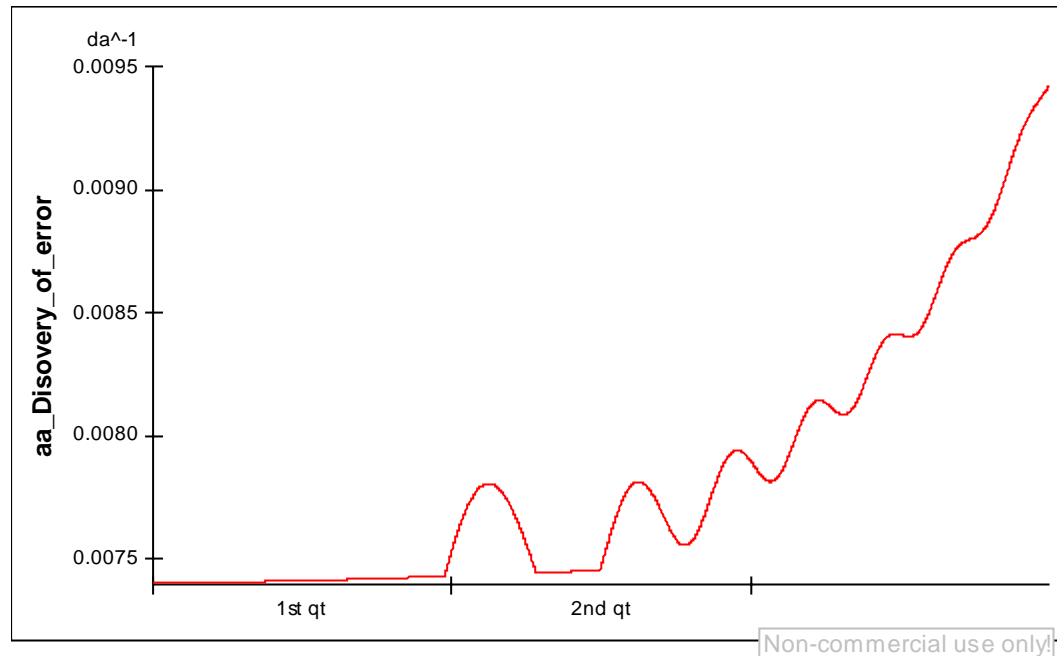


**Figure 8 : Quality of work**

This graph indicates that the quality of work is increasing because of the knowledge gained from performing in the project.

### 7.4.5 Discovery of errors

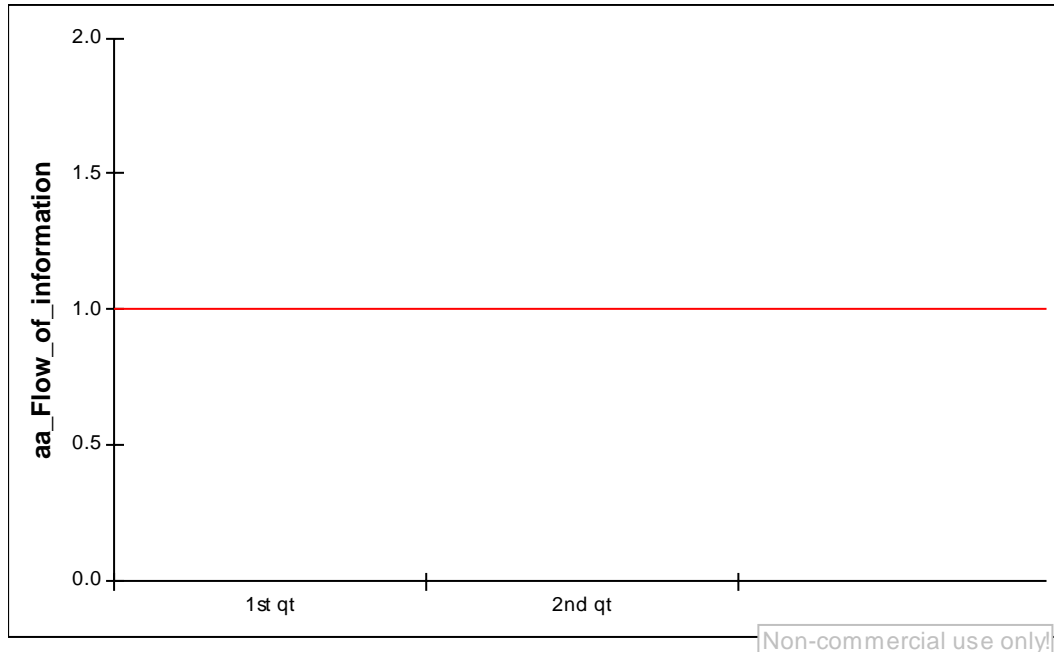
The discovery of errors increases when quality assurance starts. It drops when the number of errors discovered is solved, and then increases again when the quality assurance of the next stage starts again, and so on. It begins from the available ingredients of the office i.e. factor of designer education, experienced designer, previous designer experience, availability of information and availability of quality assurance (QA) procedures.



**Figure 9 : Rate of discovery of errors**

### 7.4.6 Flow of information

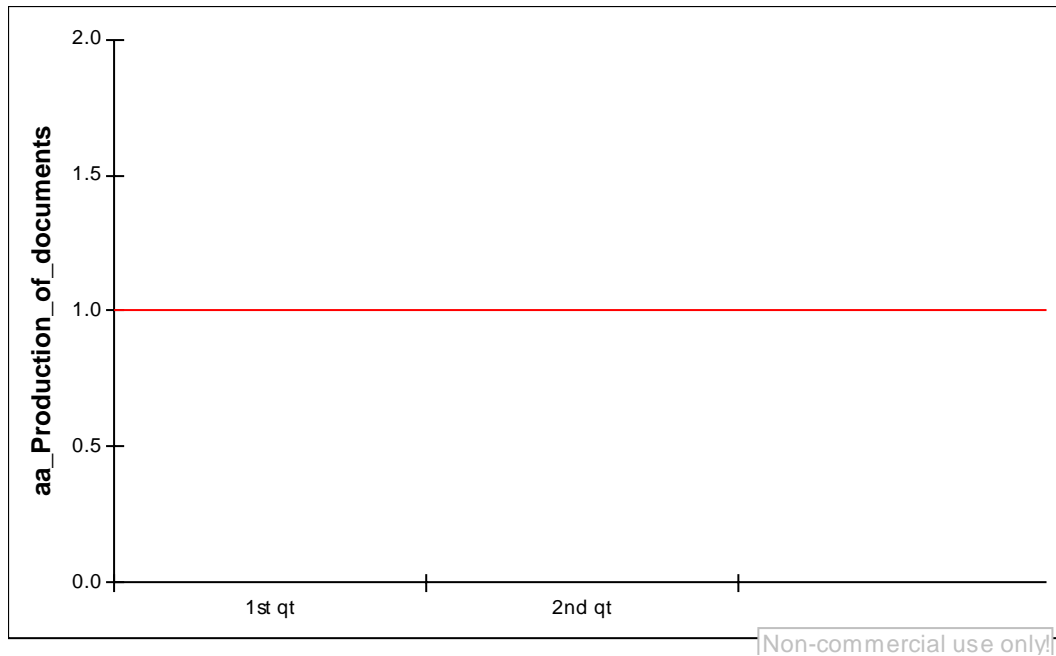
The flow of information is consistent through the whole life of the project if the factors affecting the flow are in place, i.e. amount of information, effective design team, internal approval, motivation.



**Figure 10 : Rate of flow of information**

### 7.4.7 Production of documents

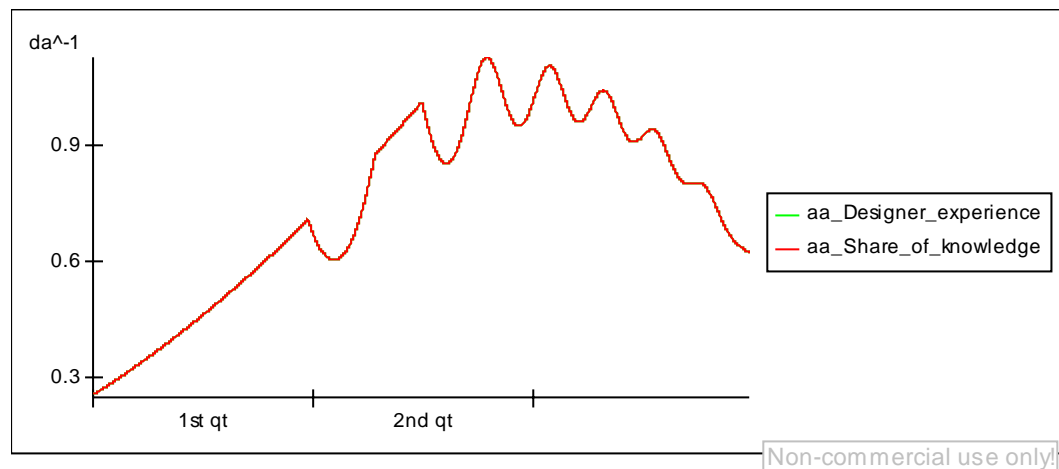
As with the previous factor, the production of document is consistent during the life of the project if the factors affecting the flow are in place, i.e. resources, design fee pressure.



**Figure 11 : Rate of production of documents**

### 7.4.8 Share of knowledge and design experience

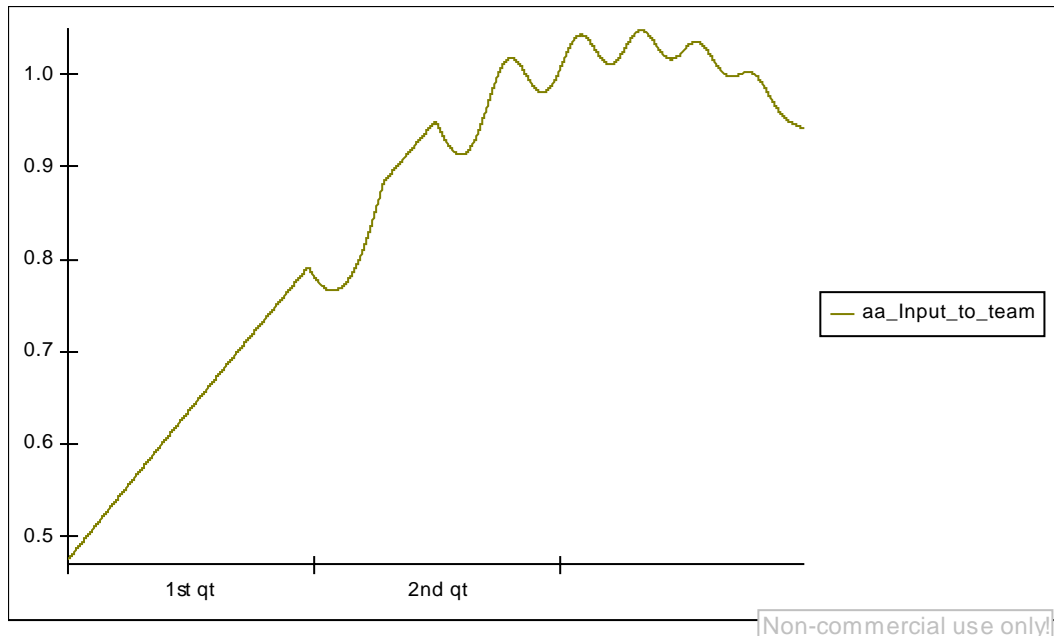
The share of knowledge and the design experience plots are identical if other factors that influence the designer experience are consistent, i.e. previous designer experience, amount of information, internal approval. Share of knowledge increases as the number of interactions increases. However, the share of knowledge will drop when the quality assurance process starts as a result of time spent by the team to solve errors discovered while reviewing the documents.



**Figure 12 : Rate of share of knowledge and designer experience**

### 7.4.9 Input to team

The input of the team increases as the progress of the work is carried out, and drops when the quality assurance process starts as a result of the time spent by the team in solving the errors discovered while reviewing the documents.



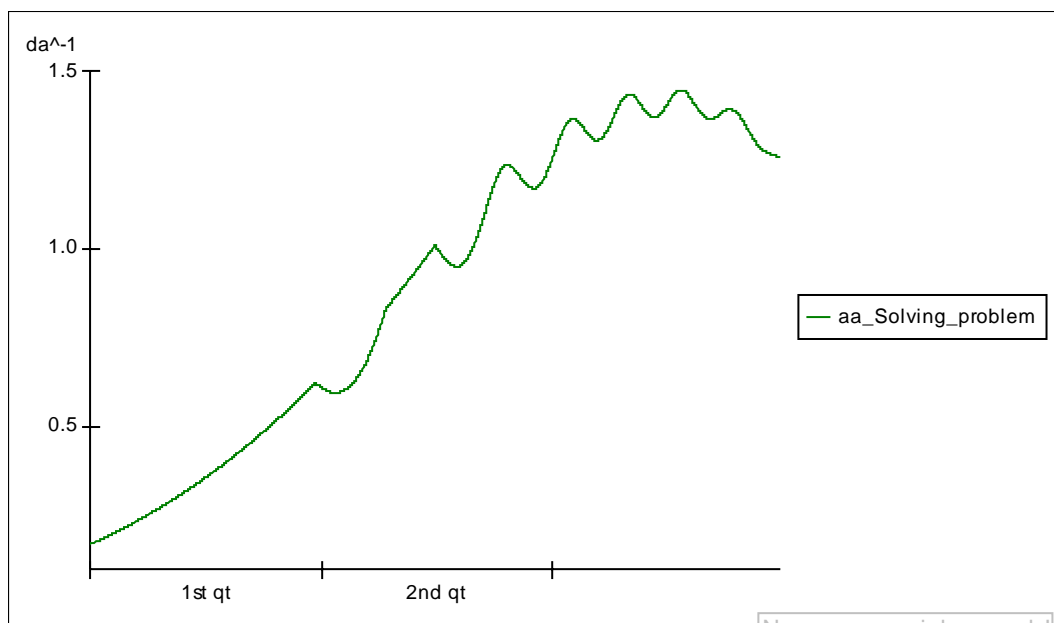
**Figure 13 : Rate of input of team**



### 7.4.10 Solving problems

The solving of problems starts as the project progresses, then drops when the quality assurance process starts as a result of solving the errors discovered while reviewing the documents.

All these factors commence from the non-zero point at the start of the project owing to the ingredients of the design office, i.e. factor of designer education, experienced designer, previous designer experience, availability of information, and availability of QA procedures.



**Figure 14 : Rate of solving problems**

### **7.5 Structure oriented behaviour validation using sensitivity analysis**

To help the research to assess the model structure/behaviour, the sensitivity analysis will be performed on the influencing factors of the model.

Out of the factors identified in Chapter Five affecting the generation and solving problems in the construction documents, the model presented in Chapter Six indicates that the following factors (as they are the only constant factors in the model) were directly affecting the generation of errors in the construction documents:

1. Factor of error due to interaction
2. Working hours per week per designer
3. Salary Standard
4. Time required to produce a document
5. Number of disciplines
6. Number of phases
7. Procedure to produce documents
8. Previous designer experience
9. Number of documents produced
10. Availability of information
11. Availability of quality assurance procedures
12. Culture of the team
13. Experience of the designers in similar projects
14. Designer education
15. Reputation of the designer
16. Contractual design time

Using such analysis can easily disclose how likely best and worst case scenarios are. The sensitivity analysis available within the modelling software(s) can automatically change variable values and compute new results. Another advantage of this analysis will be in explicating the risky factors in the model. In other words, this process analyzes how sensitive the results are to changes in these uncertainties, and thus discloses how vulnerable the model is.

The sensitivity analysis in Powersim (the software used for the modelling in the thesis) uses Monte Carlo and Latin Hypercube sampling methods to produce sample value sets for the selected assumptions defined by probability distributions. This is

required to approximate the probability distribution function of the selected effects. Latin Hypercube is the recommended method, but the Monte Carlo method can be used. The Latin Hypercube is ten times better than the Monte Carlo technique (Powersim user manual, 2003). It combines the advantages of simple random sampling (as used in the Monte Carlo technique), and full factorial designs, which means that all areas of the sample space are represented. The probability distribution of each assumption is segmented into a number of non-overlapping intervals with equal probability. For each assumption, a sample is generated from each interval.

The validation process using the sensitivity analysis will be performed by selecting first each constant variable (as mentioned above) influencing the performing of the model and the effect variables (i.e. the total correctly solved errors). The value of each variable will be varied and, using the modelling software, the effects of the changes will be analyzed in the value of the factor on the selected effect variables.

Besides the above advantage of the result, the sensitivity analysis produces distributions of values for the effect variables. The probability of results in different ranges can be studied, and below or above certain percentiles. This way the model's robustness can be tested to variations in assumptions, and the likelihood of undesirable results can be seen, as well as favourable results.

The charts will show the degree of the variation in the output of the model (i.e. correctly solved problems) if the value of the variables is changed within the specified range (lowest (worst) and highest (best-case) scenarios) for the following factors:

1. Factor of error due to interaction: the model will be tested when the rate of error due to interaction is as low as 0 error per interaction, up to as high as 1 error per interaction.
2. Working hours per month per designer: when it is 160 hr/mo/person to 208 hr/mo/person.
3. Salary standard: when it is \$0.1 /person/month to \$1 /person/month
4. Required time to produce a document for 55 hr/doc with standard deviation of 5 hr/doc.
5. Number of disciplines: from 1 discipline to 10 disciplines.
6. Number of phases: from 1 phase to 8 phases.
7. Procedure to produce documents from 0 to 1 where 0 is no procedure available to 1 where a proper procedure is in place.

8. Previous designer experience from 0 to 1, where 0 means there is no experience and 1 there is previous experience for the designers.
9. Number of documents produced, from 1 document to 100 documents.
10. Availability of information from 0 to 1, with 0 where there is no information and 1 full information is available.
11. Availability of quality assurance procedures from 0 to 1, where 0 means there is no quality procedure in place and 1 there is a full quality procedure in place.
12. Culture of the team from 0 to 1, where 0 means that the culture of the team is hostile, and 1 the culture of the team is proper and adequate.
13. Experience of the designers with similar project, from 0 to 1; 0 means there is no experience in similar projects and 1 there is good experience in similar projects.
14. Designer education, from 0 to 1: where 0 means there is no good education and 1 there is adequate education.
15. Reputation of the designer, from 0 to 1, where 0 means there is no reputation and 1 is adequate reputation of the designer.
16. Match of the goals, from 0 to 1, where 0 is mismatch of the goals of the project and those of the designer and 1 is matching the goal of the project with the designer.
17. Contractual design time from 270da and standard deviation is 30da.

The effect of the variation of each factor will be studied within its range on the model and the result will be shown on high-low charts that display graphs showing bands of the lowest to the highest output values over time, as affected by variations in the values of the factor.

The ability built in Powersim has been used to show the result when the value is the highest (high) and the lowest (low). The standard deviation caused by the change in the value of the factor has been shown in the table under each factor. The higher the value of standard deviation, the higher impact the change of value will have on the correctly solved errors.

To reduce the repetition in explaining the value of the factors, the value in the tables shown at the beginning of each factor will be explained. The table represents the total number of errors solved correctly by the value of the summary of the following:

Low represents the lowest value in the range and high represents the maximum value within the specified range.

5 percentile represents 5% of the value and 95 percentile represents the remaining 95%.

10 percentile represents 10% of the value and 90 percentile represents the remaining 90%.

25 percentile represents 25% of the value and 75 percentile represents the remaining 75%, and finally 50 percentile represents 50% of the value of the factor.

As stated before, the simulation is a micro-world that lets us test our decisions in a safe environment, without taking risks. The simulation allows us to test various scenarios, and to assess the risks associated with them.

The simulation model may yield several possible strategies to solve the research problem. Based on the knowledge gained by the simulations, the scenario that solves the problem in the best way will be selected.

**For clarity of the charts, X axis represents the total time allocated for the design and production of the construction documents in months and Y axis represents the total number of errors.**

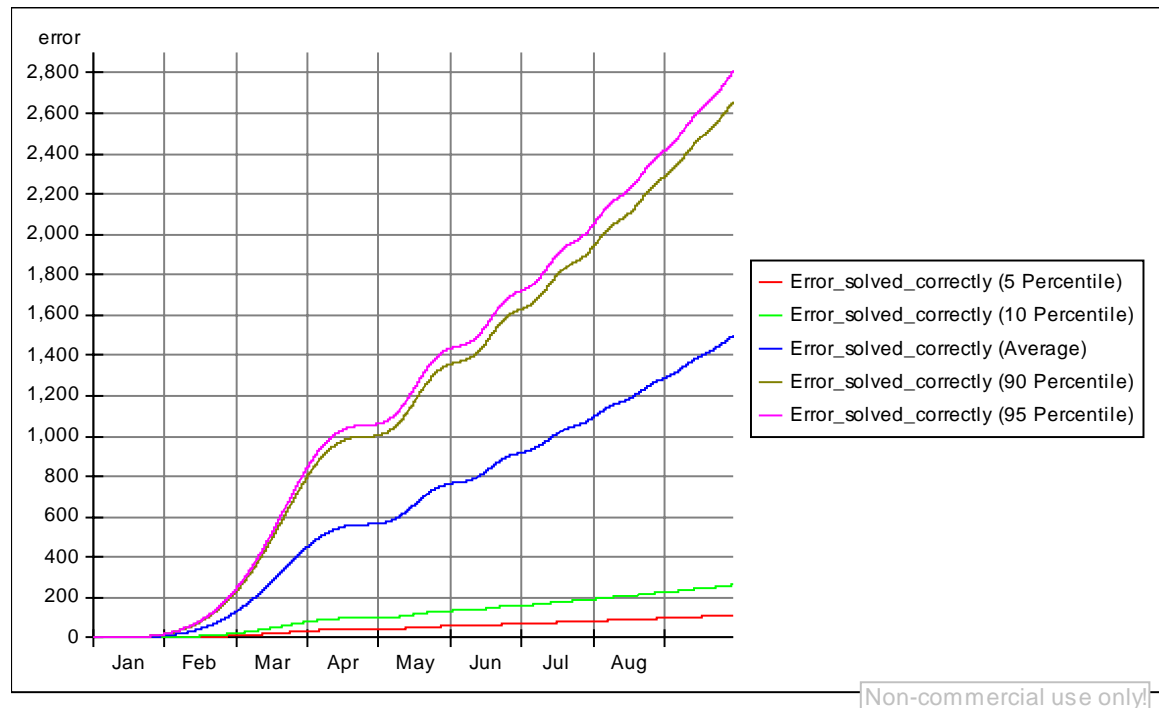
### 7.5.1 Factor of errors due to interaction

As has been discussed previously, the factor of error due to interaction in the model is assumed to be 1 error/interaction; however, a sensitivity analysis will be used to see how the model performs in different situations when the factor of error due to interaction varies from as low as 0 to as high as 1. As the difference between low to high, 5 to 95 percentile or 10 to 90 percentile increases, the impact of the change in value on the factor will be higher.

<b>Value of the factor</b>	<b>Value</b>	<b>Percentage of errors solved correctly</b>	
Low (0 error/interaction)	30	1%	
5 Percentile	91	4%	
10 Percentile	212	9%	
25 Percentile	2660	24%	
50 Percentile	1179	49%	
75 Percentile	1783	75%	
90 Percentile	2146	90%	
95 Percentile	2267	95%	
High (1error/intraction)	2387	100%	
Standard deviation	698	31%	

When the value of the factor is 0 errors per interaction, the model indicates that there will be no errors in the construction documents, and this is natural. However, the other outcome is that the model is sensitive to the change in the value of this factor as the number of correctly solved errors is proportional to the value of the factor, as shown in figure 15. However, the standard deviation indicates that the

total effect of the range of the value is high, which is normal, as it is natural for the errors solved correctly to increase when rate of errors due to interaction increases.



**Figure 15 : Factor of errors due to interaction sensitivity analysis**

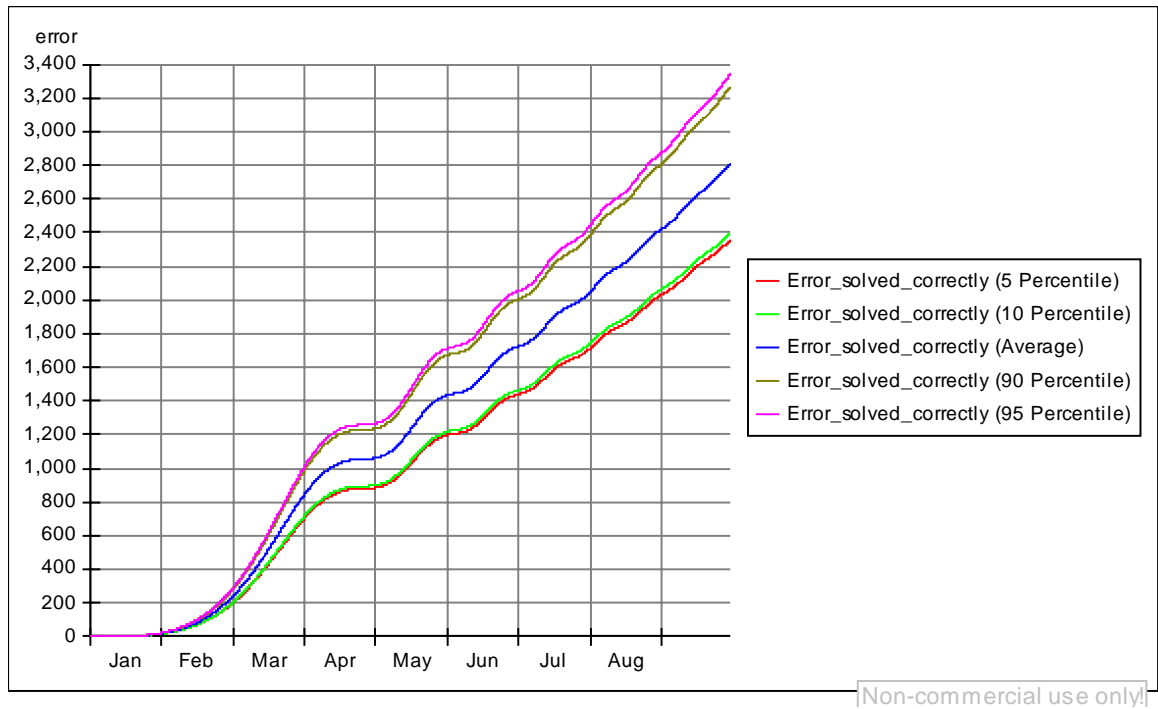
### 7.5.2 Working hours per week per designer

The standard number of working hours per month in Saudi Arabia 208<<hr/mo/person>> is assumed in the model. However, even in cases where the value of the factor is as low as 160 hr/mo/person, up to 68% of errors will be solved correctly. These results indicate that the model is not so sensitive to the change of working hours per week, as shown in figure 16. This factor impacts mainly on the available number of designers for the job. The more working hours per month per person, the fewer personnel in the project, and the fewer working hours per month per person, the more personnel for the project.

An increase in the number of designers will increase the possibility of errors caused by an increase in interaction, communication and coordination within the team while producing the construction documents. For this reason, the correctly solved errors in the model decrease when the number of working hour per month per person increases.

<b>Value of the factor</b>	<b>Value</b>	<b>Percentage of errors solved correctly</b>	
Low (160 hr/mo/person)	1891	68%	
5 Percentile	1907	69%	
10 Percentile	1938	70%	
25 Percentile	2038	74%	
50 Percentile	2231	81%	
75 Percentile	2468	89%	
90 Percentile	2636	95%	
95 Percentile	2698	98%	
High (208 hr/mo/person)	2763	100%	
Standard deviation	256	9%	



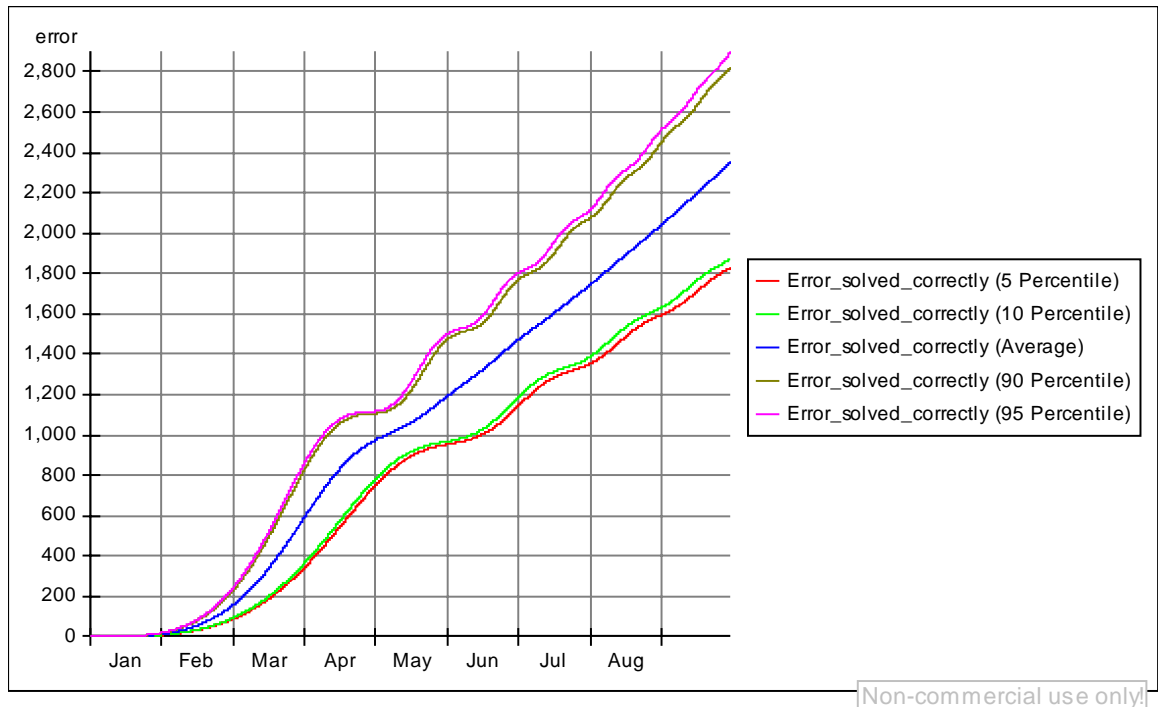


**Figure 16 : Sensitivity the of model to the change of working hours /month/person**

### 7.5.3 Salary standard

The model will not change significantly if the standard salary drops from 1\$/person/mo to as low as 0.1 \$/person/month, as shown in figure 17. Decreasing the value of the factor to the lowest will impact only less than 29% of the total errors solved correctly. This phenomenon can be attributed to other factors in the system, such as management of the design office; culture of the team, etc., as discussed in the model description in chapter 6.

<b>Value of the factor</b>	<b>Value</b>	<b>Percentage of errors solved correctly</b>	
Low (0.1\$/person/month)	1453	61%	
5 Percentile	1471	61%	
10 Percentile	1506	63%	
25 Percentile	1641	68%	
50 Percentile	1867	78%	
75 Percentile	2120	88%	
90 Percentile	2286	95%	
95 Percentile	2339	97%	
High (1\$/person/month)	2339	100%	
Standard deviation	282	12%	

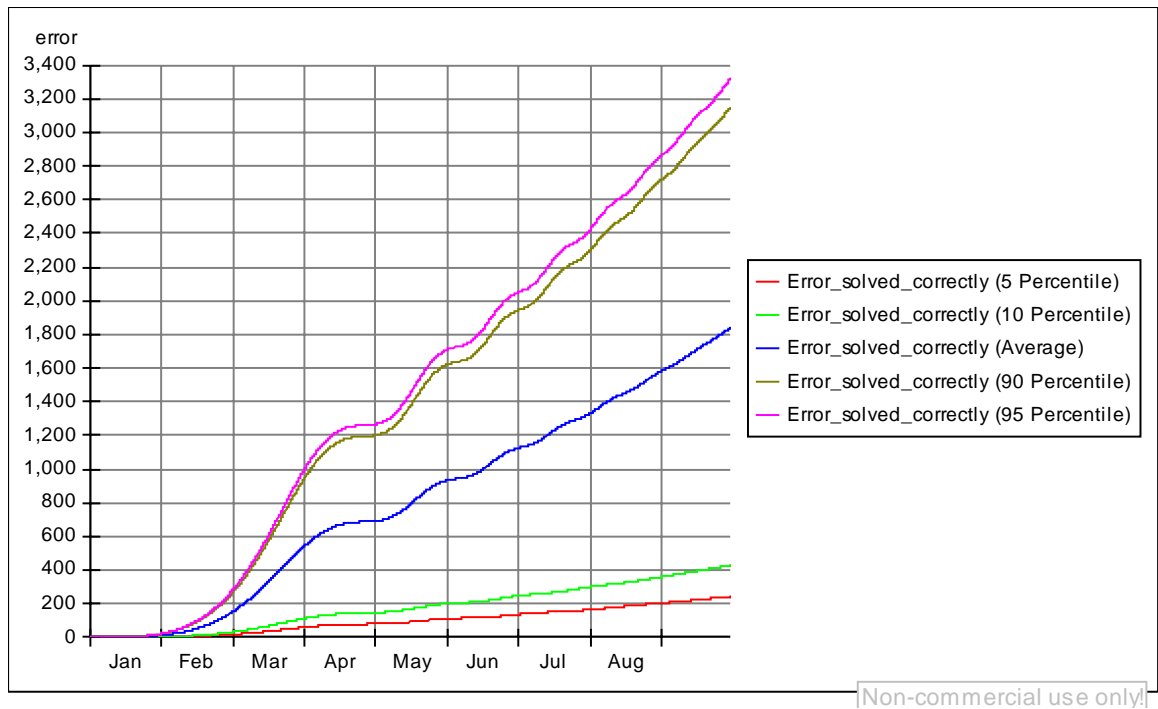


**Figure 17 : Sensitivity of the model to the change in salary standard**

#### 7.5.4 Time required to produce a document

The sensitivity analysis indicates that the model is sensitive to the change in the value of this factor, as the number of correctively solved errors is proportional to the value of the factor, as shown in figure 4. However, the standard deviation indicates that the total effect of the range of the value is high and the value of factor should be kept as high as possible, as indicated in figure 18. When the time is short, the time available for review and solving is limited, which impacts upon the number of errors solved correctly. However, further reduction in the allowable hours per document will produce fewer correctly solved problems, as the whole document will not be solved completely; furthermore, the time will not be sufficient to allow the designer to solve all the problems addressed. On the other hand, when more time is available, more errors will be discovered and will be solved correctly.

<b>Value of the factor</b>	<b>Value</b>	<b>Percentage of errors solved correctly</b>	
Low (1 hr/document)	119	5%	
5 Percentile	202	7%	
10 Percentile	354	13%	
25 Percentile	779	28%	
50 Percentile	1467	52%	
75 Percentile	2136	76%	
90 Percentile	2542	90%	
95 Percentile	2678	95%	
High (60 hr/document)	2813	100%	
Standard deviation	788	28%	



**Figure 18 : Sensitivity of model to change the required hours to produce a document**

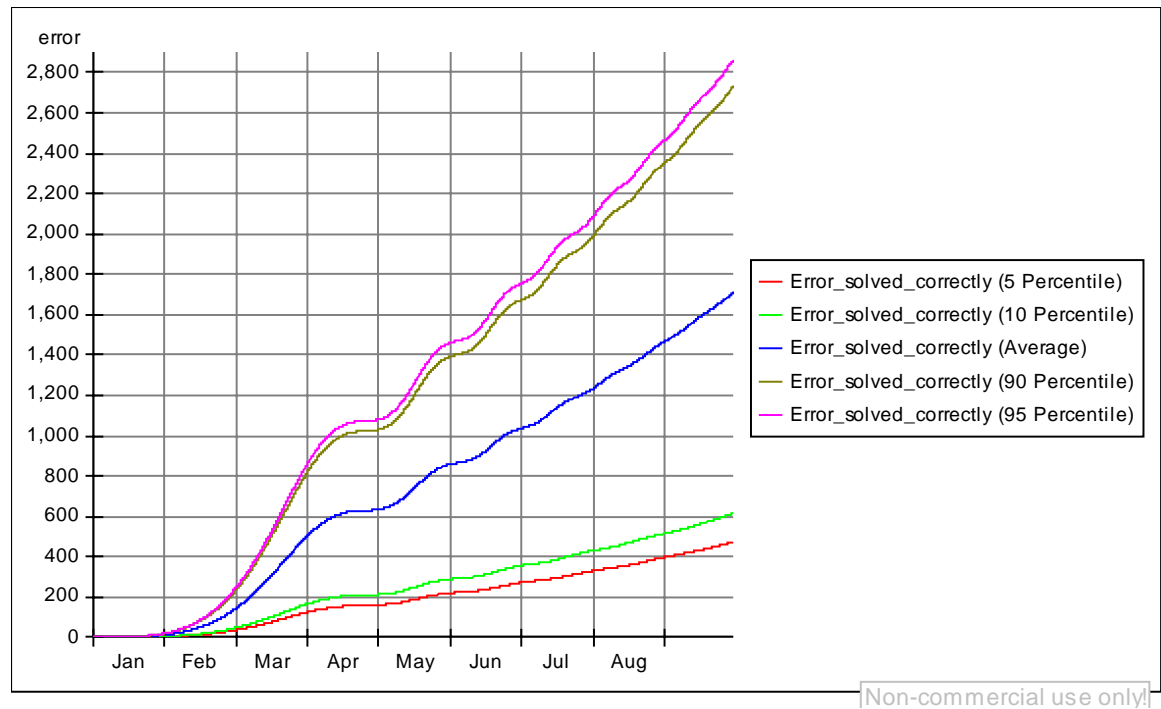
### 7.5.5 Number of disciplines

The number of disciplines affects the generation of errors in significant matters, as the number of interactions and level of coordination required in the project depend to a great extent on the number of disciplines working on the project.

Value of the factor	Value	Percentage of errors solved correctly	
Low (1 discipline)	402	13%	
5 Percentile	473	16%	
10 Percentile	614	20%	
25 Percentile	1020	34%	
50 Percentile	1679	56%	
75 Percentile	2338	78%	
90 Percentile	2735	91%	
95 Percentile	2867	96%	
High (10 disciplines)	2867	100%	
Standard deviation	765	27%	

However, the sensitivity analysis of the output of the model, from 1 discipline to 10 disciplines, supports such arguments as shown in figure 19. When more disciplines exist in the system more errors have to be resolved correctly, and fewer disciplines will lead to fewer problems having to be solved.

It is necessary to mention that this factor is a *de facto* of the project and is directly dependant on the nature and type of the project; as the number of disciplines increases, more coordination will be required to respond to such increases.



**Figure 19 : Sensitivity of the model to the number of disciplines**

### 7.5.6 Number of phases

Increasing number of phases will help in solving more problems owing to the review that takes place at the end of the phase. However, a reduction of the phases to a point below a certain number will not reduce the number of correctly solved errors.

<b>Value of the factor</b>	<b>Value</b>	<b>Percentage of errors solved correctly</b>	
Low (1 phase)	2389	45%	
5 Percentile	2393	45%	
10 Percentile	2397	45%	
25 Percentile	2422	46%	
50 Percentile	2494	47%	
75 Percentile	2963	56%	
90 Percentile	4066	77%	
95 Percentile	4702	89%	
High (8 phases)	4066	100%	
Standard deviation	793	17%	

These can be caused by the other factors in the system, which will solve a certain number of problems in the system regardless of the number of phases, as discussed in the model description chapter.

Therefore the number of phases will not affect the model in a significant way, as shown in the table and in figure 20, which represents the system from 1 phase to 8 phases, the maximum recommended by RIBA. The chart indicates that the more phases there are available, the more problems will be solved correctly, as the model assumes that the quality control occurs at the end of the phase. While reducing the number of phases will not help reducing the number of error solved correctly, it is worth mentioning that the model is showing an increase in the number of correctly



solved errors when the number of phases increases, owing to a recheck that happens every time the QA takes place, which indicates that unnecessary effort is spent checking work that has already been checked at least once before.

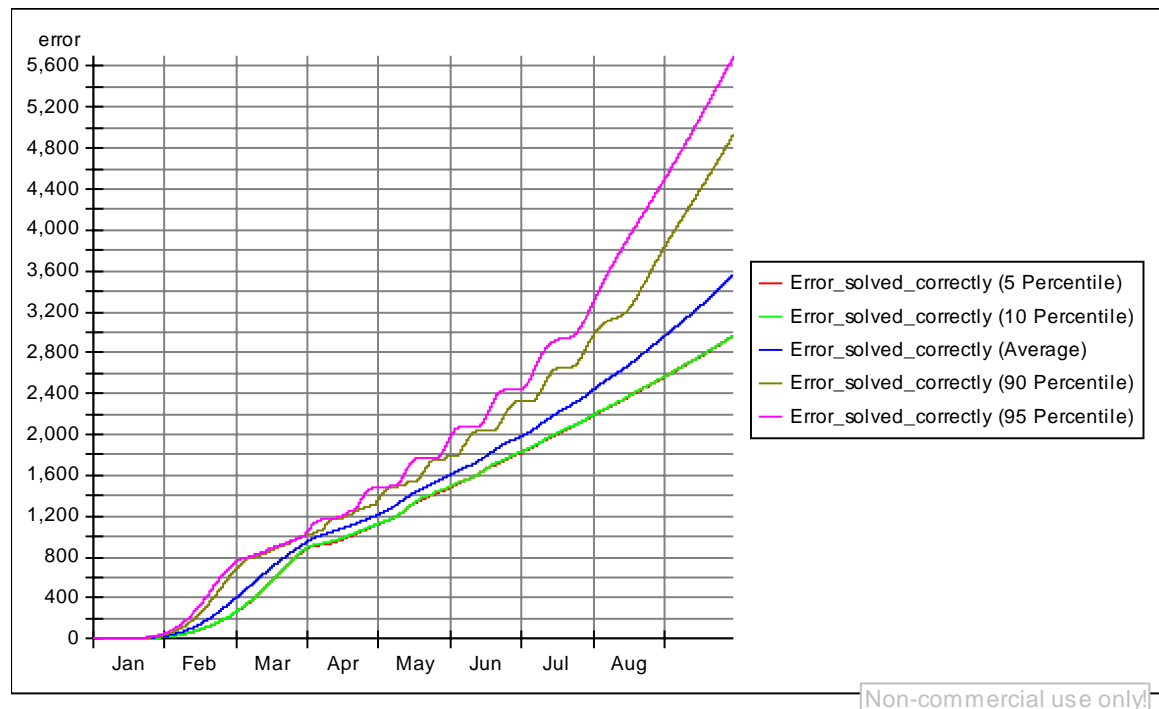


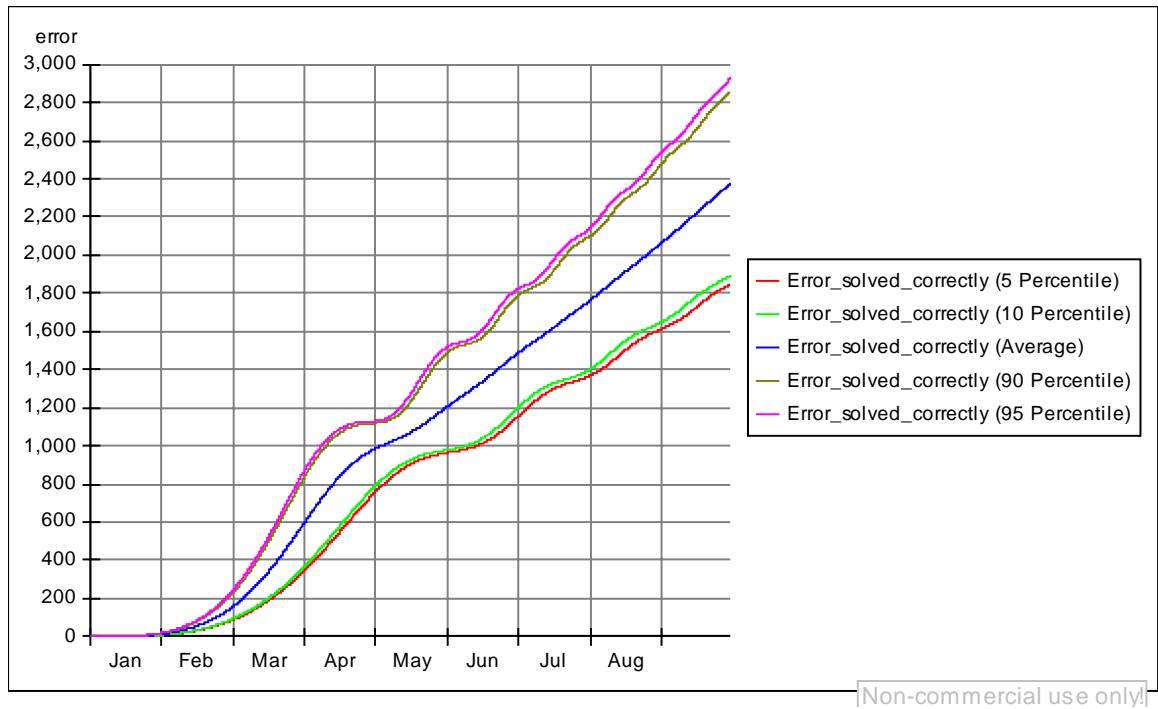
Figure 20 : Sensitivity of the model to the change of number of phases

### 7.5.7 Procedure to produce documents

The availability of a procedure to produce documents will not influence the model in a significant way, as shown in figure 21 which represents the charts from 0 (where there is no procedure) to 1 (where full procedure is implemented in the working place).

<b>Value of the factor</b>	<b>Value</b>	<b>Percentage of errors solved correctly</b>	
Low (0)	1468	60%	
5 Percentile	1486	61%	
10 Percentile	1522	63%	
25 Percentile	1658	68%	
50 Percentile	1888	78%	
75 Percentile	2143	88%	
90 Percentile	2311	95%	
95 Percentile	2365	97%	
High (1)	2365	100%	
Standard deviation	285	12%	

These can be attributed to the fact that other factors will compensate for the missing of the procedure, as discussed in the model description chapter.



**Figure 21 : Sensitivity of the model to the availability of procedure, 0 to 1**

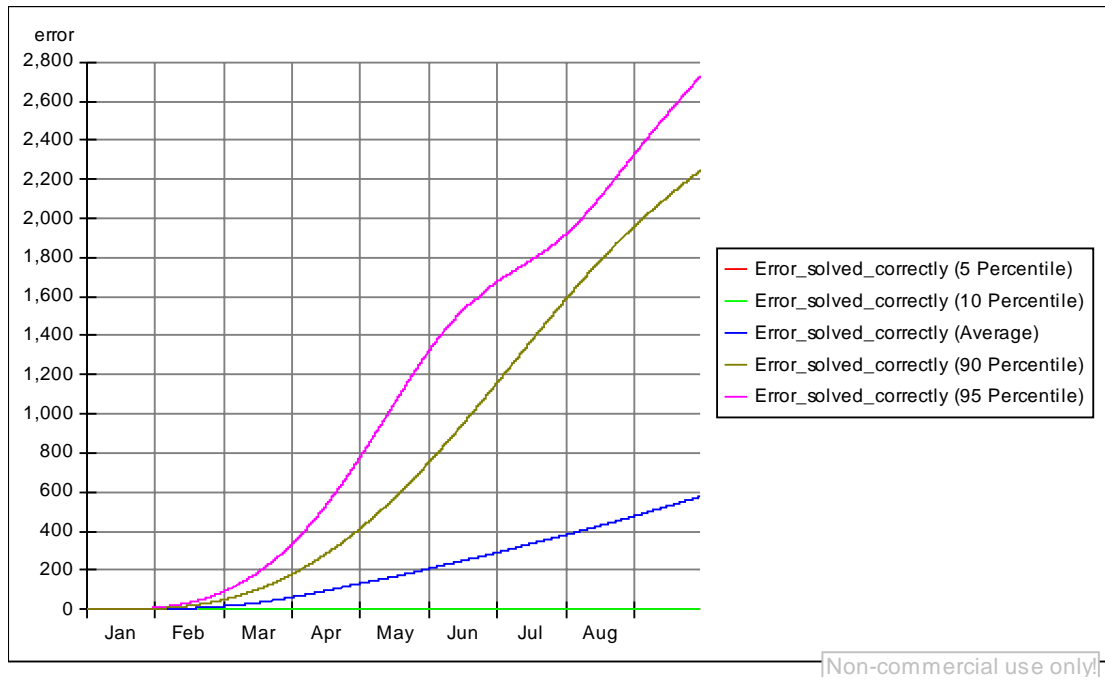
### 7.5.8 Previous designer experience

The cumulative previous designer experience of the team in similar projects (full project or partial) will influence the model in a significant way, as shown in figure 8, from 0 where no cumulative experience is available at all within the design team and 1 where the team has experience in such projects.

The sensitivity analysis indicates that 10% drop in this value will result in only 74% of the errors being solved correctly, while any drop of more than 50% will result in a completely wrong solution, as shown in figure 22.

However, this factor can not be replaced and it should be considered as a serious factor that impacts on the quality of the construction documents.

Value of the factor	Value	Percentage of errors solved correctly	
Low (0)	0	0%	
5 Percentile	0	0%	
10 Percentile	0	0%	
25 Percentile	0	0%	
50 Percentile	15	1%	
75 Percentile	569	23%	
90 Percentile	1797	74%	
95 Percentile	2183	90%	
High (1)	2429	100%	
Standard deviation	749	34%	



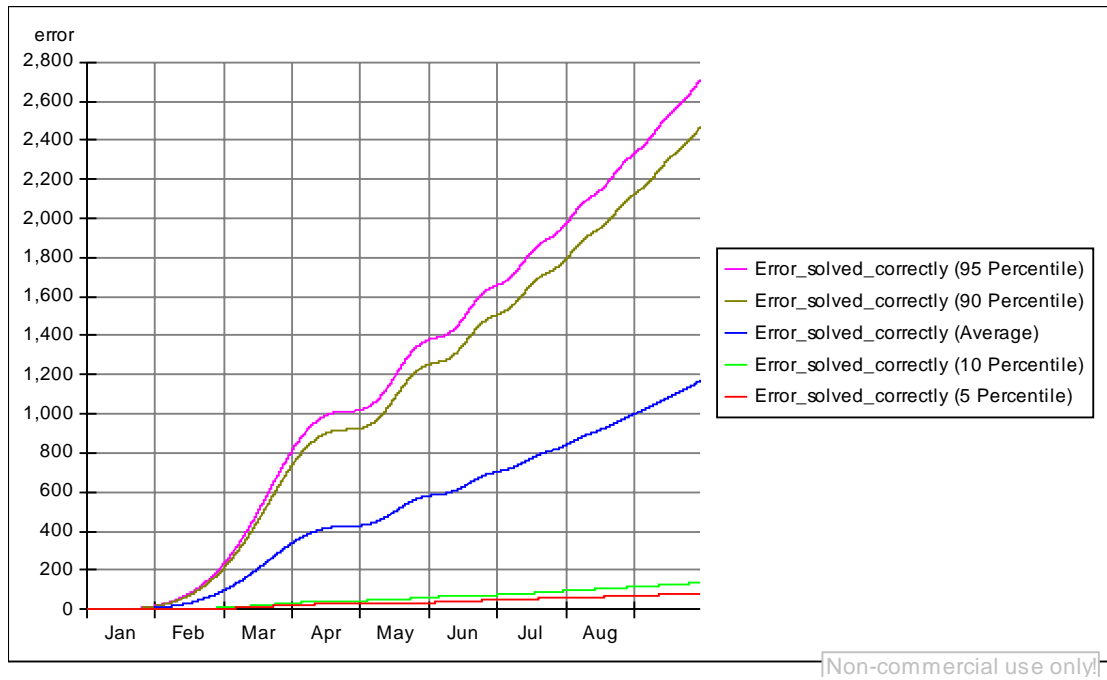
**Figure 22 : Sensitivity of the model to the previous project experience**

### 7.5.9 Number of documents produced

The number of documents will influence the model in a significant way as the number of errors solved is related mainly to the number of documents produced, as shown in figure 23, which ranges from 1 document to 100 documents.

<b>Value of the factor</b>	<b>Value</b>	<b>Percentage of errors solved correctly</b>	
Low	53	2%	
5 Percentile	70	3%	
10 Percentile	114	5%	
25 Percentile	298	12%	
50 Percentile	773	32%	
75 Percentile	1470	61%	
90 Percentile	1992	83%	
95 Percentile	2187	91%	
High	2187	100%	
Standard deviation	702	32%	

It is a fact that the number of errors is basically dependant on the number of documents produced for the project. However, this factor will not be considered in the analysis, as the number of documents of the project will be a de facto of the project which is required to explain the project to the project stakeholders and cannot be compensated in any way. Other measures should be considered to eliminate the number of errors in the construction documents, regardless of the number of documents.



**Figure 23 : Sensitivity of the model to the number of documents produced, 1 -100**

### 7.5.10 Availability of information

The sensitivity analysis indicates that the availability of information will change the output of the model significantly, as indicated in figure 10 where the range is from 0 to 1, where 0 means there is no information available to the designer team while 1 indicates the full availability of information to the design team. The complete absence of the factor may not result in a complete lack of correctly solved errors owing to other factors, such as transfer of knowledge, ingredients of the design team etc.

Value of the factor	Value	Percentage of errors solved correctly	
Low (0)	831	34%	
5 Percentile	896	37%	
10 Percentile	1032	42%	
25 Percentile	1490	61%	
50 Percentile	2142	88%	
75 Percentile	2282	94%	
90 Percentile	2365	97%	
95 Percentile	2396	99%	
High (1)	2429	100%	
Standard deviation	488	20%	

However; even though the information will be absent at the beginning of the project, some information will be available to the team as project progresses, owing to knowledge transfer gained from other members of the team.



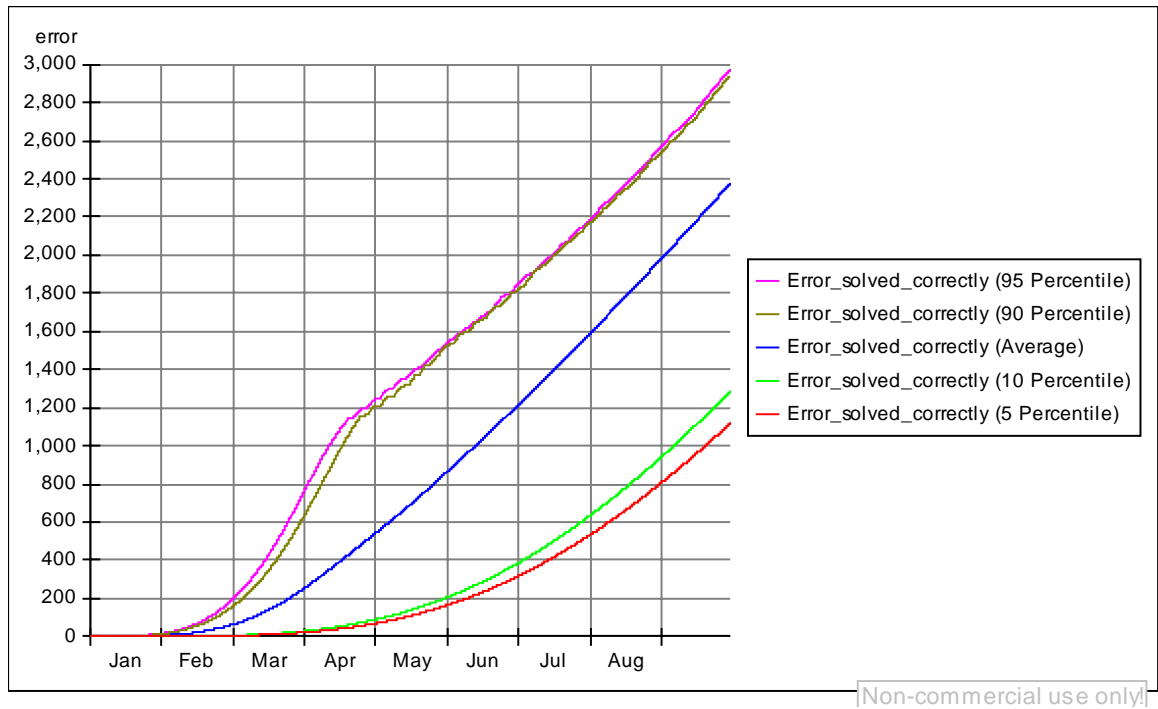


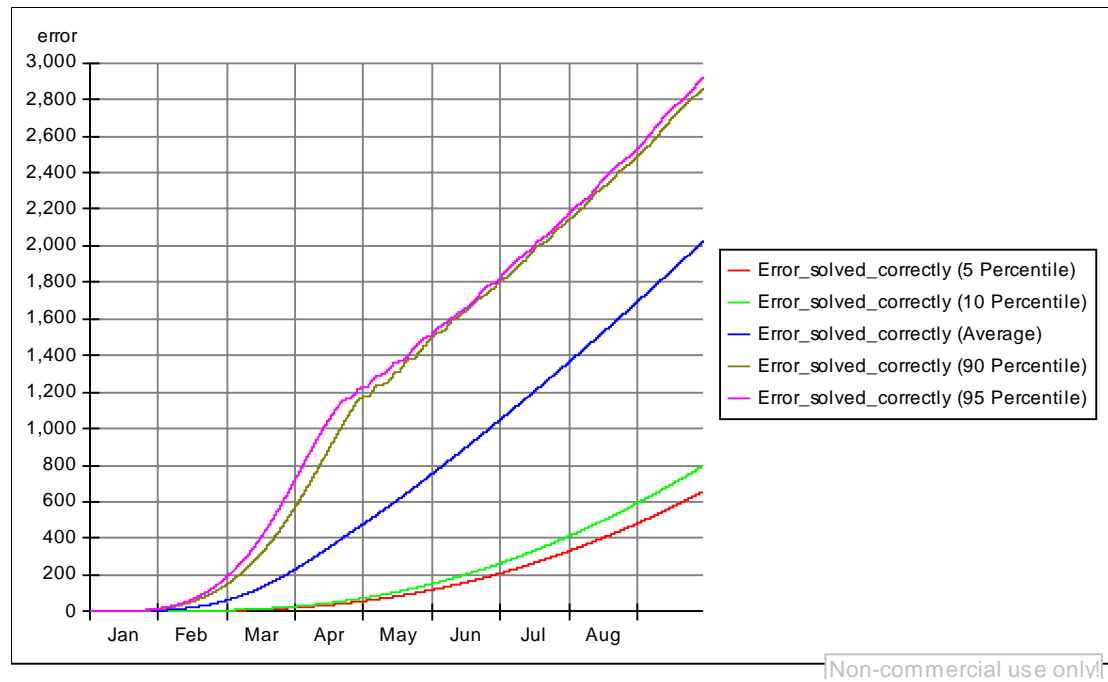
Figure 24 : Sensitivity of the model to the availability of information

### 7.5.11 Availability of quality assurance procedure

The sensitivity analysis indicates that the availability of a quality assurance procedure will change the output of the model significantly, as indicated in figure 25, within the range from 0 to 1, where 0 represents the absence of the quality assurance procedure and 1 represents the availability of the quality assurance procedure.

<b>Value of the factor</b>	<b>Value</b>	<b>Percentage of errors solved correctly</b>	
Low (0)	472	19%	
5 Percentile	525	22%	
10 Percentile	638	26%	
25 Percentile	1023	42%	
50 Percentile	1755	72%	
75 Percentile	2183	90%	
90 Percentile	2298	95%	
95 Percentile	2354	97%	
High (1)	2425	100%	
Standard deviation	622	26%	

However, the absence of a quality assurance procedure while producing the construction documents will not prevent some problems (about 19%) being solved owing to the ingredients of the design team (education, experience, transfer of knowledge. etc.) which help to resolve some problems as the project progresses, as discussed in the model description chapter.



**Figure 25 : Sensitivity of the model to the availability of the quality assurance procedure**

### 7.5.12 Culture of the team

The sensitivity analysis indicates that the culture of the team will not change the output of the model significantly, as indicated in figure 26, within the range from 0 to 1, where 0 represents the hostile type of culture within the design team and 1 represent the steady and stable culture within the design team. The analysis indicates that a hostile type of culture will impact only 26% of the correctly solved errors as other factors will balance the disturbance in the models, such as design management.

<b>Value of the factor</b>	<b>Value</b>	<b>Percentage of errors solved correctly</b>	
Low (0)	1870	74%	
5 Percentile	1910	74%	
10 Percentile	1946	86%	
25 Percentile	2053	80%	
50 Percentile	2177	85%	
75 Percentile	2297	89%	
90 Percentile	2373	92%	
95 Percentile	2398	93%	
High (1)	2570	100%	
Standard deviation	152	6%	

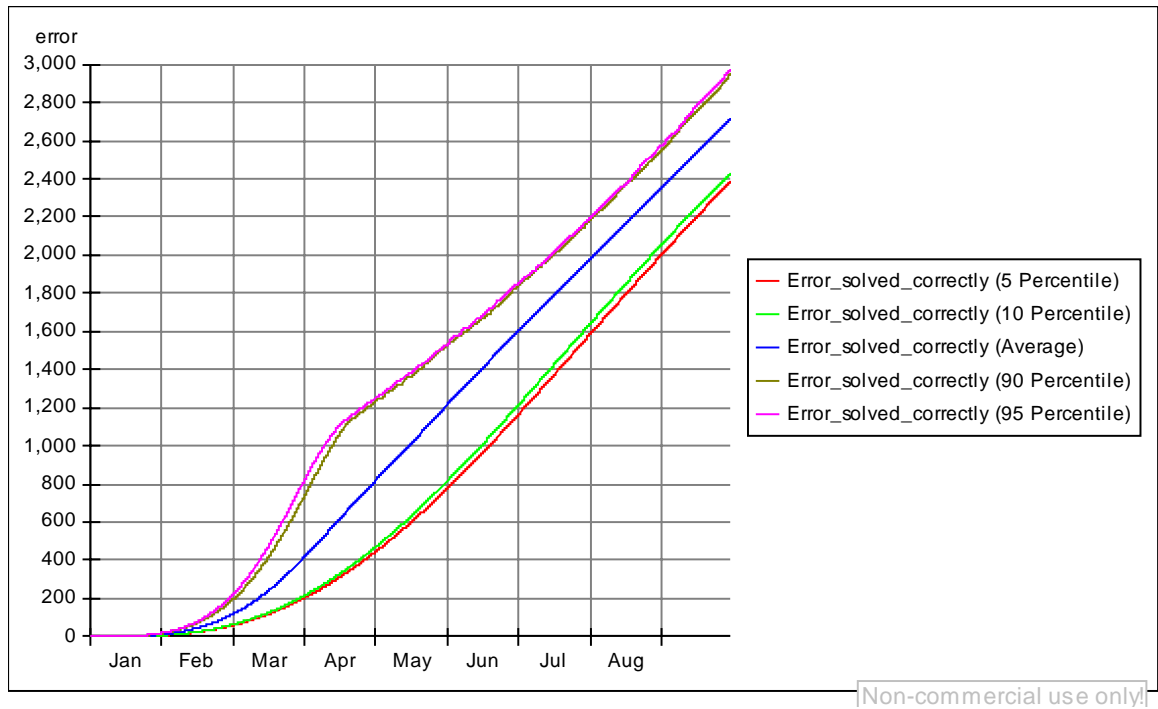


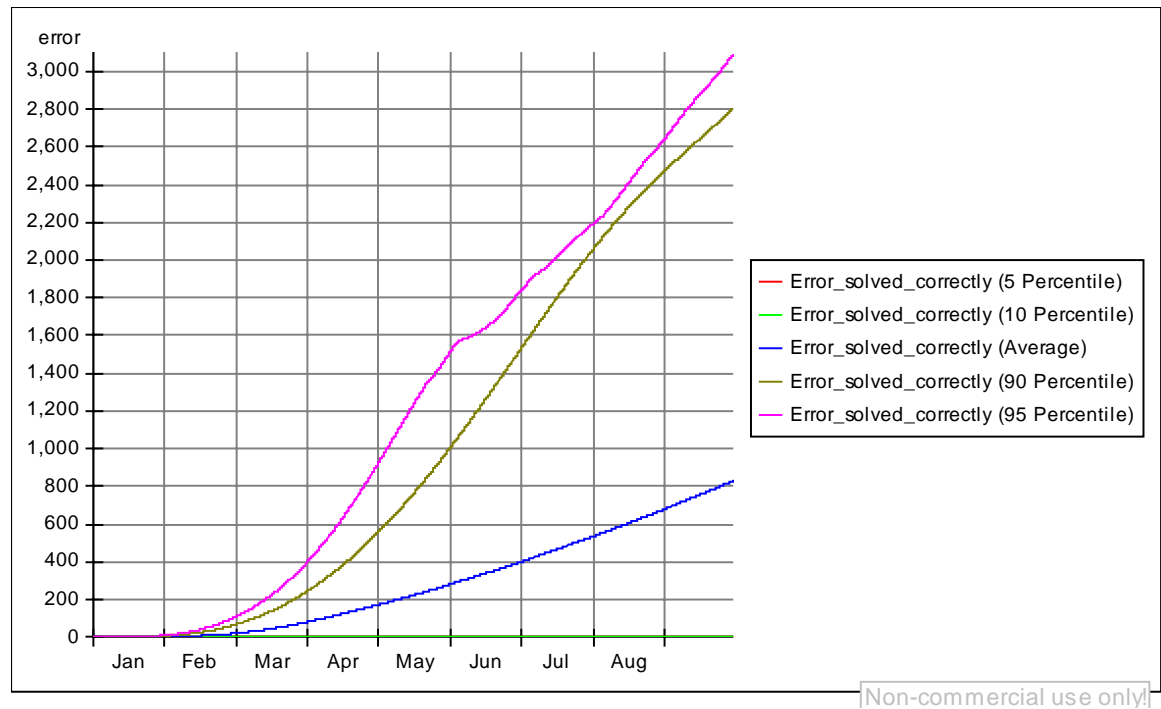
Figure 26 : Sensitivity of the model to change in the culture of the team; 0 -1

### 7.5.13 Experience of the designers

The built up and cumulative experience of the designers in the work affects the generation of errors in significant matters, as problems could be solved by the previous experience of the designers.

<b>Value of the factor</b>	<b>Value</b>	<b>Percentage of errors solved correctly</b>	
Low (0)	0	0%	
5 Percentile	0	0%	
10 Percentile	0	0%	
25 Percentile	3	0%	
50 Percentile	99	4%	
75 Percentile	1150	45%	
90 Percentile	2243	88%	
95 Percentile	2477	98%	
High (1)	2536	100%	
Standard deviation	887	36%	

When the value of the experience drops below 10%, the number of correctly solved problems reduces dramatically, as indicated in the table. However, the sensitivity of the model supports such arguments, as shown in figure 17, in which the range varies between 0 and 1, where 0 represents the absence of experience within the design team and 1 represents the availability of experience.



Non-commercial use only

**Figure 27 : Sensitivity of the model to the change of previous experience of the designer**

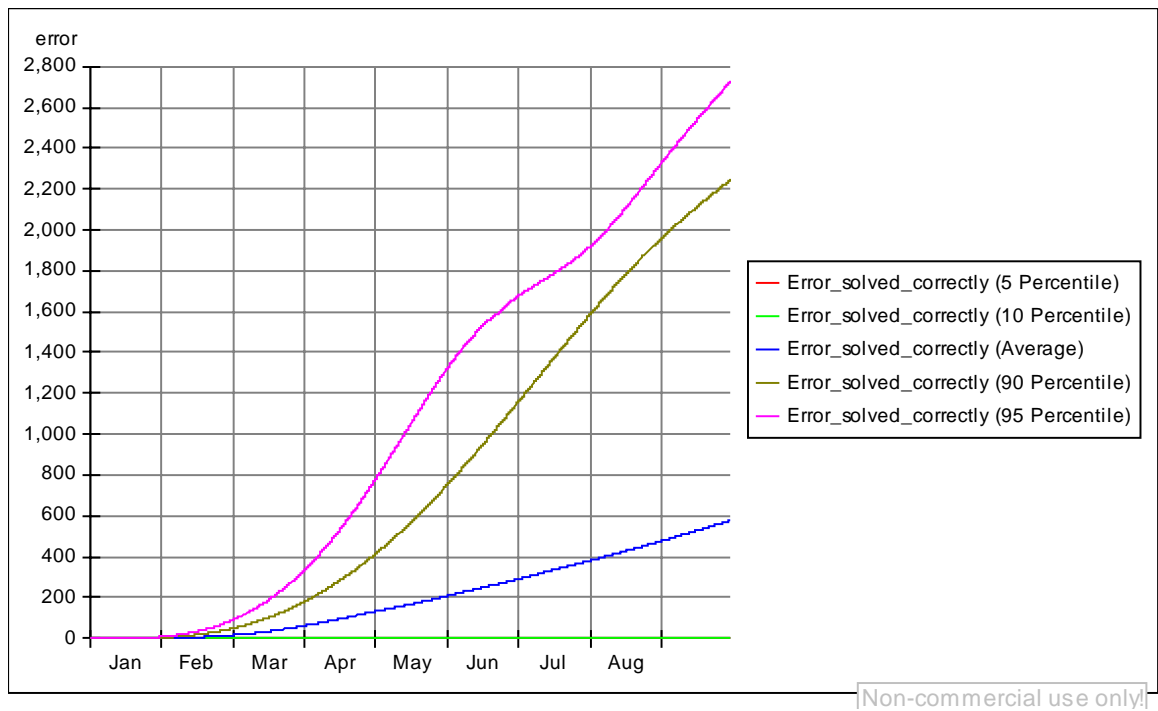
### 7.5.14 Designer Education

Similar to designer experience, the designer's education affects the model in a significant way, as shown in figure 28, in which the range varies from 0 to 1, where 0 represents inadequate education within the design team and 1 represents the adequate education within the design team.

Value of the factor	Value	Percentage of errors solved correctly	
Low (0)	0	0%	
5 Percentile	0	0%	
10 Percentile	0	0%	
25 Percentile	0	0%	
50 Percentile	15	1%	
75 Percentile	569	23%	
90 Percentile	1797	74%	
95 Percentile	2183	90%	
High (1)	2429	100%	
Standard deviation	749	34%	

The table indicates that a reduction of the factor of education below 5% will impact on the model in a significant way. The better the education of the available designers; the more problems will be solved correctly and vice versa: when the team does not have proper education, the number of correctly solved errors will suffer by an enormous degree.





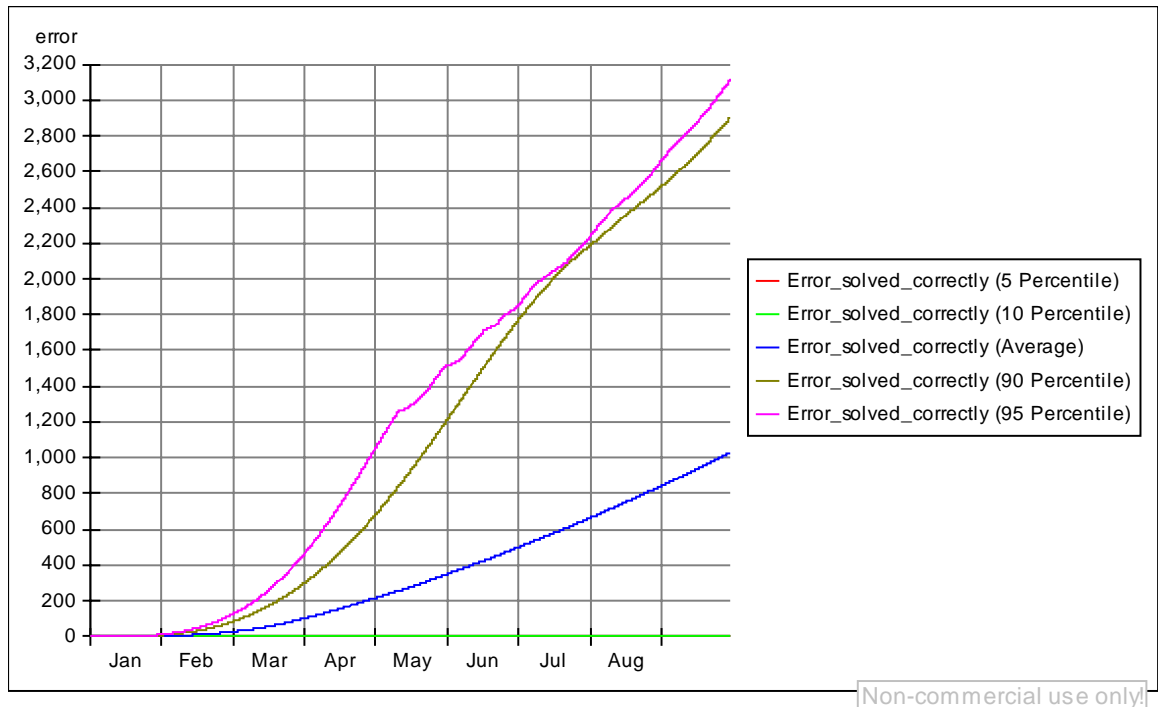
**Figure 28 : Sensitivity of the model to the change of the education of the designers**

### 7.5.15 Reputation of the designer

The reputation of the designer is a factor of designer education, experienced designer, and previous designer experience. As these factors impact on the model, the reputation of the designer will also affect the model in a significant way, as shown in figure 29 within the range from 0 to 1; where 0 represents the lack of the reputation and 1 represents the availability of the adequate reputation. The drop of the value of the reputation factor below 10% will reduce the number of correctly solved errors radically, as shown in the table.

Value of the factor	Value	Percentage of errors solved correctly	
Low (0)	1	0%	
5 Percentile	2	0%	
10 Percentile	3	0%	
25 Percentile	21	1%	
50 Percentile	298	12%	
75 Percentile	1569	61%	
90 Percentile	2324	90%	
95 Percentile	2508	98%	
High (1)	2570	100%	
Standard deviation	927	37%	

The greater the reputation of the designer the more problems will be solved correctly, as the reputation will normally have been gained from the designer experience, education and procedures followed while producing the documents.



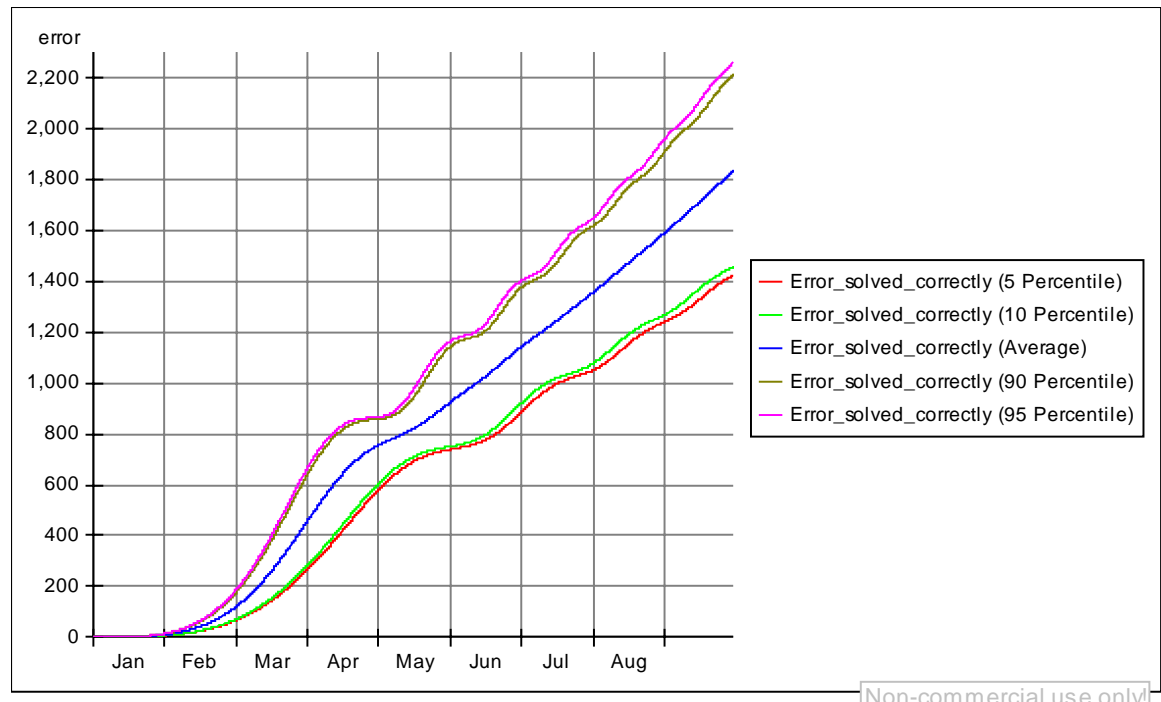
**Figure 29 : Sensitivity of the model to the change of the reputation of the designer**

### 7.5.16 Match of the goals

The match of goals of the designers with the objectives of the project does not mean that more errors will be generated in the construction documents, as the variables do not affect the model in a significant manner, as shown in figure 30 within the range from 0 to 1, where 0 represents the mismatch of the goals while 1 represents matching of the goals. A drop of 25% in the value of the factor impacts on only 12% of the correctly solved errors, as shown in the table.

<b>Value of the factor</b>	<b>Value</b>	<b>Percentage of errors solved correctly</b>	
Low (0)	1132	60%	
5 Percentile	1148	61%	
10 Percentile	1175	63%	
25 Percentile	1278	68%	
50 Percentile	1456	77%	
75 Percentile	1656	88%	
90 Percentile	1795	95%	
95 Percentile	1836	98%	
High (1)	1880	100%	
Standard deviation	223	12%	

This could be owing to the other factors, such as contractual arrangement, management of the team, education.



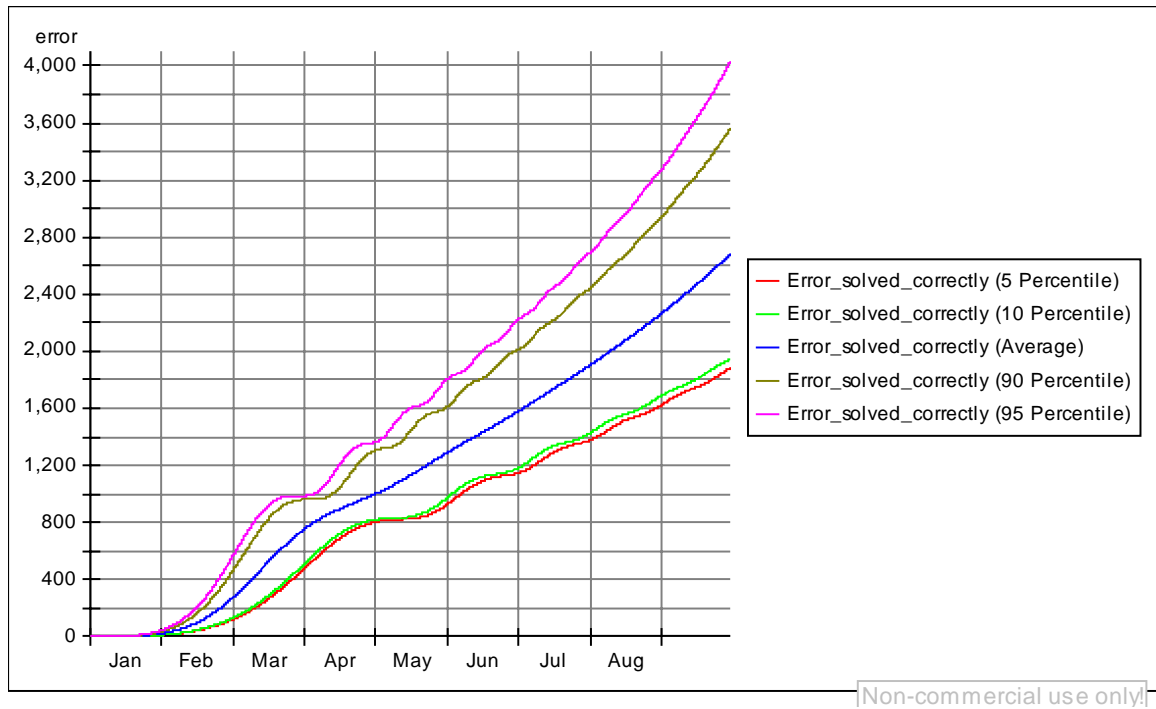
**Figure 30 : Sensitivity of the model to the change of the reputation of the designer**

### 7.5.17 Contractual Design Time

Contractual design time affects the model in a significant way as shown in figure 31; if the contractual design time drops by 5%, the result will be that only 73% of the errors will be solved correctly, and in the case of a drop of 10% only, the number of errors solved correctly is as low as only 64%, which indicates a high impact on the model.

<b>Value of the factor</b>	<b>Value</b>	<b>Percentage of errors solved correctly</b>	
Low	1132	26%	
5 Percentile	1230	28%	
10 Percentile	1360	31%	
25 Percentile	1578	36%	
50 Percentile	1875	42%	
75 Percentile	2294	52%	
90 Percentile	2802	63%	
95 Percentile	3195	72%	
High	4437	100%	
Standard deviation	659	15%	

The more design time available the more problems will be solved correctly and vice versa when the time is not available.



**Figure 31 : Sensitivity of the model to the change of contractual design time**

The following table summarizes the value of all the factors. As mentioned before, the higher the difference between low and high and 5 and 95 percentile, the more sensitive the factor to the change.

Legend	Factors	0P	5 P	10 P	25p	50p	75p	90 P	95 P	100 P	0%	5%	10 %	25 %	50 %	75 %	90 %	95 %	100 %
F1	Factors of error due to interaction	30	91	212	574	1179	1783	2146	2267	2387	1%	4%	9%	24%	49%	75%	90%	95%	100%
F2	Working hour per week per designer	1891	1907	1938	2038	2231	2468	2636	2698	2763	68%	69%	70%	74%	81%	89%	95%	98%	100%
F3	Salary Standard	1453	1471	1506	1641	1867	2120	2286	2339	2401	61%	61%	63%	68%	78%	88%	95%	97%	100%
F4	Required time to produce a document	119	202	354	779	1467	2136	2542	2678	2813	4%	7%	13%	28%	52%	76%	90%	95%	100%
F5	No of disciplines	402	473	614	1020	1679	2338	2735	2867	2999	13%	16%	20%	34%	56%	78%	91%	96%	100%
F6	No of phases	2389	2393	2397	2422	2494	2963	4066	4702	5290	45%	45%	45%	46%	47%	56%	77%	89%	100%
F7	Procedure to produce documents	1468	1486	1522	1658	1888	2143	2311	2365	2428	60%	61%	63%	68%	78%	88%	95%	97%	100%
F8	Previous designer experience	0	0	0	0	15	569	1797	2183	2429	0%	0%	0%	0%	1%	23%	74%	90%	100%
F9	Number of document produced	53	70	114	298	773	1470	1992	2187	2392	2%	3%	5%	12%	32%	61%	83%	91%	100%
F10	Availability of information	831	896	1032	1490	2142	2282	2365	2396	2429	34%	37%	42%	61%	88%	94%	97%	99%	100%
F11	Availability of quality assurance procedure	472	525	638	1023	1755	2183	2298	2354	2425	19%	22%	26%	42%	72%	90%	95%	97%	100%
F12	Culture of team	1890	1910	1946	2053	2177	2297	2373	2398	2570	74%	74%	76%	80%	85%	89%	92%	93%	100%
F13	Experience of the designers	0	0	0	3	99	1150	2243	2477	2536	0%	0%	0%	0%	4%	45%	88%	98%	100%
F14	Designer education	0	0	0	0	15	569	1797	2183	2429	0%	0%	0%	0%	1%	23%	74%	90%	100%
F15	Reputation of the designer	1	2	3	21	298	1569	2324	2508	2570	0%	0%	0%	1%	12%	61%	90%	98%	100%
F16	Match of the goals	1132	1148	1175	1278	1456	1656	1795	1836	1880	60%	61%	63%	68%	77%	88%	95%	98%	100%
F17	Contractual Design time	1132	1230	1360	1578	1875	2294	2802	3195	4437	26%	28%	31%	36%	42%	52%	63%	72%	100%

Table 2 : Summary of errors solved correctly per percentage of each factor



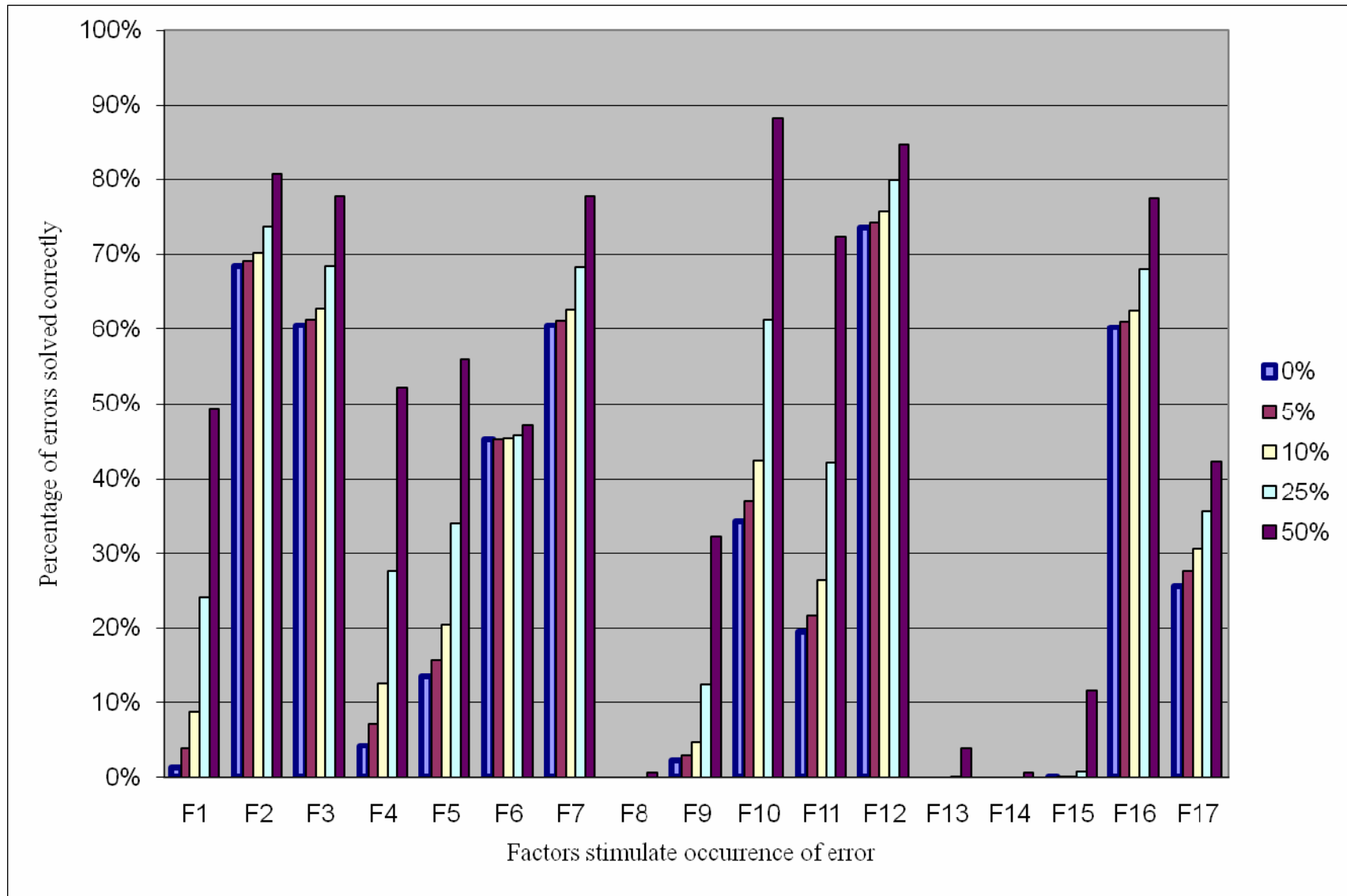
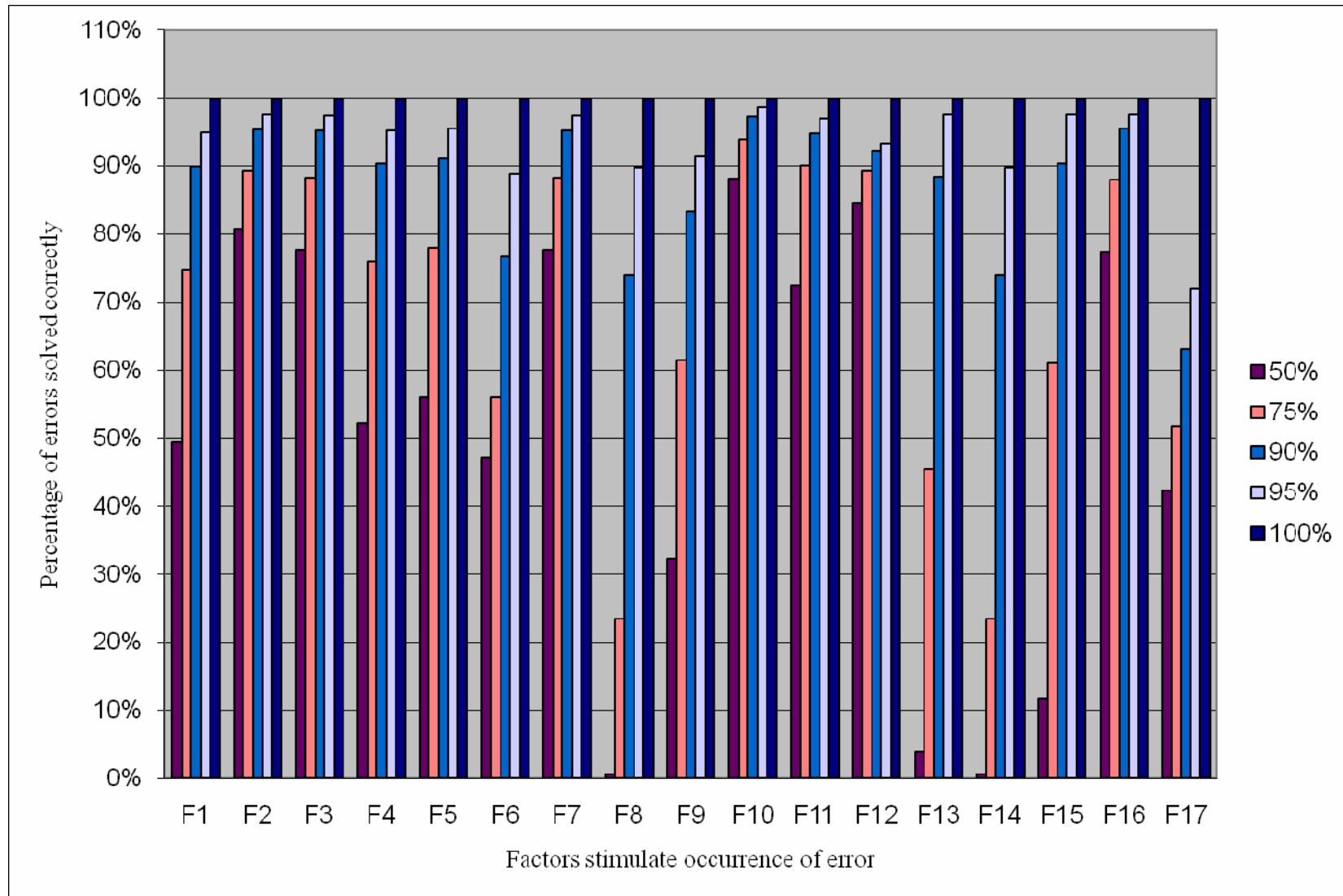


Figure 32 : Summary of error solved correctly per percentage (0%-50%) of each factor



**Figure 33 : Summary of errors solved correctly per percentage (50%-100%) of each factor**

## **7.6 Behaviour of factors affecting the generation of errors in the construction documents**

Much of the management literature suggests that improvement activities should focus on finding and relaxing the current bottleneck inhibiting the throughput of any process (Sterman 2000, p753; Goldratt and Cox 1986). Focusing improvement efforts on the current bottleneck immediately boosts throughput, while any effort to improve non-bottleneck activities is wasted.

From the previous analysis of the factors directly influencing the generation of errors in the construction documents, the effect of changing one variable was shown while fixing the remaining variables on the models. Based on this knowledge, it is possible to develop a policy for reducing the occurrence of errors in the construction document and influence those factors that stimulate the occurrence of errors.

While the best policy to reduce the number of error generated in the construction document is by maintaining the factors identified as the main cause in their supreme shape (i.e. the highest value identified in the beginning of this chapter), it is still sensible to seek scenarios that reduce the range for factors while maximizing the number of errors solved correctly.

The following factors were considered as decision factors that could interact with each other in the process of solving problems in the construction documents:

- Working hours per week per designer
- Salary standard
- Required time to produce a document
- Number of disciplines
- Number of phases
- Procedure to produce documents
- Previous designer experience
- Availability of information
- Availability of quality assurance procedure
- Culture of team
- Experience of the designers
- Designer education

- Reputation of the designer
- Match of the goals

However, the following factors were considered as de facto of the project and cannot be changed and other means of the above factors should be considered, including:

- Number of disciplines: as this factor is the required discipline for the type of project and cannot be reduced.
- Number of the documents produced: similar to the above factor, it is required for explaining and dispensing the intent of the project.
- Contractual design time: while the design team could ask for time to carry out the project, it is normal in the industry - to a certain degree - to accept an imposed contractual design time from the client.
- Factor of error due to the interaction, as this factor is an assumption that is made to see the occurrence of errors in the construction document. It will be natural that this factor will determine the number of errors generated in the construction documents.

As discussed previously, the behaviours of the model for the above factors at different values (minimum and maximum value) behave differently for each identified factor. However, further study of the behaviour of factors revealed an archetype that allows the grouping of the factors under similar behaviour. These archetypes are derived from the percentage of deviation of each factor, as shown in Table 2.

Legend	Factors	Deviation	% Deviation
F1	Factors of error due to interaction	698	29%
F2	Working hour per week per designer	256	9%
F3	Salary Standard	282	12%
F4	Required time to produce a document	788	28%
F5	No of disciplines	765	26%
F6	No of phases	793	15%
F7	Procedure to produce documents	285	12%
F8	Previous designer experience	749	31%
F9	Number of document produced	702	29%
F10	Availability of information	488	20%
F11	Availability of quality assurance procedure	622	26%
F12	Culture of team	152	6%
F13	Experience of the designers	887	35%
F14	Designer education	749	31%
F15	Reputation of the designer	927	36%
F16	Match of the goals	223	12%
F17	Contractual Design time	659	15%

**Table 3: Percentage of deviation in the sensitivity analysis**

These archetypes of behaviour resulting from the standard deviation can be classified as follows:

- Deviation percentage <10%
- Deviation percentage 10%-15%
- Deviation percentage 15%-20%
- Deviation percentage 20%-25%
- Deviation percentage 25%-30%
- Deviation percentage 30%-35%
- Deviation percentage >35%

### 7.6.1 Category 1: factors with deviation less than 10% between high and low value

Category 1 factors represent the least sensitive factors in the model, as change in the value of the factors from high to low will have a low impact on the correctly solved problems. The difference between the minimum and maximum value of the factors will only reduce the number of correctly solved errors to less than 50%. In other words, the value of the factors will not affect the number of correctly solved problems dramatically.

The least sensitive factors were

- Culture of the team
- Working hour per week per designer

By using the model and studying the value of these factors, the researcher found that up to a 5% drop in the value of factors will drop the number of correctly solved problem by 7% and 2% consequently and similarly in a 10% drop it will drop the number by 8% and 5% consequently, while a 100% drop of value (from high to low) will drop the number of correctly solved errors to only 26% and 32% consequently.

However; reducing these two factors by 40% shows a reasonable output, as indicated in the graph.

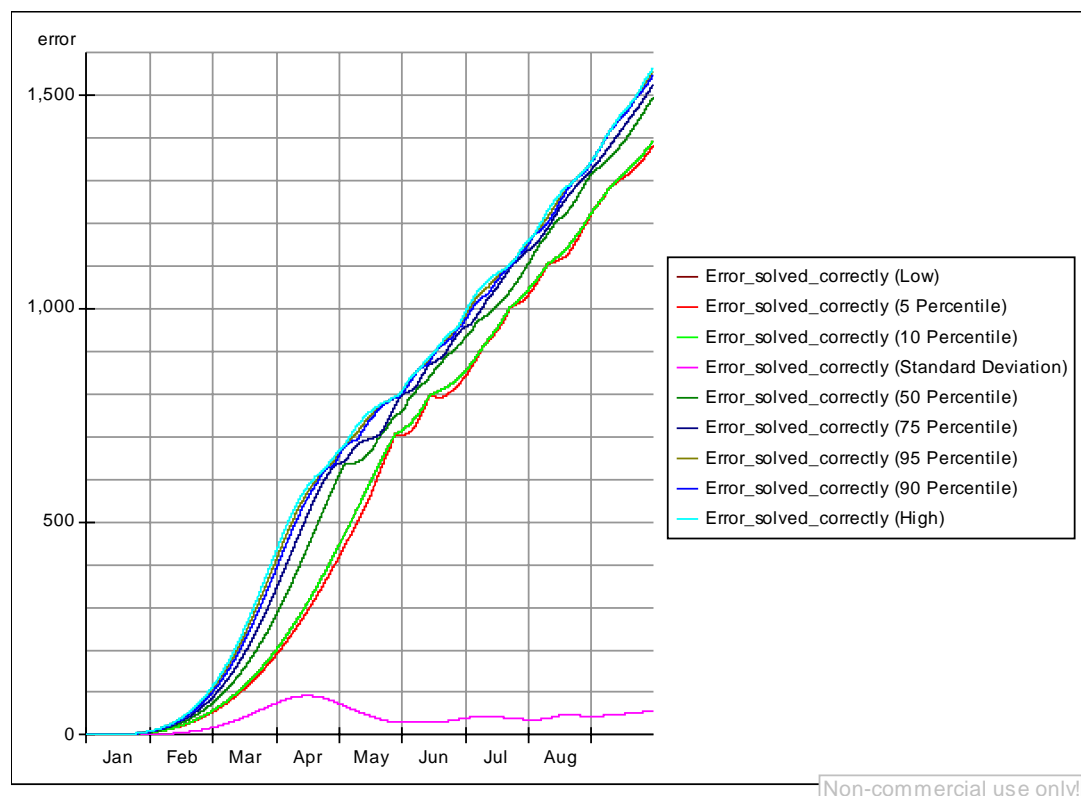


Figure 34 : Combined behaviour of category 1 factors

### 7.6.2 Category 2: factors with deviation between 10%-15% for high and low value

Category 2 factors are those factors that have a deviation from 10% up to 15% between low and high values. These factors are:

- Procedure to produce documents
- Salary standard
- Match of the goals

By using the model and studying the value of these factors, the researcher found that a 5% drop in the value of the factors will drop only about 3% in the number of correctly solved errors, a 10% drop in value will only drop 5% in the number and a 25% drop will drop by 12% while a 100% drop of value will drop the number of correctly solved errors by 40% only.

However; reducing these two factors by 25% shows a reasonable output, as indicated in the graph.

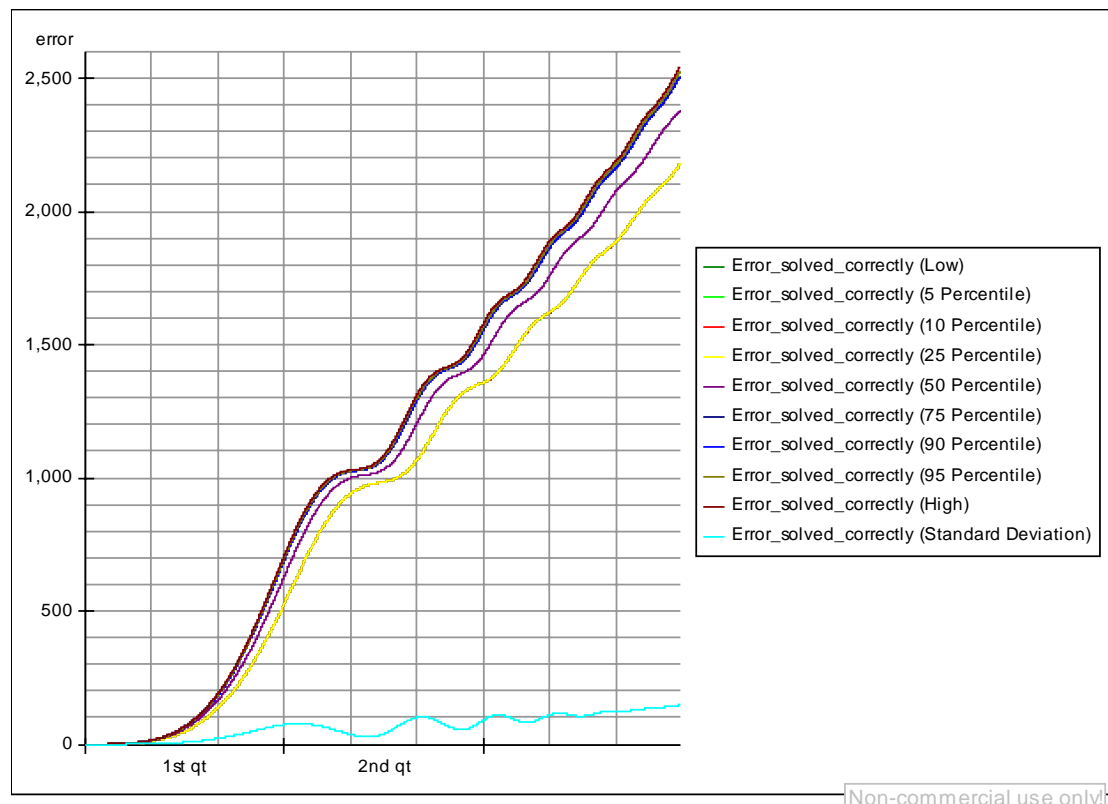
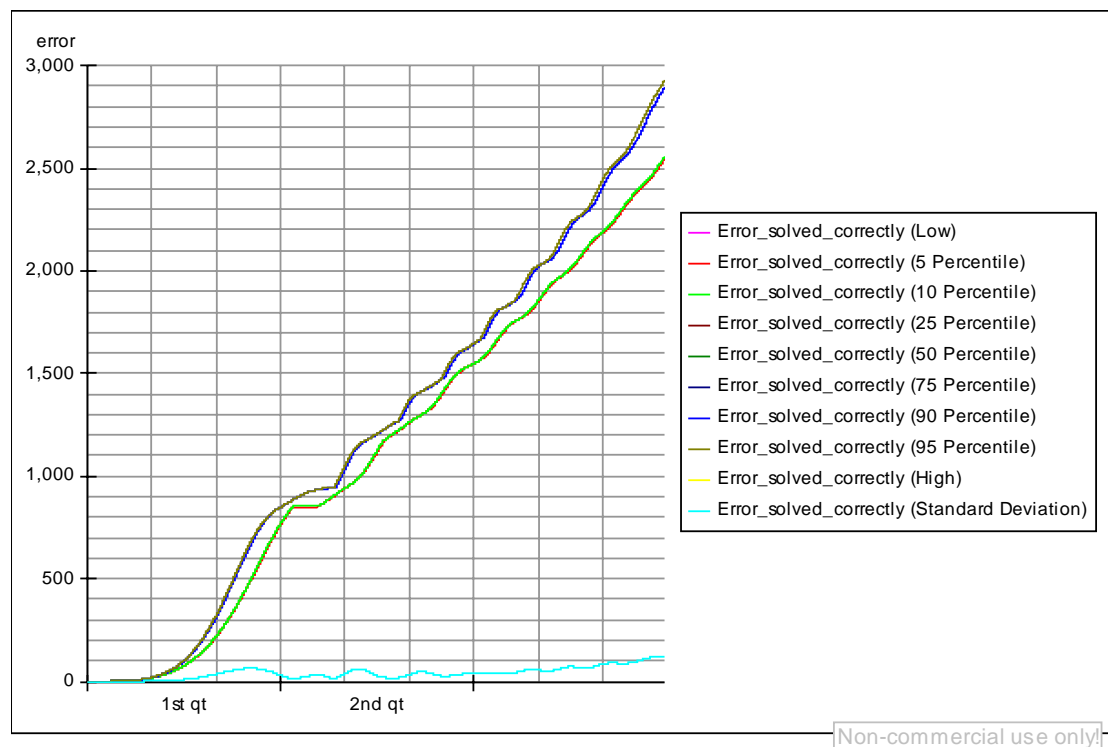


Figure 35 : Combined behaviour of category 2 factors

### 7.6.3 Category 3: factors with deviation between 15%-20% for high and low value

The only factor under this category is the number of phases. A drop in the number of phases to 4 phases will drop the value of correctly solved problems to 44%, while reducing more phases than that will reduce up to 55% only.

This may be, as mentioned before, that it impacts the frequency of quality control on the output of the construction documents process.



**Figure 36 : Category 3 factors combined behavior**



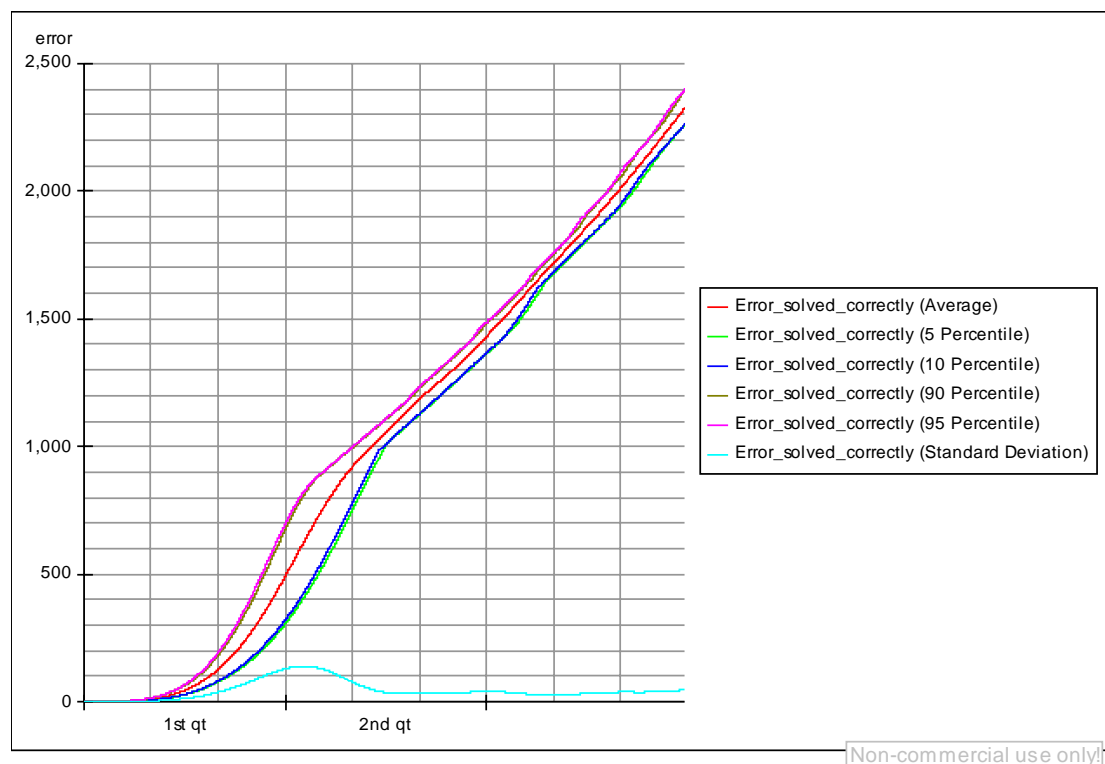
#### 7.6.4 Category 4: factors with deviation between 20%-25% for high and low value

The only factor under this category is the availability of information.

Using the model and changing the value of this factor shows that a drop of 5% in the value of the factor will impact on only 1% of the correctly solved errors, while a drop of 10% will influence only 3%, a drop of 25% will influence the model by 6% and a drop of 100% (lowest value) will impact the model by 66%.

This behaviour indicates a high impact of the factor on the model if the value drops more than 50%.

However, the analysis indicates that a drop of up to 30% in the value will result in a reasonable drop in the correctly solved problems,



**Figure 37 : Combined behaviour of category 4 factors**

### 7.6.5 Category 5: factors with deviation between 25%-30% for high and low value

The two factors under this category are availability of QA procedures and required time to produce a document. Using the model and changing the value of these factors shows that a drop of 5% in the value of the factors will impact on 3 and 5% of the correctly solved errors, while a drop of 10% will influence the impact by 5% and 10% consequently. A drop of 25% will influence 10% and 24% and a drop of 100% will impact on 81% and 96% consequently.

The noticeable behaviour is the change of the value of these two factors, even though they are in very close deviation: 26% and 28%.

However, the analysis indicates that a drop of 20% in the value of these two factors will result in a reasonable drop in the number of correctly solved problems.

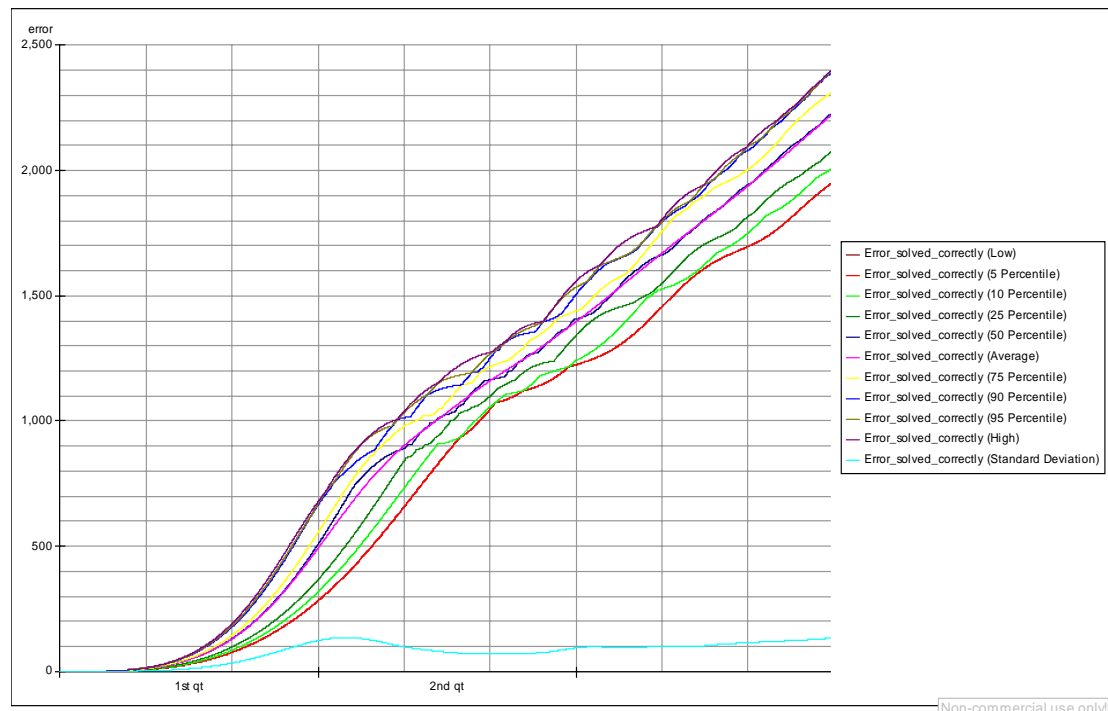


Figure 38 : Category 5 factors combined behaviour

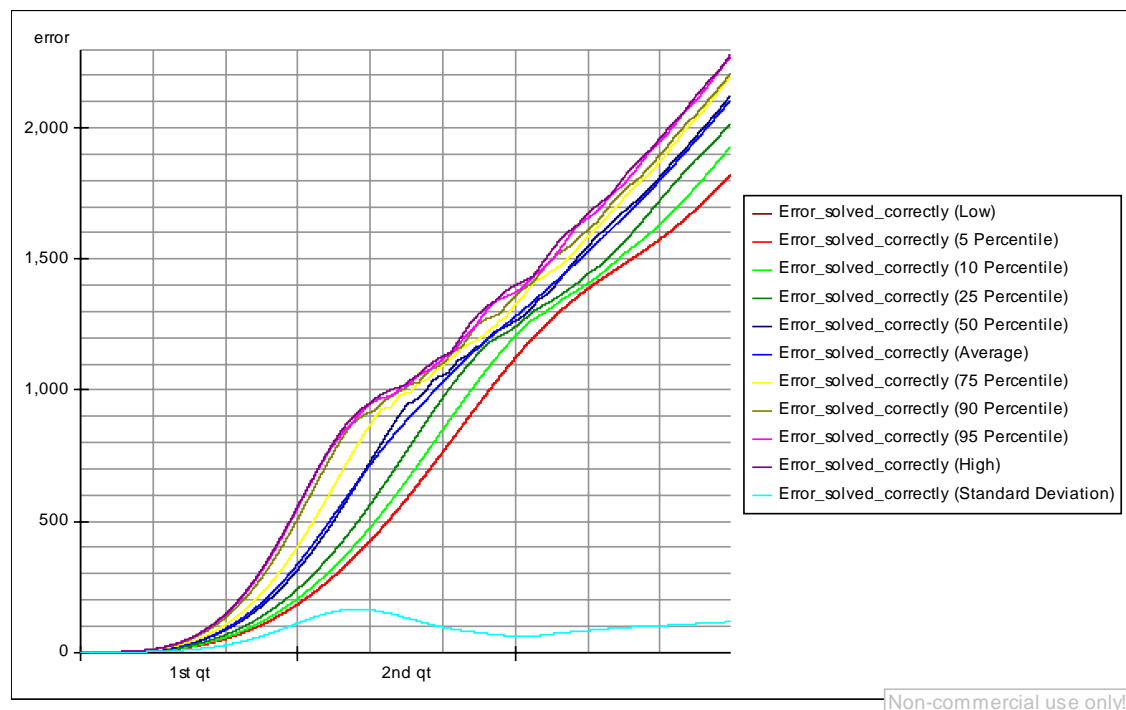
### 7.6.6 Category 6: factors with deviation between 25%-30% for high and low value

Category 6 factors are those factors that deviate from 25% up to 30% between low and high values. The factors under this category are

- Previous designer experience
- Designer education

The slight drop in the value of the factor (5%) will impact on the model in a 10% drop of the correctly solved errors, a 10% drop in value will impact on about 26%, while a big drop in the number of correctly solved errors will occur when a drop of 25% occurs in the value of the factor, while none of the errors will be solved correctly if the value of the factors is the lowest (i.e. 0).

However, the analysis indicates that a drop of up to 5% only in the value of these factors will result in a reasonable drop in the number of correctly solved problems.



**Figure 39 : Combined behaviour of category 6 factors**

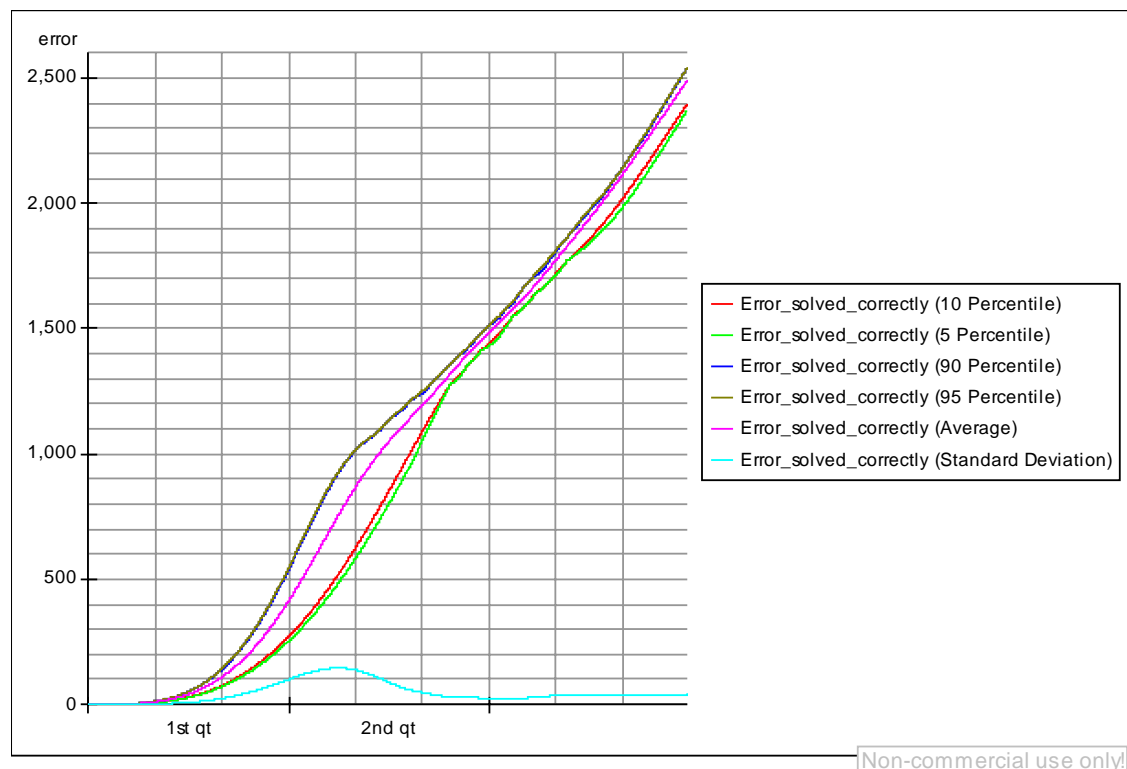
### 7.6.7 Category 7: factors with deviation between 30%-35% for high and low value

The factors under this category show different behaviours under different values of the factor. These factors are

- Experience of the designers
- Reputation of the designer

While a slight drop (5%) in the value of the factors will impact on only 2% of the model result, and a 10% drop will impact on 10% of the model result, a big drop will happen when the drop of 25% in the value of the factors occurs. Similar to the previous category, none of the errors will be solved correctly if the value of the factor is the lowest (i.e. 0).

However, the analysis indicates also that a drop of up to 5% only in the value of these factors will result in a reasonable drop in the number of correctly solved problems.



**Figure 40 : Category 7 factors combined behaviour**

### **7.7 Classification of sensitivity of the factors:**

From the above categorization, it is concluded that the factors show two types of behaviours. The first one is when the standard deviation of the factor is below 20% where the model shows reasonable behaviour up to a certain drop in the value of the factors. The other category is when the standard deviation is above 20% where the model is under full control of the value of the factor when the values of the factors drop below 10%.

From this conclusion it is possible to draw a scenario that allows a reasonable drop in some factors while fully making sure of preventing a drop in some other factors.

The first group of factors to allow a reasonable drop in their values are:

- Culture of the team
- Working hours per week per designer
- Procedure to produce documents
- Salary standard
- Match of the goals
- Number of phases

The contractual design time was dropped from this group, as discussed earlier.

The second group of factors that should be under firm control to prevent any drop in the value are:

- Availability of information
- Availability of quality assurance procedure
- Required time to produce a document
- Previous designer experience
- Designer education
- Experience of the designers with similar projects
- Factor of reputation of the designer

The factor of error caused by the interaction, number of documents produced, and number of disciplines, were all dropped from this list, as discussed earlier.

However, after further analysis of group 2 categories, it was concluded that the following are the most inflexible factors:

- Previous designer experience
- Designer education
- Experience of the designers with similar projects
- Factor of reputation of the designer

These factors do not accommodate a drop in their value of more than 5% to allow a reasonable drop in the number of correctly solved problems. Furthermore, a lack of these factors will mean a complete collapse in the system of solving problems correctly.

The following table summarises the above discussions:

Drop of value of correctly solved errors												
Group	Category	Legend	Factors	Devia /100p	100p - 5p	100p - 10p	100p - 25p	100p - 0p	5% drop	10% drop	25% drop	100% drop
Group 1	1	F12	Culture of team	6%	172	197	273	680	7%	8%	11%	26%
		F2	Working hour per week per designer	9%	65	127	295	872	2%	5%	11%	32%
	2	F7	Procedure to produce documents	12%	63	117	285	960	3%	5%	12%	40%
		F3	Salary Standard	12%	62	115	281	948	3%	5%	12%	39%
	3	F16	Match of the goals	12%	44	85	224	748	2%	5%	12%	40%
		F17	Contractual Design time	15%	1242	1635	2143	3305	28%	37%	48%	74%
Group 2	4	F6	No of phases	15%	588	1224	2327	2901	11%	23%	44%	55%
		F10	Availability of information	20%	33	64	147	1598	1%	3%	6%	66%
	5	F5	No of disciplines	26%	132	264	661	2597	4%	9%	22%	87%
		F11	Availability of quality assurance procedure	26%	71	127	242	1953	3%	5%	10%	81%
		F4	Required time to produce a document	28%	135	271	677	2694	5%	10%	24%	96%
		F1	Factors of error due to interaction	29%	120	241	604	2357	5%	10%	25%	99%
	6	F9	Amount of document produced	29%	205	400	922	2339	9%	17%	39%	98%
		F8	Previous designer experience	31%	246	632	1860	2429	10%	26%	77%	100%
	7	F14	Designer education	31%	246	632	1860	2429	10%	26%	77%	100%
		F13	Experience of the designers	35%	59	293	1386	2536	2%	12%	55%	100%
		F15	Reputation of the designer	36%	62	246	1001	2569	2%	10%	39%	100%

Table 4 : Grouping of factors as per sensitivity of the factors

## **7.8 Validating the findings of the research model for the most sensitive factors**

To validate the findings of the model and the above discussion, a series of case study projects were studied to verify the output of the simulation model.

The projects were selected pragmatically, as mentioned before, i.e. according to their availability. Eisenhardt (1989, p537) supports the use of cases that are polar or of a unique nature. Furthermore, he contends that cases that are selected randomly are considered to be neither necessary, nor even preferable.

The description of the project was given by the project manager and the people who were closely involved in the decision-making process of each project, It is important for the case study projects to be of similar nature; however, owing to the difficulty of obtaining such detailed information about projects of similar nature and conditions within the constraints of time and budget, the effect of the external factors on the case study projects was reduced by selecting a representative company of the Saudi designer offices, where case study projects can be accessed and personnel can be interviewed. This condition was necessary for two reasons; first; projects will be under similar levels of fees charged, reputation, classification, employee skills and types of projects handled, and second: projects will be under similar types of design management.

Based on the above conditions, one case study for each most sensitive factor was studied to validate the findings of the simulation model. However, owing to the difficulty of measuring all numbers of correctly solved errors in the given time, it was considered appropriate to study the case study data for the extreme conditions (failure to produce completely correct drawings to indicate the validity of model for that factor).

### **7.8.1 Lack of professional education**

As shown and discussed in the output of the model, lack of professional education can lead to total collapses in the system of solving the problems correctly while developing the construction documents.

As explained in the previous chapter, professional education is an input into the following factors:

- Design office ingredient



- Designer salary
- Effective design team
- Efficiency of production
- Knowledge pre exist
- Proper analysis
- Reputation of designer

and these factors influence many others.

### **Case study 1**

The design office was developing a multi-floor office building that consists of 3 floors of offices and 2 basements for car parking. As part of the work that is required to develop the concept design drawing, one architect (Architect A) was assigned to resolve the stairs of the building. The architect was appointed newly in the office; his CV showed 7 years of experience. The stairs were ordinary and required a series of calculations for risers and trade dimensions in coordination with the structure and the overall sections of the building. The architect failed to resolve the overall size of the stair's core and the location of openings to various floors.

Even though the architect has many years of experience, lack of proper professional education hindered him from proper thinking and logical sequence of developing the ideas. His work was reworked through another architect (Architect B) who has a similar number of years of experience but with more advanced and accredited professional education.

Good performance will not take place without proper and professional education/training to guide the architect systematically and in logical order.

Architect A hours	227
Architect B hours	97
Total hours	324
Year of experience of Architect A	7
Year of experience of Architect B	7

### **Types of errors: Designer errors**

Interdisciplinary coordination problems (Plans and Sections)

Disciplines coordination problems (Architecture and Structure)

**Stage of documents:** Preliminary documents

**Type of education of (Arch A):** 4 year Bachelor's degree from non-accredited university

**Years of Experience (Architect A):** 6 years

**Type of education of (Architect B):** 5 year Bachelor degree from an accredited university.

**Years of Experience (Architect B):** 6 years

**Discovery of the issue:** Claims from colleagues, senior architect review

**Consequence:** Rework

**Reason for error:** Lack of professional education

### **7.8.2 Lack of experience**

Existence of proper education is not enough to solve the problems that emerge while producing the construction documents, as shown in the output of the model: lack of professional experience can lead to total collapses in the system of solving the problems correctly while developing the construction documents. This output was also noted by Coles (1990): the use of technically inexperienced and/or unqualified staff leads to errors and omissions being made in contract documentation if such employees are not adequately supervised.

As explained in the previous chapter, experience is an input to the following factors:

- Reputation of designer
- Knowledge pre exist
- Design office ingredient

and these factors influence many others.

### **Case study 2**

This case study explains the situation concerning lack of experience in one of the team members.

The office was approached by one of its regular clients to design a private villa that was designed for him by a famous architect. The office, as part of its marketing strategy with the client, agreed a low fee for developing the construction documents.

The office decided to handle the project through one of its junior architects (Architect A). The architect has a bachelor's degree from a reputable and accredited university within the region. He had worked in the office for the previous three years, developing small details of various projects under the full supervision of senior architects. The young architect started working on the project and developing the concepts of plans, elevations, sections and details and coordinating the various engineering system. As the work was progressing, many claims were raised to the project manager regarding the delay in producing documents and incorporating the engineers' requirements into the design. The project manager, by way of encouraging the young architect, set the priorities for the young architect for developing the documents to cope with the requirements of different disciplines. After periodical reviews of the document, the project manager realized that the progress of the project was very slow and a lot of time was being consumed for the project without adequate progress in the production of the construction documents. The project manager appointed another more senior architect (Architect B) to develop the documents of the villa. The review of the documents produced so far in the project revealed serious errors in the documents, interdisciplinary coordination issues, discipline coordination issues and missing details in various parts of the project. The documents were reworked in various parts and the errors were corrected. The project ran out of its budgeted hours and expenditure and there was a delay in the submission of the documents.

Architect A hours	220
Architect B hours	178
Total hours	398
Years of experience of Architect A	3
Years of experience of Architect b	8

**Types of errors:** Missing information

- Designer errors
- Unsolved problem
- Coordination between disciplines

Interdisciplinary coordination among plans, elevations, sections and details

**Stage of documents:** Construction documents

**Consequence:** Rework

Financial loss to the design office

Time delay

**Discovery of the issue:** During periodical review of the documents.

**Reason of error:** Lack of experience

**Original time of the project:** 4 weeks

**Time delay in the submission:** 4 weeks

### **7.8.3 Lack of good reputation of the design office**

The existence of proper education and experience is not enough in preventing errors, if there is no willingness to maintain a good reputation for the office, as exhibited in the model of the thesis. However, it is important to mention that reputation is a factor of designer education, as is a designer experienced with similar projects, previous designer experience and the factor of reputation.

As explained in the previous chapter, the factor of reputation is an input to only one factor:

- Reputation of designer

But the reputation of the designer affects many other factors such as:

- Quality of work
- Probability of error
- Number of designer availability factor
- Design management
- Design fee required
- Design fee factor
- Design fee available

And these factors influence many others and so on.

### **Case study 3**

Some foreign companies come to Saudi to earn money quickly without taking care of keeping good records in the market. The other reason for this is that the current

situation in Saudi construction does not require professional indemnity insurance which would hold the designer responsible for any fault on his part.

The client approached the first design office for the development of a concept design for a complex of hotels, shopping mall and residential apartments of various sizes. The office got the project through personal contact with the owner. The main designer of the office had graduated from a reputable university in the USA. The office work strategy entails getting the project, preparing some documentation, and obtaining high fee compensation. The office is not concerned with building long relationships with clients through the production of high level quality documents. The design office prepared the documents and handled them to the client to pursue the approval from different authorities. The local planning office requested the review of registered and qualified offices as per their regulations. A second good reputable office (case studies office) was approached for reviewing the documents. The review revealed problems in interdisciplinary coordination, violation of municipal regulations, violation of safety codes and designer errors. The second office, in coordination with the client, reworked the documents and corrected all the errors revealed in the review.

**Types of errors:** Missing information

Designer errors (floor height)

Unsolved problems

Coordination between disciplines (column location, mechanical shafts)

Interdisciplinary coordination among plans, elevations, sections and details

Violation of code for safety

**Stage of documents:** Preliminary design documents

**Consequence:** Rework

Financial loss to the client following delay of project

Time delay

**Discovery of the issue:** During municipal review of the documents.

**Reason for error:** Lack of good reputation

#### **7.8.4 Lack of experience with similar projects**

As discussed in the output of the model, lack of experience in similar projects can lead to total collapses in the system of solving the problems correctly while developing the construction documents.

As explained in the previous chapter, lack of experience is an input into the following factors:

- Reputation of designer
- Design office ingredient
- Designer salary
- Effective design team
- Proper analysis
- Knowledge pre exist
- Designer experience
- Efficiency of production

and these factors influence many others.

#### **Case study 4**

The project comprised the designing of four TV studios with associated spaces of control rooms, editing suits, workshops and broadcasting facilities, rentable office spaces, multipurpose hall, media training centre and business centre in Riyadh, Saudi Arabia. The mechanical department engineers stated their capability in designing the HVAC system of the project, based on their long experience of designing various projects in the past (none was TV studio related). After developing their drawings which were checked by the department head, who has extensive experience in designing HVAC system, but again none was TV studio related, the drawings were sent to the studio consultants of the project to coordinate their requirements with the HVAC design; he showed some concern and suspicions regarding the system. The system was passed on to the TV studio HVAC specialist consultant for review and advice. He pointed out serious problems in the design of the HVAC systems, the selection of appropriate equipment that maintains the noise and vibration noise, calculations and layout perspectives. The design of the HVAC system had to be reworked completely from scratch. The whole effort and cost were wasted, there was

delay in the submission of the project and a bad image was presented to the client.

The following table summarizes the case study data:

HVAC design hour	873 hr	
HVAC CADDing	712 hr	
Total hours	1585 hr	
Number of personnel	4	
Years of experience of the main designer	21 years	
Cumulative years of experience	45 years	

The findings of the case study confirm the finding of the model that, in spite of good standing in other factors, serious and major errors will not be prevented in the construction documents if there is lack of knowledge with similar projects in the past.

**Nature of project:** Special

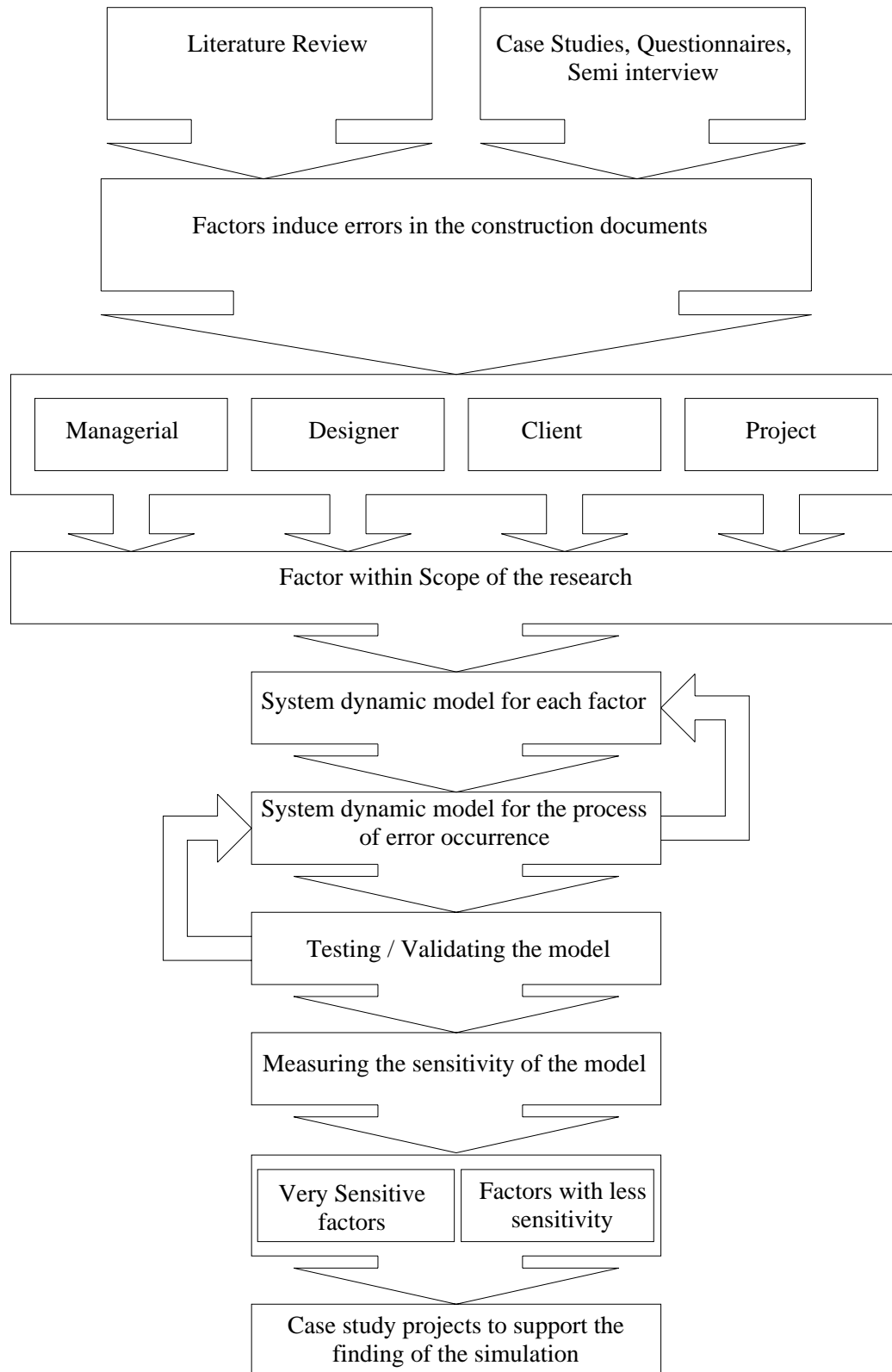
**Experience in TV studio:** 0

**Nature of errors:** Designer error

**Reason of error:** Lack of experience with similar projects

**Who discovered the errors:** An external auditor.

The following chart (Figure 41) summarizes the road map of how the research was developed from the early analysis of literature review, case study projects and interviews. The diagram indicates also the role of the case study projects to support the finding of the model proposed for the research, which explains the relationship between various factors that induce the occurrence of errors in the construction documents and existence of errors in the construction documents.



**Figure 41 : Road map of the research findings**



## 7.9 Summary

It is difficult to say that the model is "correct" or even finished, so no models are valid or verifiable in the sense of establishing their truth. The question facing modellers is never whether a model is true but whether it is useful. The choice is never to use a model but which model to use. Selecting the most appropriate model is always a value judgment to be made by making reference to the purpose. Without a clear understanding of the purpose for which the model is to be used, it is impossible to determine whether it should be used as a base for action or not. The research model was validated on this base structurally and behaviourally using the recommended tests.

Further behaviour analysis of the model identified factors that stimulate the occurrence of errors which have relatively large or little influence on model behaviour. The analysis showed two types of behaviours. The first one is when the standard deviation of the factor is below 20% where the model shows reasonable behaviour up to a certain drop in the value of the factors. The second category is when the standard deviation is above 20% where the model is under full control of the value of the factor when the values of the factors drop below 10%.

Among group 2 factors, the most serious factors that affect the generation of errors in the construction documents are previous designer experience, designer education; experience of the designers with similar projects and factor of reputation of the designer. These factors should be taken into consideration when preparing for the production of the construction documents. The findings of the model were supported by case study projects for each one of these factors.

8.1	Introduction.....	360
8.2	Recapitulation .....	360
8.3	Determination of research hypothesis validity .....	361
8.4	Major findings and discussions.....	362
8.4.1	Source of errors in construction documents.....	362
8.4.2	Major sources of errors in construction documents.....	363
8.4.3	Errors in construction documents can be managed.....	363
8.4.4	The role of construction documents in project behaviour .....	364
8.4.5	The role of nonlinear relationships, feedback, and delays in project behaviour.....	364
8.4.6	Project constraints.....	364
8.4.7	System dynamics as a tool for research projects .....	365
8.5	Contributions.....	365
8.5.1	A new research tool .....	366
8.5.2	A new tool for practitioners and construction document production insights .....	367
8.5.3	Improved understanding of tangible and intangible factors .....	367
8.5.4	Improved understanding of the error occurrence structure and relationships .....	368
8.5.5	Improved understanding of consequences of decisions over time.....	368
8.6	Limitations of the research.....	369
8.7	Future research.....	371
8.8	Conclusions.....	371

## **8.1 Introduction**

System thinking requires both understanding that "we can never say that the model is "correct" or even finished and humility about the limitations of our knowledge. Such humility is essential in creating an environment in which we can learn about the complex systems in which we are embedded and work effectively to create the world we truly desire" (Sterman, 2002). However, while a model captures only a small portion of the complexity of any real multi-product development environment, the features represented capture an important set of dynamics that play a critical role in determining an overall error occurrence system in construction documents.

The research has proved that factors that stimulate errors while producing construction documents can be modelled. The model of the research can be used to reduce / eliminate the occurrence of errors through understanding the behaviour of the most influential factors that induce the occurrence of errors in construction documents.

## **8.2 Recapitulation**

Successful production of construction documents is critical to competitiveness in the construction industry. Changing competitive forces such as increased project sophistication and accelerating technology are increasing the difficulty and leverage of managing the production of construction documents. Successful management of these projects requires the understanding and use of the dynamics of projects. A dynamic simulation model was built using the system dynamics methodology. Out of 39 factors identified influencing the occurrence of errors in the construction documents, the research model integrates 24 internal factors that stimulate the generation of errors in construction documents. The simulations describe the behaviour generated by the interaction of these factors. Model simulations indicate that the factors can be classified mainly into two categories. The first one includes the factors where the model shows reasonable behaviour up to a certain drop in the value of the factors; among these factors were: culture of the team, working hours per week per designer, procedure to produce documents, salary standard, match of the goals and number of phases. The second category is where the model is under full control of the value of the factors when the values of the factors drop below 10% of its optimum

value. Among the most sensitive factors of the model were: previous designer experience, designer education, experience of the designers with similar projects and factor of reputation of the designer. The model structure helps explain the causes of this behaviour.

### **8.3 Determination of research hypothesis validity**

This section revisits the research hypotheses presented in Chapter one. Each is considered in turn, and the extent to which the research study accepted or rejected its validity is summarized.

#### **Hypothesis One:**

The research model accepted the first hypothesis: "Reduction in the amount of errors will follow when the design management of projects gives greater emphasis to removing the causes of problems rather than trying to counteract the symptoms".

The series of models built showed that removal of the cause of errors will reduce/eliminate the occurrence of errors in construction documents. In particular, great attention should be directed to the sensitive factors in which a slight change in their value will have a significant impact on the number of correctly solved errors, i.e. previous designer experience, experience of the designers with similar projects and factor of reputation of the designer. This hypothesis was also supported by the case study projects.

#### **Hypothesis Two:**

While recognizing the fact that models capture only a small portion of the complexity of any real environment and are simple representations of the real world, the research supports the acceptance of the second hypothesis: "Factors stimulating errors in the construction documents can be mapped". The model and relationship estimated between factors and the complex interaction of different factors and the validated behaviour of the model presented in this research also support the hypothesis. The output of these maps can be utilized to produce archetypes that illuminate the structures and behaviours behind the occurrence of

errors for the purpose of reducing/eliminating errors while producing the construction documents".

This hypothesis was supported by Sterman (Sterman, 2000) who stated that causal loop diagrams can be used as a quick capture of the hypotheses concerning the cause of dynamics.

### **Hypothesis Three:**

The research supports the acceptance of the third hypothesis. Out of 39 factors influencing the occurrence of errors in the construction documents identified in the research, 24 factors were used to build up the research model, owing to the complex nature of the factors that stimulate the occurrence of errors in the construction documents. Using the model, the research was focused toward finding the internal factors that could be controlled by the party producing the construction documents.

## **8.4 Major findings and discussions**

The major findings of the research are:

### **8.4.1 Source of errors in construction documents**

Within the scope and limitation of the current research, use of the model of the thesis showed (Chapter 6) the following factors as the source of errors in construction documents, with varying degrees of influence:

- Culture of the team
- Working hours per week per designer
- Procedure to produce documents
- Salary standard
- Match of the goals
- Number of phases
- Availability of information
- Availability of a quality assurance procedure
- Required time to produce a document
- Previous designer experience

- Designer education
- Experience of the designers with similar project
- Factor of reputation of the designer

Understanding how each of identified factors influence the occurrence of errors while producing the construction documents and differentiate between symptom and real cause is an important step that could help professionals to control / eliminate the occurrence of errors in construction documents.

#### **8.4.2 Major sources of errors in construction documents**

As has been proved by the model constructed by the thesis and validated by the case study projects (Chapter 7), the following factors are the major sources of errors in construction documents:

- Previous designer experience
- Designer education
- Experience of the designers with similar projects
- Factor of reputation of the designer

The research draws the attention of professionals to these important factors. These factors could be a major source of errors in the construction documents which should be addressed and handled with great care in projects.

#### **8.4.3 Errors in construction documents can be managed**

Despite the fact that some of the factors that stimulate occurrence of errors are a combination of "soft" and "hard" factors, the research managed to prove, at least theoretically, that management of errors in construction documents is possible (Chapters 5, 6 and 7). As has been shown in the model description, the generation of errors in the construction documents can be controlled to a large degree by knowing which factors have a great impact on the stimulation for generation of errors while producing construction documents. Proper monitoring of these factors might be crucial for this type of problems.

#### **8.4.4 The role of construction documents in project behaviour**

The complex relationship between factors, as described in the thesis, indicated that small drop in the value of certain factors beyond their optimum values will have a tremendous effect on the quality of the construction documents. Maintaining the quality of the construction documents, as discussed in Chapter 1, is a major component in controlling the variations of construction projects. Therefore, controlling the factors identified through the thesis during the production of construction documents will help in controlling the behaviour of the project at later stages.

#### **8.4.5 The role of nonlinear relationships, feedback, and delays in project behaviour**

The research shows that several of the important relationships which drive the behaviour of the project, in particular the relationships that describe the generation of errors in construction documents such as quality of work, rate of coordination, rate of communication etc. as discussed in the model description, are nonlinear (Chapter 6).

The research also shows that projects have many potentially important feedback loops. Some are closed loop flows of work or errors in which components of the project leave a position or condition in the project through the development work and return to the condition for a repeat performance of the development work. Many other potentially important feedback loops return information about project conditions for use in decision making. These feedback flows of work, errors, and information are dynamic and critical to describing the causal relationships within a project which drive behaviour.

The construction document production process does not move instantaneously or without bias. Understanding the size and character of the delays that alter these flows is important in relating project structure to behaviour; such delays are like start of "quality assurance and coordination". Changing those delays can be a potentially effective tool for improving project performance.

#### **8.4.6 Project constraints**

Some factors of the model interfere with many other rate and auxiliary factors. Because of this, the research shows that development of construction documents has many constraints on their behaviour which resist adjustment in the performance of the

model. The most influential factors, as discussed in Chapter 7, are those of Category Two factors such as education, experience, etc.

Another partial explanation is that the size of the system is limited by the number of documents produced which limit the available tasks in the model as well as the contractual time available to solve the tasks of the model. These constraints will be partially released only if errors are discovered by the model; then the limit of the model will be extended to accommodate these extra erroneous tasks.

#### **8.4.7 System dynamics as a tool for research projects**

There is a gap between the primary methods currently used to describe, model, communicate and manage projects and the complexity of the structures which drive the behaviour of those projects. Many project models do not include the impacts of feedback, delays and nonlinear relationships in the evolution of a project. Current project management practice is based on open loop, single link linear causal relationships which can be, and often are, reduced to lists of rules-of-thumb guidelines (Ford, 1995, p295). These tools are incapable of capturing the dynamic project behaviour, as discussed in Chapter 3.

Based on this argument, the system dynamics methodology and its adjacent tools such as causal loop diagrams can describe project complexity. The research indicates that the system dynamics methodology is a potential tool for bridging the gap between current project tools and project complexity. It has proven itself successful as a tool for investigation and learning. It may be proper to conclude that using system dynamics to describe project complexity will increase the demand for explanatory and management practice tools.

### **8.5 Contributions**

Simulation has been used with considerable success in a variety of applications in construction management. The verdict is the same: improved understanding of the decisions increases the success rate. Using simulation as part of the decision support process may improve the understanding of many important aspects, described hereafter.



### 8.5.1 A new research tool

The error model presented in this research provides a first attempt to integrate into a testable framework the error-solving and generation process. The model represents descriptions of how different factors interact to impact dynamically the production of construction documents. The model does this by integrating many project factors into a single project model, introducing and testing several new dynamic project structures and building a flexible project model.

The new structures include:

- Explicit and separate descriptions of the factors that stimulate the occurrence of errors in the construction documents process, including:
  - The available work relationship describing constraints of the project, such as number of documents to be produced and contractual design time.
  - An explicit description of how each factor impacts on the process of producing the construction documents.
  
- Explicit loop flows of correct and defective tasks

This model contributes an explicit stock of work solved correctly owing to the ingredient of the design office, work waiting to be checked and work waiting to be corrected.

- Co-flow structures for correct and defective tasks.

This allows more explicit and detailed modelling of the causes of error generation and discovery, and their impact.

- Generic project structure

A flexible project model structure allows the modelling of many different types of projects.

### **8.5.2 A new tool for practitioners and construction document production insights**

The insights described in the model description chapter (Chapters 5 and 6) are a major contribution of this research. They illustrate the need for tools which facilitate the expansion of project models by practitioners to include dynamic issues. The model of error occurrence in the construction documents created by this research is one such tool. The model can help practitioners further reduce the occurrence of errors by improving the understanding of project dynamics in several ways:

- The model can be calibrated and used to improve understanding of the impacts of specific project factors on project performance.
- The model could be the basis for the development of improved project management heuristics which consider the dynamic impacts.
- The model can be used to investigate the generic impact of project structures and changes in the development of construction document management parameters.
- The model can be revised to focus on a specific type of dynamic behaviour and developed into a "management simulator" suitable for facilitating learning about the dynamics of projects by the project team managers.
- The simulation model may serve different purposes within the project team. It can be used as a communications tool, helping the team in conveying the strategies to other team members or stakeholders. It may be used as a training tool for the employees, helping to build their knowledge of how the construction document processes work, or it can continue to be developed to deal with more specialized problem definitions.
- After implementing strategies in the real-world system, the results should be checked towards the simulation. If the examination shows that the model behaviour and prediction were not satisfactory, the inner modelling loop will be checked and further experiments with the research model will be carried out before implementing new strategies.

### **8.5.3 Improved understanding of tangible and intangible factors**

The description of the model and estimation of the relationships among factors that stimulate the occurrence of errors in construction documents are a step toward an improved understanding of the role of tangible and intangible factors. We should not

be looking at just the "hard" facts, to include also "soft" parameters, such as culture of team, level of knowledge and experience, employee morale, and so on. It is important to understand the relationships between "soft" and "hard" factors to be able to understand how the occurrence of errors behaves over time. Investment in staff training in the company will be reflected in the ability to support the development of high quality documents, which in turn affects the ability to improve the productivity, which in the end improves the results and the profile of the company. Both tangible and intangible factors can easily be visualized and included in the research simulation model.

#### **8.5.4 Improved understanding of the error occurrence structure and relationships**

Many companies across the world have invested large amounts of money in improved quality control systems, organizational insight, competitive analyses, and the like. Large investments have been made in quality certification systems, and less attention has been paid to identifying the structures that drive these parameters and how they influence other parts of the organization. Gaining awareness about how the system is built up and how it works will help us to avoid solutions that only treat the symptoms of an underlying problem without curing the problem itself.

Through the model and its simulation and description, the identification and building of such relationships have in themselves improved the understanding of the structures within the consultant offices. It enables the consultants to think more about the cause and effect relationships that exist within their control to avoid placing blame in favour of finding the true long-term solution to a problem.

#### **8.5.5 Improved understanding of consequences of decisions over time**

The decisions made today will have an impact on the documents produced over time, but have all the cascading effects of the decisions on the short, medium, and long term been properly analyzed? Many companies have experienced a short-term gain from a given decision, but realized, sometimes too late, the devastating consequences in the longer run. For example, the consequences of the work of non-experienced staff on the quality of construction documents were shown in the project. Using the research model and simulating the decisions will allow the company to test their strategies in a

safe and secure environment, and to analyze the relationships between the functional areas that drive the company into the future.

## **8.6 Limitations of the research**

This is the art of modelling: it is subjective and in the end it is difficult to say that the model is "correct" or even finished. It is simply one representation of reality, built to explain a particular problem. We may find that we learn more in the process of creating the model than in manipulating it after it is finished. As the model is designed and built to represent a class of problems (occurrence of errors in the construction documents), the variety of projects within that class will always require model calibration to reflect specific projects realistically. The limitations of the model specified in this thesis suggest important issues for the broader application of the model and its underlying concepts within the class of development projects.

- Most significant, as mentioned above, the proposed framework represents an abstraction from the details of a real construction document production process. Interactions were assumed between disciplines only and the interactions between the disciplines themselves were not considered. All the components of a specific product were aggregated into a single category, "task"; and the myriad activities required to create a product are considered simply "solving problems". Nevertheless, while the model is exceedingly simple, relaxing some of its most extreme assumptions would likely strengthen rather than weaken our main conclusions.
- Similarly, only one type of resource was considered, "people", explicitly accounting for a range of capabilities and solving many problems that do not fall into the domain of a single expertise. The argument is similar to that made above.
- Data deficiencies: no numerical data were available for many of the variables used in the model; instead most of the data collected and used for building the model's relationships and validations were qualitative and limited to a limited number of experts (11 experts) in the field and a small number of case study projects (not significant statistically). While using such an approach was supported by pioneers of the system dynamics fields (Forrester, 1961; Vennix

et al., 1992; Sterman, 2000), the argument is that omitting variables known to be important because numerical data are unavailable is actually less scientific and less accurate than using limited expert judgment to estimate their values. "To omit such variables is equivalent to saying they have zero effect – probably the only value that is known to be wrong" (Forrester, 1961). It is believed that using more significant data or more statistical parameter estimation and numerical data would likely strengthen rather than weaken our model and main conclusions. The quantification of soft variables often yields important insight into the dynamics of a system (Sterman, 2000, p854).

- The model does not consider the errors which stem from ignorance, fraud and negligence. Such limitation was emphasized in other research (Andrew, 1996; Rollings et al., 1991; Kletz, 1985)
- Model size: the size and resulting complexity of the model will tend to increase as the model is applied to every type of error identified previously.
- Impact on each type of error. Owing to the above limitation, the model does not explain the impact of each factor on the individual type of errors, as discussed in the type of errors occurring chapter (Chapter 4).
- Level of detail: in order to focus the model on the research objectives, some assumptions are made, such as start-up of quality assurance and start-up of the tasks, as discussed in the model description chapter (Chapter 6). These assumptions need to be validated and tested.
- Model boundary: the model boundary has been limited to the design office, as the staff there are concerned with the production of the construction documents. However, it will be more appropriate if the dynamics of factors related to the clients, project management, and project uniqueness are included within the model boundary.
- Organizational and development culture boundaries: producing construction documents for projects which span organizational and cultural boundaries can generate issues concerning how the different organizations and cultures interact. These are not addressed here, but can be very important and should be considered in the application of the model to projects with significantly different or separate organizations and cultures.
- Environmental change: even though "peace of change" was included in the research model, changes in the project environment can also be a significant

factor in the occurrence of errors in construction documents. Technology development and competition among projects for resources may require additional model structures or special attention to model data.

### **8.7 Future research**

The finding and limitations of this work point to potentially valuable extensions. They include the following investigations:

- Add the interactions between the disciplines themselves, such as coordination between different parts of the same discipline, e.g. plans, elevations, sections and details.
- Relax the model boundary assumptions to include multiple projects, environmental changes, etc.
- Add model structures to internalize currently exogenous inputs, such as clients, project management and project factors, to the model.
- Increase the level of details, by further study of the assumptions included in the model, because these assumptions may reveal and force the model to behave differently.
- Use more statistical data to estimate parameters and assess the ability of the model to replicate historical data when numerical data are available.
- Most businesses will go through a constant development, and new challenges will constantly be met, requiring new strategies to be made and implemented. Keeping the simulation model up-to-date with regard to new markets, competitors, organization changes and so on, allows design offices to keep a decision support tool fully functional at any time.

### **8.8 Conclusions**

This research addressed the important issue of the cause of errors while producing construction documents by building, testing and applying a dynamic simulation model. Nonlinear relationships, feedback and delays were found useful in describing the drivers of dynamics behaviour. The concept of error-solving as a set of interactive demand-driven activities was used to build rich descriptions of causal relationships using prior theoretical knowledge extracted from the literature, case study projects, and depending on the experience of people interviewed.

This model can be used as a valuable tool in communicating the impacts of complex structures on the behaviour of errors in construction documents. The development of new or improved tools for communicating and management is also expected to be essential in translating improved knowledge and understanding into enhanced project performance.

This research has contributed insights concerning the dynamics of projects, a tool for future research and a tool for improving the understanding of the occurrence of errors in production of construction document. This work has created opportunities for expanding the study of project dynamics in several potentially valuable directions.

This research points to ways of improving performance through improved understanding of the structure of the occurrence of errors in construction documents. Future research will expand and refine the understanding and use of dynamics to improve the efficiency and performance of projects in the construction industry.

## References

---

### References:

1. Abdel-Hamid T.K., (1989), The dynamics of software project staffing, A system dynamics based simulation approach, IEEE transactions in Software Engineering, 15, 109-119
2. Abolnour, M.M., (1994), The Relationship of Fee Structure in Engineering Offices and Design Deficiency. MSc dissertation, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.
3. ACSNI, (1993), Advisory Committee on the safety of the nuclear installations – Study group on human factors, Third report: Organizing for safety, HMSO, London
4. Arditi, D, Elhassan, A and Toklu, Y. C., (2002), Constructability analysis in the design firm; Journal of Construction Engineering and Management Vol 128 No 2 pp 117e126
5. Agar, M.H. (1986), Independents Declared, Smithsonian Institution Press, Washington, DC.
6. Aggarwal, R. and Rezaee, Z., (1996), Total quality management for bridging the expectations gap in systems development; International Journal of Project Management, 14 (2,) April 1996, 115-120.
7. Ahmed SM., (1999), Risk management trends in Hong Kong construction industry: a comparison of contractors and owners perceptions. Engineering, Construction and Architectural Management 1999;6(3):225–34.
8. Ahuja, (1980), A Successful construction cost control, Woly, New York.
9. Al-Ghafli, M., (1995), Delay in Construction of Public Utility Projects in Saudi Arabia. MSc dissertation, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.
10. Al-Subaie, O.S., (1987), Construction Claims in Residential Houses in Saudi Arabia. MSc dissertation, King Fahd University of Petroleum and Minerals, Dharan, Saudi Arabia.
11. Ana Cristina, John K., Martin E. and Arto K., (2004), Building a project ontology with extreme collaboration and virtual design and construction, Advanced Engineering Informatics, V. 18, 71-83



## References

---

12. Andersen DF and Rohrbaugh JW, (1992), Some conceptual and technical problems in integrating models of judgment with simulation models, *IEEE Transactions on systems, Man and Cybernetics* V22 (1)L 21-34
13. Andi and Takayuki Minato, (2003), Design documents quality in the Japanese construction industry: factors influencing and impacts on construction process , *International Journal of Project Management*, Volume 21, Issue 7, October 2003, Pages 537-546
14. Andi and Takayuki Minato, (2003a), Representing causal mechanism of defective designs: a system approach considering human errors, *Construction Management and Economics*, (21) 297-305
15. Andrew Atkinson, (1996) Human error in the management of building projects, *Construction Management and Economics*, V16, 339-349.
16. Andrew N., Simon A, Tarek H., Antony T., (1998), Planning building design by simulating information flow, *Automation in Construction*, V. 8, p149-163
17. Anon, (2000), Impossible to be built design drawing. *Nikkei Construction*; 253:60–85 [in Japanese].
18. *The Architect's Handbook of Professional Practice* (1994), AIA, 12<sup>th</sup> Edition, AIA Press.
19. Arild, Sigurdson (1996), Principle errors in capital cost estimating work, *Project Management Journal*, Sept 1996 issue, pp 27-34
20. Arthur, D.J.W. and Winch, G.W., (2005) Extending model validity concepts and measurements in system dynamics. *The 23rd International Conference of the System Dynamics Society* July 17-21, 2005 Boston.
21. Asad S. and Dainty A. (2005). Job Motivational Factors for Disparate Occupational Groups Within The UK Construction Sector: A Comparative Analysis. *Journal of Construction Research*, Vol. 6, No. 2, 223–236.
22. Ashworth A., (1994), *Cost Studies of Buildings*,
23. Atkins, L., Undated, *Causal Modeling*, Open University Course, Block Seven, Part 3,OU Press.
24. Barlas, Y. and Kanar K.(1999), structure-oriented Behaviour Tests in Model Validation, *Proceedings of the 4<sup>th</sup> Systems science European congress*, Valencia, Spain, pp 269-286
25. Barlas, Y. (1996) Formal Aspects of model Validity and validation in system dynamics; *System Dynamics Review*; V12 (3):193-210

## References

---

26. Barlas, Y. (1989). Multiple tests for validation of system dynamics type of simulation models. *European Journal of operational research*. V42 (1) : 59-87
27. Barnes M. (1989), 'Construction Project Management', Proceedings of a conference held at the Regent Crest Hotel London, 30 June 1989 for the Association of Project Managers.
28. Barnes M. (1987), A new style contract for engineering projects: summary of a specification prepared for the Legal Affairs Committee of the Institution of Civil Engineers, Martin Barnes Project Management, UK.
29. Barnett A.M. (1988/9), 'The many guises of a project manager', *Australian Institute of Building Papers*, vol. 3, pp. 119-134.
30. Bendell, A., (1988), "Introduction to Taguchi Methodology", *Taguchi Methods: Proceedings of the 1988 European Conference*: , Elsevier Applied Science, London, England, pp. 1-14.
31. Bennett J. (1993), 'Japan's Building Industry: The New Model', *Construction Management and Economics*, vol. 11, no. 1, pp. 3-17.
32. Berkeley D., Humphreys P.C. & R.D. Thomas, (1991), 'Project risk action Management', *Construction Management and Economics*, vol. 9, pp. 3-17.
33. Bernard R. (1999), *Social research methods : Qualitative and quantitative approaches*, Sage :Newbury Park
34. Bersne, M.J. (1986), A study of forms of project organization and matrix management: Case studies from the construction industry, PhD thesis, University of Nottingham, UK.
35. Best, R. and Valance, G., (1999), *Building in value, pre-design issues, Arnold and the contributors*, London, UK.
36. Blockley, D.I. (1992), *Engineering Safety*. McGraw-Hill, New York.
37. Bresnen M.J. & Haslam C.O. (1991), 'Construction industry clients: a survey of their attributes and project management practices', *Construction Management and Economics*, vol. 9, pp. 327-342.
38. Bresnen M.J., Haslam C.O., Beardsworth A.D., Bryman A.E. & Hell E.T. (1988), 'Performance on site and the building client', *Occasional paper no. 42*, Chartered Institute Of Building, Ascot, UK.
39. Brown, A.W. (1996), A Causal path model to measure project management performance in public sector building projects in Scotland, PhD thesis, Napier University Edinburgh, UK.

## References

---

40. Brown C, Beaton H., (1990), " Looking back at design, looking forward to construction", ASCE Journal of management Engineering, vol. 6(3), pp 342-349
41. Brown, L., Henry, C., Henry, J. and McTaggart, R. (1982) 'Action Research: Notes on the National Seminar', Classroom Action Research Network Bulletin 5: 1–16.
42. Brewer, J. & Hunter, A. (1998). Multimethod research: A synthesis of styles. Newbury Park, CA: Sage.
43. Brunsson, N., (1993), The Irrational Organization, John Wiley, Sons, Chichesters, London
44. Bubshait A., Al-Said F., Abolnour M., (1998), Design Fee Versus Design Deficiency, Journal of Architectural Engineering, V4 (2), 44-46
45. Building Research Establishment (1981). "Quality control on building sites". Current paper 7/81, Garston, UK.
46. Burati, J. L., Farrington J.J. and Ledbetter W. B. (1992), Causes of quality deviations in design and construction. ASCE Journal of Construction Engineering and Management, 118 (1), 34-49
47. Burns R. (2000), Introduction to research methods, SAGE Publication.
48. Busby, J. S., (2001), Error and distributed cognition in design, Design Studies, V 22 (3),p233-254
49. Business Council of Australia (1993a), Case Studies of Project Implementation in the Building Construction Industry, BCA, Melbourne.
50. Business Council of Australia (1993b), Fundamentals of Project Implementation for the Building and Construction Industry, BCA, Melbourne.
51. CCTA, (1995), the government Center for Information, System Management of Program Risk, HMSO, London
52. Chalmers, A.F. (1976), What is this called Science? An Assessment of the nature and status of science and its methods, in Perry and Coote (1994).
53. Chapman, R. J. (2001), The controlling influences on effective risk identification and assessment for construction design management, International Journal of Project Management, V19, p147-160.
54. Chapman, R.J. (1999) The likelihood and impact of changes of key project personnel on the design process ; Construction Management and Economics 17 (1), pp. 99-106

## References

---

55. Chang CL, Ogunlana SO, Saeed K. (1991) Construction Project management: A system dynamic model. .System Dynamics '91. Bangkok, 1991, pp. 108-115.
56. Charles, T. Jahren and Ashe, A.M. (1990), Predictors of Cost Overrun Rates, Journal of construction engineering and Management, 116(3), September
57. Chase R.B. & Aquilano N.J. (1981), Production and Operations Management - A Life Cycle Approach, 3rd edn., Richard Irwin, Illinois.
58. Chentiz, W.C. and Swanson, J.M. (1986). From practice to Grounded Theory, Addison-Wesley, Menlo Park, CA.
59. CIB, (1993), Building Pathology, A state of the Art Report, CIB report, Publication 155.
60. CIDA (1995), Measuring up or mudding through: Best practice in the Australian non-residential construction industry, Construction Industry Development Agency and Master Builders Australia, Sydney, Australia, pp 59-63
61. Chang, Cl. Ogunlana So. Saeed K., (1991), 'Construction Project Management: A system dynamic Model'. System Dynimcs 1991, Bangkok, pp 108-115
62. Chadwick, W.L. (1986) Impact of design, construction and cost on project quality, ASCE Journal of professional issues in engineering, V 112(2), 69-79
63. Choy W.K. & Sidwell A.C., (1991), Sources of variation in Australian construction contracts, The Building Economist, vol. 30, No. 3, pp. 25-31.
64. Cnudde, M., (1990), Lack of Quality in Construction – Economic losses, pp 508-515, CIB International Symposium at the University of Technology, Sydney, 14-21 March 1990
65. Cook, L., (1990), Partnering, contracting for the future, (1990), ASCE Journal of Construction management and Engineering , 6(4) 431-446
66. Coles, E.J. (1992), Planning Building Design in Architectural Management, Nicholson, M.P. (ed), E & F.N. Spon, London
67. Coles, E. J. (1990), Design Management: A study of practice in the building industry. The Chartered Institute of Building, Occasional paper No 49, p32
68. Collins, (1987), Collins English language dictionary, Haper Collins Publishers, London.

## References

---

69. Construction Industry Institute Australia (CII Australia) (1996a) Constructability manual CII Australia, Australia
70. Construction Industry Institute (CII) (1986) A primer CII, Austin, Texas
71. Construction Industry Institute Constructability: (1986), A primer. Publication 3-1, Austin, Texas, July 1986, pp6-12
72. Construction Project Information Committee (CPIC), (2003), Production information: a code of procedure for the construction industry, CPI Publication
73. Construction Management Committee (CMC) of the ASCE construction Division (1991), "Constructability and constructability programs: while paper" ASCE Journal of construction Engineering and Management, V 117, No 1, pp 67-89.
74. Cooper, Kenneth G., (1993), the rework Cycle: Benchmarks for the project Manager, Project Management Journal, V24,1
75. Coyle, R. G, (2000), Qualitative and Quantitative modeling in system dynamics: Some research questions, System Dynamics Review, V16 (3), 225-244
76. Coyle, R.G. (1996), System Dynamics Modeling, A practical Approach, Chapman& Hall, London.
77. Coyle, R. G, (1986), The Practice of System Dynamics: Milestones, Lessons and Ideas from 30 Years of Experience, System Dynamics Review, V14, pp343-366.
78. Coyle, R.G. (1983), Who rules the waves - a case study in system description, Journal of the Operational Research Society, vol. 34, no. 9: 885-898.
79. Coyle, R.G. (1984a), East and West and North and South, in: FUTURES, vol. 16: 594-609.
80. Coyle, R.G. (1984b), A systems approach to the management of a hospital for short-term patients, Socio-economic Planning Sciences, vol. 18: 219-226.
81. Coyle, R.G. (1985), 'A system description of counter-insurgency warfare, Policy Sciences, vol. 18: 55-78.
82. Coyle, R.G.(1977), Management System Dynamics, Wiley, London
83. Coyle, R.G. and Alexander, M.W.D. (1996), Two approaches to qualitative modelling of a nation's drug trade?, System Dynamics Review, vol.13, no. 3, (Fall), 1996.

## References

---

84. Coyle, R.G. and Exelby, D.(2000), The validation of commercial system dynamics models, *System Dynamics Review*, V 16(1) p 27-41
85. Craig, W. Kirkwood, (1998), *System Dynamics Methods, A quick Introduction*,
86. Davis, K., Ledbetter, W.B. and Burati, J.L. (1989). "Measuring Design and Construction Quality Costs." *Journal of Construction Engineering and Management*, 115 (3), 385-400.
87. Dean C. Karnopp, Ronald C. Rosenberg, (1990), *System Dynamics: a Unified Approach*, John Wiley & Sons, Inc.
88. DeGues, A.P., (1992), modeling to predict or to learn?, *European Journal of Operational research*, 59(1), pp 1-5
89. De Vaus D.A. (1991), *Surveys in Social Science*, 3rd edition., Allen and Unwin, London.
90. Diekmann J.E. and Nelson, M.C., (1985), Construction claims : Frequency and Severity. *Journal of Construction Engineering and Management*. ASCE 115(3), 385-400.
91. Dew, J.R. (1991), in Search of the root cause, *Quality Progress*, March 1991
92. Dissanayaka, S.M. and Kumarasawny, M.M., (1997), Re-engineering Procurement Frameworks and Relationships, *Proceedings of the International Conference on Construction Process Re-engineering*, Australia, p157-167
93. Drucker P.F. (1974), *Management Tasks - Responsibilities - Practices*, Harper & Row, New York.
94. Eckart Frakenberger, Petra Badke-Schaub, (1998), Modelling design process in industry – Empirical investigations of design work in practice, *Automation in Construction*, V. 7, p139-155
95. Edwin B. Dean, (1991) Taguchi Approach To Design Optimization For Quality And Cost:An Overview, the 1991 Annual Conference of the International Society of Parametric Analysts.
96. Edwin B. Dean,(1990), The Design-To-Cost Manifold, *International Academy of Astronautics Symposium on Space Systems Cost Methodologies and Applications* San Diego California U.S.A. May 10-11,
97. Evbuomwan, N. and Anumba, C., (1996), Toward a Concurrent engineering model for design and build projects. *The structural Engineer*. 1996, 74(5). pp 73-78

## References

---

98. Fazio P, Moselhi O, Theberge P., Revay S., (1988), Design impact of construction fast track, *Construction management and economics*, V 5, p195-208
99. Ferguson, H., and Clayton, L. (1988). *Manual of professional practice “Quality in the constructed project: A guideline for owners, designers, and contractors.”* ASCE, New York, N.Y., Vol. 1.
100. Flanagan R.& Tate B.,(1997), *Cost control in Building design*,
101. Franks, J. (1990), *Building Procurement Systems 2<sup>nd</sup> ED*. CIB , UK
102. Fellows, R.F.F. (1997), *The culture of Partnering*, *Proceeding of the CIB W-92 Procurement Systems Symposium*. Univ. of Montreal, Montreal, Canada pp 193-202
103. Fellows, R. and Liu, A. (1997) *Research Methods for Construction*, Blackwell Science, Oxford.
104. Ford D. N. (1995), *The dynamics of project management: an investigation of the impacts of project process and coordination on performance*, PhD thesis ,Department of civil and environmental engineering, MIT
105. Ford D.N. and F. Pena, (1994) *The design of proactive feedback system for construction project management*, *Proceeding of computing in civil engineering*.
106. Ford D. and Sterman J. (1998) *Expert Knowledge elicitation for improving mental and formal models*, *System Dynamics Review*, 14(1),31-68.
107. Forrester JW (1975), *Industrial dynamics – a response to Ansoff and Sievin*, in *Collected paper of Jay W Forrester*, Wright-Allen Press, Cambridge, MA, 151-165
108. Forrester JW, (1970), *Industrial Dynamics – A Response to Ansoff and Slevin*, in *Collected papers of Jay W Forrester*, Wright-Allen Press: Cambridge, MA, 151-165
109. Forrester, J.W. (1968) *A Response to Ansoff and Levin*, *Management Science* 14 : 601-618
110. Forrester, J.W., G.W. Low and N.J. Mass (1974), *The Debate on world dynamics : A response to Nordhaus*, *Policy Sciences* 5 : 169-190

## References

---

111. Forrester, J.W. and Senge, P.M. (1980) "Tests for Building Confidence in System Dynamics Models," In System Dynamics, A. A. Legasto, Jr. and e. al. (Ed.), 14, North-Holland, New York, 1980, pp. 209-228.
112. Gardiner, J. (1994), Management of design documentation : Where do we go from here? Construction and management: Recent advance, R. R. Wakefield and D.G. Carmichael, Eds, Balkema, Rotterdam, the Netherlands, 113-118
113. General Accountancy Office (GAO), (1978), Computer Aided Design US Department of Commerce, Washington, USA,
114. Giddens, A. (1976), New Rules of Sociological Method, Hutchinson, London.
115. Gill J. NS Johnson P. (1991), Research Methods for Managers, Paul Chapman, London, p110-113
116. Glasser, B.G. and Strauss, A.L. (1967), The discovery of Grounded theory, Strategies for Qualitative research, Aldine Publishing, Chicago.
117. Goldratt, E. and J. Cox (1986) The Goal: A Process of ongoing improvement, revised ed. Croton on Hudson, NY: North River Press.
118. Gray C. & Flanagan R. (1984), 'US productivity and fast-tracking starts on the drawing board', Construction Management and Economics, vol. 2, no. 3, pp. 133-144.
119. Greenberger, M., M. Crenson, and B. Crissey (1976) Models in the Policy Process. New York: Russell Sage Foundation.
120. Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Toward a conceptual framework for mixed-method evaluation designs. Educational Evaluation and Policy Analysis. V11, 255-274
121. Hillabrandt, P. M. and Cannon, C., (1990), The modern Construction Firm, London
122. Hammarlund Y., Jacobsson S., Josephson, P.-E., (1990), Quality Failure Costs in Building Construction, CIB International; Symposium at the University of Technology, Sydney, 14–21 March 1990.
123. Hayes R.W., Perry J.G., Thompson P.A., & Wilmer G., (1986), Risk Management in Engineering Construction, Thomas Telford, London.



## References

---

124. Hastak, Makarand, and Vagegas, Jorge, (1996), COMPASS – New paradigm for project cost control strategy and planning, *Journal of Construction Engineering and Management*, Sep 1996, V. 122(3), pp 254-264
125. Hibberd, P.R., (1980), *Buidling contract variations*, MSc, Thesis, UMIST, UK.
126. Hinkle D.E., Wiersma W. & Jurs S.G., (1988), *Applied Statistics For The Behavioural Sciences*, 2nd edn., Houghton Mifflin, Boston.
127. Hersey P. & Blanchard K., (1982), *Management of Organizational Behaviour: Utilizing Human resources*, 4<sup>th</sup> edition. Prentice-Hall International, Englewood Cliffs, New Jersey.
128. Hogarth, R.M., (1980), *Judgment and Choice*, Wiley, New York
129. Hollnagel E., (1993). *Human reliability analysis: Context and control*. London: Academic Press.
130. Hon S.L., Gairns D.A. & Wilson O.D. (1988/89), 'Buildability: A review of research and practice', *Australian Institute of Building Papers*, vol. 3, pp. 101-118.
131. Hoshmand, L. T., (2003), Can lessons of history and logical analysis ensure progress in psychological science? *Journal of Theoretical and Philosophical Psychology*, 13, 39-44.
132. Huot JC. Sylvestre Y., (1995), An application of System Dynamics to the construction of a major building, *System Dynamics '85*. Vol. 1, Colorado, USA, pp 384-409.
133. Jessen, SA, (1988), Can Project dynamics be modeled?, *Proceeding of international conference of system dynamics Society*, p171-187.
134. Jo, H. H. Parsaei, H. R. and Sullivan, W.G., (1993), *Principle of current Engineering*. In *Concurrent Engineering Contemporary Issues and Modern Design Tools.*, pp 3-23
135. John M. Kamara, Chimay J. Anumba, Nosa F.O. evbuomwan, (2001), Assessing the suitability of current briefing practices in construction within a concurrent engineering framework, *International Management of Project Management*, Vol. 19, pp. 337-351
136. Johnson B. and Onwuegbuzie A., (2004), Mixed Methods Research: A Research Paradigm: Whose Time Has Come, *Journal of Educational Researcher*, V 33, No 7, pp 14-26.

## References

---

137. Johnson, R.B. & Turner, I. A., (2003), Data collection strategies in mixed method research. In A. Taskakkori and C. Teddlie (Eds.), Handbook of mixed methods in social and Behavioural research (pp. 297-319). Thousand Oaks, CA: Sage.
138. Jones, P. and Nathan, N.D., (1990), Supermarket roof collapse in Burnaby, British Columbia, Canada, Journal of Performance of constructed Facilities, V 4(3), 142-160.
139. Josephson P.-E., Hammarlund Y., (1999); The causes and costs of defects in construction : A study of seven building projects; Automation in Construction, V 8.681–687
140. Kaka A. & Price A.D.F., (1991), 'Relationship between value and duration of construction projects', Construction Management and Economics, vol. 9, pp. 383-400.
141. KACKAR, R. N., (1989), Taguchi's quality philosophy: analysis and commentary, In Quality Control, Robust Design, and the Taguchi Method, edited by K. Dehnad (Pacific Grove, CA: Wadsworth & Brooks/Cole Advanced Books & Software).
142. Kaminetzky, D., (1991) Design and construction Failures – Lessons from Forensic Investigations. McGraw-Hill, New York.
143. Kangari R., (1995), Risk management perceptions and trends of US construction. Journal of Construction Engineering and Management; 121(4):422–9.
144. Kartam NA, Kartam SA., (2001), Risk and its management in the Kuwaiti construction industry: a contractors' perspective. International Journal of Project Management ;19:325–35.
145. Kelly J., Male S., (1998), Value Management in design and construction, E&FN SPON publication,
146. Kerzner, H., (1998), Project Management, A systems Approach to Planning, Scheduling, and Controlling, 6th Edition, John Wiley & Sons Inc.
147. Kharbanda O. P., Stallworthy E. A., Williams L.F., (1983), Project Cost Control in Action, 1983.
148. Kidder L. H. and Judd C. M., (1986), research Methods in Social relations; CBS college publishing, New York, pp 178-188.

## References

---

149. Kim, D. H., (2000), A simulation method for cognitive maps, Proceedings of International Conference of Systems Thinking in Management Conference, Deakin University, Australia, Nov 2000.
150. Kim, D.H., (1992), Toolbox: Guidelines for drawing Causal Loop diagrams, The system thinker, Vol. 3, No 1, PP 5-6
151. Kirby J. G., D. A. Furry & D.K. Hicks, (1988), Improvement in design review management, Journal of construction engineering and management, V114, No. 1 March.
152. Kletz, T. A., (1985), An engineer's view of Human Error. Institute of chemical engineers, Rugby, UK.
153. Klir, G., (1991): Facets of Systems Science. New York: Plenum Press
154. Koskela, L., (1992), Application of the new production philosophy to construction; CIFE technical report (#72) September
155. Koskela, L., Huovila, P. and Lautanala, M., (1994), Fast or concurrent – the Art of getting construction improved. Proceedings of the 2<sup>nd</sup> international conference on lea construction, Santiago, Chile
156. Kothari, C.R., (1997), Research Methodology methods & Techniques, Wisha Prakashan, New Delhi, India
157. Kwahk, K.-Y. and Kim, Y.-G., (1998), Supporting business process redesign using cognitive maps, Decision Support Systems 25, 1999: 155-178, Elsevier.
158. Lam, K.C. Gibb, A.G.F. and Sher, (1997), Selection of Procurement Path for Highly Serviced Hospital Buildings. Proceedings of the CIB W-92 Procurement Symposium. Canada, pp345-355
159. Langford, V., Fellows R. F., & Newcombe R., (1986), Variations in building contracts: the role of the social system. CIB 86 Advancing building technology, V 8, Translating research into Practice , 3522-30
160. Lawson, B., (1997), How Designer Think, The Architectural Press, London.
161. Latham report, (1994), Constructing the team, HMSO, London
162. Levin R.I., (1987), Statistics For Management, 4th edn., Prentice Hall International, New Jersey.
163. Losee, J., (1972), A Historical Introduction to the Philosophy of Science, Oxford University Press, London.

## References

---

164. Love P.E.D., Mandal, P., Smith, J and Li H., (2000), Modelling the dynamics of design error induced rework in construction, *Construction Management and Economics*, 18, 567-574
165. Love, P.E.D., Li, H. Mandal, P., (1999), Rework: a symptom of dysfunctional supply chain, *European Journal of Purchasing and Supply Management*, 5(1), 1-11
166. Love P.E.D., Gunasekaran A. and Li H., (1998), Concurrent engineering: a strategy for procuring construction projects, *International Journal of Project Management*, 16 (6), 375-383
167. Love P.E.D., Mandal, P. and Li H., (1999) Determining the casual nature of rework in construction projects, *Construction Management and Economics*, 17(4), 505-515
168. Love, P.E. Mohammed, S. and Tucker, S.N., (1996), Concurrent Engineering: a Multi-Disciplinary Approach to Construction. *International Conference on Urban Engineering in Asian Cities in the 21<sup>st</sup> century*, Bangkok, Thailand, pp232-238
169. Luis F L Reyes and Deborah L Andresen, (2004), Collecting and analyzing qualitative data for system dynamics: methods and models, *System Dynamics review*, V 19, No 4, 271-296
170. Luth, G.P., (2000) Chronology and context of the Hyatt Regency collapse, *Journal of Performance of Constructed Facilities*, 14(2), 51-61.
171. Lutz, J.D., Hancher, D.E. and East, W.E. (1989). "Framework for Design- Quality-Review Data-Base System." *Journal of Management in Engineering* 6(3), 296– 312.
172. Lyneis JM, Cooper KG, Els SA., (2001), Strategic Management of complex project, *System Dynamics Review Journal*, V17, pp 237-260
173. Institute of Civil Engineers, (1994), *New engineering contract*. Thomas Telford, London
174. Ireland V., (1987), The choice of contractual arrangement', *Proceedings of the Project Managers Forum*, Adelaide, p176-190.
175. Ireland V., (1983), *The Role of Managerial Actions in the Cost, Time and Quality Performance of High Rise Commercial Building Projects*, PhD thesis, University of Sydney, N.S.W., 1983.

## References

---

176. MacPherson, I.G., (1991), Broadgate: Phases 5, 9 and 10 A Construction manager's point of view, in 'Fast build', Ed. D Stacey, Thomas Telford, London.
177. Marsh K., (1982), The Survey Method, Allen and Unwin, London.
178. Mason J., (1996), Qualitative Researching, Stage Publishing, London, p60
179. McCormack, B. and Hill, E., (1997) "Conducting a Survey: The SPSS Workbook", International Thomson Business Press, London.
180. McGeorge D. and Palmer A., (1997), Construction Management: New Directions, Melbourne, Australia: Blackwell Science.
181. McMahan C. A., Cooke J.A. and Coleman P., (1997), A classification of errors in design, International conference on engineering design ICED97 Tampere, August 19-21,
182. Miles, M.B. and Huberman, A.M., (1984), Qualitative Data Analysis, a sourcebook of new methods, Sage, London.
183. Mohapatra, P.K.J., Mandal, P., (1989). The system dynamics paradigm, Decision, 16(4),251-266
184. Morecroft, J.D.W., (1992), Executive Knowledge, Models and learning, European Journal of Operation Research 59(1), pp 70-74
185. Morris P.W.G. (1994), The Management of Projects A New Model, Thomas Telford, London.
186. Darwish M. I., (2005), Factors affecting design and documentation quality in construction industry; MSc thesis, King Fahd University of Petroleum & Minerals, Saudi Arabia
187. Murdoch J. and Hughes W., (1997), Construction Contracts law and management. 2<sup>nd</sup> edition, E&FN Spon Publisher.
188. Naoum S. G., (1994), Critical analysis of time and cost of management and traditional contracts. Journal of Construction Engineering and Management , V120, No. 4, Dec
189. Naoum S.G. (1991), 'Procurement and project performance - a comparison of management contracting and traditional contracting', Occasional Paper no. 45, Chartered Institute Of Building, Ascot, UK.

## References

---

190. NEDO Construction Industry Sector Group, (1988), *Faster Building for Commerce*, Report prepared for the National Economic Development Office (NEDO) Commercial Building Steering Group, London.
191. Nigro, W.T., (1987). "Contract Documents: A Quality Control Guide." *Architecture*, Jan., 83-84.
192. Nikkei Construction, (2001) *How to protect from recurrence errors*, Nikkei Construction (In Japanese), 275, 46-85.
193. Nina Ryd, (2004), *The design brief as carrier of client information during the construction process*, *Design Studies* 25 (2004) 231–249
194. Nishigaki, S., Varin, J., Kando, N, Haga, T., Kunz, J.C. and Law, K. (1994), *Humanware, Human error, and hiyari-hat: a template of unsafe symptoms*, *Journal of Construction Engineering and Management*, 120(2), 421-442
195. NWPC/NBCC joint working party (1990), *No Dispute strategies for improvement in the Australian building and construction industry*, National Public Works Conference and National Building and Construction Council, Canberra.
196. Nowak, A. S., June (1992), *Human errors in structures, offshore Mechanics and arctic Engineer*, 11<sup>th</sup> international conference, Vol. II, s335-341, Calgary, Canada
197. Nuthmann C. (1994), *Using human judgment in system dynamics models of social systems*, *System Dynamics Review* 10(1): 1-27
198. O'Connor J.T. and Tucker R.I. (1986) *Industrial project Constructability improvement*, *ASCE Journal of Construction Engineering and Management* 112(1), 69-82
199. Oglesby, C. E. and Urban, J. E., (1983), *The Human resources task area*, *Computer*, 16, pp65-70
200. Ogunlana, S., Lim, J. and Saeed, K. (1998), *DESMAN, A dynamic model for managing civil engineering projects*, *Computers and Structures*, 24(3), 279-87
201. Ogunlana S. (1993), *Motivating thinking construction employees*, *Industrial Engineering Journal*, 22(2), 4-7
202. Olomolaiye P. and Price A.D.F. (1989), *A review of construction operative motivation*, *Building and Environment* 24(3), 279-287

## References

---

203. Oreskes, N, K. Sharder-Frechette, and K. Belitz (1994), Verification, validation, and confirmation of numerical models in the earth science, *Science* 263( 4 Feb), 641-646.
204. Pahl, G. and Beitz W., (1996), *Engineering Design, A Systematic Approach*, p455
205. Parke, A. (1993), Messy Research, Methodological Predispositions, and theory development in international joint ventures, *Academy of Management Review*, 18(2). P227-268
206. Patrick T. I. Lam, Franky W. H. Wong and Albert P. C. Chan, (2006). Contributions of designers to improving buildability and constructability, *Design Studies*, April 2006
207. Payne J., Bettman J. R., and Johnson E. J., (1988). Adaptive strategy selection in decision making. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 14(3), 534-552
208. Payne J. W., Johnson E. J., Bettman J. R., and Coupey, E. (1990). Understanding contingent choice: a computer simulation approach. *IEEE Transactions on systems, Man, and Cybernetic*, 20, 296-309
209. Perry, C. and Coote, L. (1994), Process of a case study research methodology; Tool for Management Development, Proceedings of Australian and New Zealand Association for Management ANZAM Conference, December, Victoria Univeristy of Wellington, New Zealand.
210. Perry, C. and Zuber-Skerritt, O. (1994) 'Doctorates by Action Research for Senior Practising Managers', *Management Learning* 25(2): 341–65.
211. Petroski, H., (1994), *Design Paradigms- Case Histories of error and judgment in Engineering*, Cambridge University Press, USA
212. Peterson, D.W. and R.L. Eberlein (1994). Reality check: A bridge between systems thinking and system dynamics. *System Dynamics Review* 10(2-3):159-174
213. Pettigew, A. (1985) Contextualist research, a naturalistic way to link theory and practice, in doing research that is useful in theory and practice, E.E. Lawler (ed), Jossey-Bass, San Francisco.
214. Prasa, B. (1996), *Concurrent Engineering Fundamentals, Integrated Product and Process Organisation. Vol 1*

## References

---

215. Pressman, A. (1993) *Architecture 101, A guide to the design studio*, Wiley, New York.
216. Pugh Roberts Associates, (1993), PA Consulting Group, PMMS-Program Management Modeling System, USA.
217. Randers J. (1980), Guidelines for model conceptualization, in *elements of the system dynamics method*, MIT press, Cambridge, MA, 117-139
218. Randolph, D.A. , Rajandra, K. and Camfield, J.J. (1987), Using risk management techniques to control construction contract costs, *Journal of Construction Engineering and Management*, ASCE, 3(4), 314-324
219. Rapoport, A. (1986): *General system theory: essential concepts & applications*. Tunbridge Wells, Kent: Abacus Press.
220. Rasmussen, J. (1986), *Information processing and human machine interaction: An approach to cognitive engineering*. New York: North Holland
221. Reason, J. (1990). *Human error*. Cambridge, England: Cambridge University Press.
222. Rehman S., Guenov M.D., (1998), A Methodology for modelling manufacturing costs at conceptual design, *Computers industry. Engineering* volume 35 3-4 pp 623-626m
223. Rianne C. V., (1998), Shared understanding as a condition for team design, *Automation in Construction*, V. 7, pp111-121.
224. Richardson G.P, (1996), Problems for the future of system dynamics, *System Dynamics Review* 12(2), 141-157
225. Richardson G.P, (1995), Problems for the future of system dynamics, in: *System Dynamics 1995-Proceedings of the international system dynamics conference*, Tokyo, Shimada T. And Saeed K (eds).
226. Richardson, G. (1991), *Feedback through in social science and systems theory*, University of Pennsylvania Press, Philadelphia.
227. Richardson GP, Pugh AL III. (1991), *Introduction to System Dynamics modeling with DYNAMO*. MIT Press, Cambridge, MA. 1991.
228. Roberts, E. (1964) *The Dynamics of research and Development*, Harper and Row, USA.
229. Roberts, Edward B. (1992). *Strategic management of technology, Global Benchmarking*, Massachusetts Institute of Technology and PA Consulting.



## References

---

230. Roberts NH, Anderson DF, Deal RM, Grant MS, Shaffer WA (1983). Introduction to Computer Simulation, The system Dynamics Modelling Approach. Addison-Wesley, Reading, MA.
231. Rochlin, G., LaPorte, T. R., and Roberts, K.H. (1987). The self-designing high reliability organization: Aircraft carrier flight operations at sea. *Naval War College Review*, (Autumn), 76-90.
232. Rodrigues, A. and Bowers, J. (1996). The role of system dynamics in project management, *International Journal of Project Management*, 14(4), 213-220.
233. Rollings, R.S. and Rollings, M.P. (1991) Pavement failures: Oversights, omissions and wishful thinking, *Journal of performance of constructed facilities*, 5(4), 271-286.
234. Romano, C. (1989), Research strategies for small business: a case study, *International Business Journal* 7(4), p35-43.
235. Rowings J.E., Nelson M.G. & Perry K.S. 1987, 'Project objective-setting by owners and contractors', A Report to the Construction Industry Institute (CII), Austin Texas.
236. Rowland, H.J. (1981), The causes and effects of change orders on the construction process, MSc Thesis presented to the Georgia Institute of Technology, Atlanta, USA
237. Rosmond, J.R. (1981), Analysis of low bidding and change order rates for navy facilities construction contracts, MSc thesis presented to Naval Postgraduate School, at Monterey, California, USA
238. Rounce, G. (1998), Quality, Waste, and cost consideration in architectural building design management. *International Journal of project management* 16(2), 123-127
239. Ryd, Nina, (2004), The design brief as carrier of client information during the construction process, *Design Studies*, V25, No 3, 230-249
240. Rukn Eldeen, M., (1999), The efficiency of cost control procedures in Saudi Arabia construction projects, MSc thesis, Department of Building Engineering and Surveying, Heriot Watt University, Edinburgh, UK.
241. Ruskin A. M., (1995), *Project Management Journal*, Sept, Managing Design to Cost Engineering Projects.

## References

---

242. Saeed, K., (1994), Contract design for large scale civil works projects or sowing seeds for harvesting court battles. Presented at Towards the new millennium, Living, learning and working, Annual conference of the World Future Society, Cambridge, MA, USA.
243. Santanu Roy, Krishnan K.S. & Mohapatra P.K.J.; (2000), Causality and validation of system dynamics models incorporating soft variables: Establishing an interface with structural equation modelling, Proceedings of the 2000 international system dynamics conference,
244. Sawczuk, B., (1992), The Management of the design process in Architectural Management, Nicholson, M.P. (ed), E.&F.N. Spon, London.
245. Sawada M. (2000), A fundamental study of risk management in construction projects—risk allocation between owners and contractors for public works. Unpublished Master thesis, University of Tokyo, Japan; [In Japanese].
246. Schon, D. (1993), The reflective practitioner, How Professionals think in action, Maurice Temple Ltd. London.
247. Sechrest, L., Sidana, S. (1995), Quantitative and qualitative methods: Is there an alternative? Evaluation and Program Planning, V18, 77-87
248. Senge, P.M. (1990) The Fifth Discipline: The Art and Practice of the Learning Organization, Doubleday, New York.
249. Seymour D. and Rooke, J. (1995), The Culture of the Industry and the culture of research, Journal of Construction Management and Economics, 13, p511-523
250. Seymour D., Rooke, J. and D. Crook (1997), Preserving Methodological consistency: A reply to Raftery, McGeorge and Walters, Construction Management and Economics, 15, p491-494
251. Schich, J.C. (1982), Trevino Project, A fast-track approach for a small construction project, 1982 Mining Yearbook, Colorado Mining Association, 74-79
252. Shaddad, M.Y.I. and Pilcher, R. (1984), The influence of management on construction system productivity, Towards a conceptual sytem causal research model, Proceeding of the CIB W65 4<sup>th</sup> International Symposium on the Organisation and Management of Construction, Waterloo, Ontario, Canada.

## References

---

253. Sharif, A. and Moledge, R. (1997), The Insensitivity of the procurement Process in the UK Construction Industry to the problems of the Occasional Buyers from the Industry. Proceeding to the CIB W-92. Procurement Symposium, University of Montreal, Montreal, Canada,
254. Shearer J. L., Murphy A. T., Richardson H.H., (1971), Introduction to System Dynamics, Addison-Wesley Publishing Co. London.
255. Shockley-Zalaback P., (1991), Fundamentals of Organizational communication, Longman, New York
256. Sidwell A.C. & Ireland V. (1987), 'An international comparison of construction Management', Australian Institute of Building Papers, vol. 2, pp. 3-12.
257. Sidwell A.C. (1984), The time performance of Construction Projects, Architectural Science Review, vol. 27, pp. 85-91.
258. Sidwell A.C. (1982), A critical study of project team organizational forms within the building process. PhD thesis, Department of Construction and Environmental Health, University of Aston in Birmingham.
259. Sigurdson A., ( 1996), Principle Errors in Capital Cost Estimating Work, Project Management Journal , Spe, p27-34
260. Simon, H. (1957), Models of Man, Wily, New York , p198
261. Sekaran, U., (1992), Research Methods for Business: A Skill-Building Approach (2nd Ed.), John Wiley and Sons, New York.
262. Senders, J.W. and Monay, N.P., (1991), Human error: cause, Prediction, and Reduction, Lawrence Erlbaum Associates, Inc., Hillsdale, New Jersey.
263. Sowers. G.F., (1993), Human Factors in civil and geotechnical engineering failures, Journal of geotechnical engineering, 199(2), 238-256
264. Stasiowski F. A., Burstein, D., (1994), Total Quality Management for the design Firm, Wiley, NY
265. Sterman, J.D., (2002), All models are wrong: reflection on becoming a systems scientist, System Dynamics Review Journal, V18 (4), P 501-531
266. Sterman, J.D., (2000), Business Dynamics: System Thinking and modeling for a complex World. Irwin/McGraw-Hill, Boston

## References

---

267. Sterman, J.D., (1992), System dynamics Modeling for Project Management, Working Paper, System Dynamics group, Sloan School of Management, MIT, Cambridge, MA
268. Sterman, J.D., (1984), Appropriate summary statistics for evaluating the historical fit of system dynamics models, *Dynamica* (10) II, Winter 51-66
269. Stewart M. G., (1992), Simulation of human error in reinforced concrete design, *Research in Engineering Design Journal*, V4, p51-60
270. Stoekel and Quirke (1992)
271. Stogdill R.M. & Coons A.E. (eds). (1957), *Leader Behaviour: Its Description and Measurement*, Research monograph no. 88, The Ohio State University, Bureau of Business Research, Columbus, Ohio.
272. Stoner A.F., Collins R.R., & Yetton P.W. (1985), *Management in Australia*, Prentice-Hall, Sydney.
273. Stretton A. & Stevens G. (1990), 'PREDICTE: an expert system for estimating indicative construction times for multi-storey buildings at the concept stages', *Proceedings of the CIB 90 International Symposium on Building Economics and Construction Management*, Sydney, March, vol. 2, pp. 590-601.
274. Taguchi, G., (1986). *Introduction to Quality Engineering*, Asian Productivity Organization (Distributed by American Supplier Institute Inc., Dearborn, MI).
275. Tilley, P.A., Mcfallan, S.L. and Tucker, S.N. (1999). "Design and Documentation Quality and its Impact on the Construction Process." CIB W55 & W65 Joint Triennial Symposium, Cape Town.
276. Terry W., Colin E., Fran A. and Andrew T.,(1995) *International Journal of Project Management*, V. 13, No 3, pp 151-155.
277. Thamhain H. J., (1996), Best Practices for controlling technology based projects, *Project Management Journal*, Dec 1996, pp37-48
278. Thamhain, Hans J. & Wilemon, David L. (1996), Building High performing engineering project team. In *the Human Side of Managing Technological Innovation*, Oxford Press.
279. Todd, D.J. (1979), Mixing qualitative and quantitative methods, triangulation in action, *Administrative Science Quarterly*, V24, pp 602-11

## References

---

280. Tombesi P. (2000), Modeling the dynamics of design error induced rework in construction :comments, Construction management and economics, vol 18, pp727-732
281. Turner Alan E., (1997), Building Procurement, 2<sup>nd</sup> edition, Macmillan Press Ltd.
282. United State Construction Engineering regulations (1984)
283. Vazquez, M., Liz M and Aracil J (1996), Knowledge and reality : Some conceptual issues in system dynamics modeling. System dynamics Review, Volume 12 (1) 21-37
284. Vennix, J. Andersen D. f., Richardson G. P., and Rohrbaugh J., (1992). "Model-building for group decision support: Issues and alternatives in knowledge elicitation," European Journal of Operational Research, vol. 59, pp.28-41.
285. Voss C. A., Russell V. and Twigg D. (1986), Implementation issues in simultaneous engineering, International Journal of Technology Management, 6(3/4), 293-302
286. Walker A. (1989), Project Management in Construction, 2nd edn., BSP Professional Books, London.
287. Walker A. & Hughes W.P. (1984), 'Private industrial project management: a systems-based case study', Construction Management and Economics, vol. 2, no. 2, pp. 93-110.
288. Walker, D. T. (1994), An Investigation Into Factors That Determine Building Construction Time Performance, PhD Thesis, Department Of Building And Construction Economics, Royal Melbourne Institute Of Technology, Australia
289. Walker, D.H.T. (1990/1), Diversity in management structures on construction sites in Australia, Australian Institute of Building Papers, vol. 4, pp. 3-22.
290. Walker D.H.T. (1989), Knowledge acquisition in the development of an expert system to determine the construction time of a project in Australia, Proceedings Artificial Intelligence in Industry and Government, Hyderabad, pp. 190-207.

## References

---

291. Weston, D.C. and Gibson, G.E. (1993), Partnering project performance in the US army Corps of Engineers. *Journal of Management in Engineering*, 1993, 9(4), 410-425
292. Weustink, I.F., Brinke, T., Streppel, A.H. Kals, H., (2000), A generic framework for cost estimation and cost control in product design. *Journal of Material Processing Technology* 103 (2000) 141-148
293. Weustink, I.F. (1997), Cost Control in Product design, MSc Thesis, Laboratory of production and design engineering, Department of Mechanical Engineering, Univ. of Twente, Enschede,
294. White, A.D. (1980), Coordination problems in fast-track commercial construction, MA thesis, MIT
295. Whittington, C., Livingstone, A. and Lucas, D.A. (1992) Research into Management, Organizational and Human Factors in the construction industry. HSE contract research Report No. 45/1992. HMSO, London
296. Williams Trefor, 2000, Focusing Research on Fundamental Issues, Department of Civil and Environmental Engineering, Rutgers University
297. Williams T. ,Eden C., Ackermann F., and Tait A. (1995), Vicious Circles of Parallelism, *International Journal of Project Management*, 13(3), pp151-155
298. Wilson, N. and McClean, S., (1994), Questionnaire Design: A Practical Introduction, University of Ulster, Newtownabbey, Co Antrim.
299. Wilson, P.F., Dell, L.D. and Andreson, G.F., (1993), Root cause analysis: A tool for total Quality Management, ASQC Quality Press, ASQC, Milwaukee, Wisconsin, USA
300. Winter R. (1987), Action research and the nature of social enquiry, Avebury.
301. Wolstenholme E.F. (1999), Qualitative versus Quantative Modeling: The Evolving Balance, Special issue on System Dynamics of the *Journal of Operation Research Society*.
302. Wolstenholme E.F. (1990), *System Enquiry: A system dynamics approach*, Wiley Chichester.
303. Wolstenholme, E.F. (1985), A method for qualitative system dynamics, *Proceedings of the System Dynamics Conference*, Denver, Colorado, USA.

## References

---

304. Wolstenholme, E.F. and Coyle, R.G. (1983), Development of system dynamics as a rigorous procedure for system description, *Journal of the Operational Research Society*, vol. 34: 569-581.
305. Woods D., Johannesen L., Cook R. and Sarter N., (1994), *Behind human error: Cognitive systems, computers, and hindsight*, CSEIAC, Wright-Patterson Air Force Base, Ohio, USA.
306. Yin, R., (1994), *Case Study Research: Design and Methods (Second Edition)* , Sage, Beverly Hills, CA
307. Yui Wei; Pius J. Egbelu , *International Journal of Computer Integrated Manufacturing* V: 13, No: 1 Pp50 – 63
308. Zikmund, W., (1988), *Business Research Methods*, Dryden, Chicago.

## **Appendix A**



## Appendix A: Full List of the Model's Equations

---

```
mainmodel Designer Influence {
aux aa_Designer_experience {
autotype Real
autounit da^-1
def Previous_designer_expereince*aa_Share_of_knowledge
*Amount_of_information
*Internal_approval
}
aux aa_Discovery_of_error {
autotype Real
autounit da^-1
def Document_review/Available_design_time
}
aux aa_Flow_of_information {
autotype Real
def AVERAGE(Amount_of_information
,Effective_design_team
,Internal_approval,Motivation
)
}
aux aa_Input_to_team {
autotype Real
def Breifing_to_team+Technical_knowledge_availability
//this factor ensure that proper and enough knowldge has been feed to the design team
}
aux aa_Production_of_documents {
autotype Real
def Resources*Design_fee_pressure
}
aux aa_Quality_of_work {
autotype Real
autounit da^-1
def (Design_office_ingredient*Rate_of_Communication)+
(Availability_of_QA_procedure
*Coordination*Share_of_understanding*Resources*Reputation_of_designer
*Knowledge)
// I removed the discovery of errors from this variable
//It gives better result
}
aux aa_Share_of_knowledge {
autotype Real
autounit da^-1
def (Knowledge*Tranfer_of_knowledge)
*Pressure_of_design_time
*No_of_designer_pressure
*Rate_of_Communication*Available_design_time
}
aux aa_Solving_problem {
autotype Real
autounit da^-1
def MIN(Capacity_to_solve_problem,
(Knowledge*aa_Share_of_knowledge/Rate_of_Communication)
*Workload
*aa_Discovery_of_error
*Proper_analysis*Accountability+Rate_of_coordination)
}
aux Accountability {
autotype Real
def GRAPH(Effective_design_team,0,.2,{0,.2,.4,.6,.8,1//Min:0;Max:1//})
}
const Amount_of_document_produced {
autotype Real
autounit doc
init 100<<doc>>
permanent
}
```

## Appendix A: Full List of the Model's Equations

---

```
aux Amount_of_information {
1
autotype Real
def GRAPH(Clear_deliverable,0,.1,{0,.1,.2,.3,.4,.5,.6,.7,.8,.9,1//Min:0;Max:1//})
}
aux Amount_of_work_with_designer {
autotype Real
def No_of_designer_available/No_of_designers_required
// this equation tells that when percentage of available people to required are higher
// then we have extra staff and the amount of work load with designer are low
//while when the percentage are low the work load with designer are high
}
aux Auto_error_solving {
autotype Real
autounit error/da
def Auto_problem_solver*Factor_of_error_due_to_interaction
}
aux Auto_problem_solver {
autotype Real
autounit da^-1
def (aa_Flow_of_information
+aa_Input_to_team
+Knowledge)
*aa_Quality_of_work
}
const availability_of_information {
autotype Real
init 1
permanent
doc the total influence of communication is calculated based on the average influence of all factors on
communication
}
const Availability_of_QA_procedure {
autotype Real
init 1
//0 there is no QA available
//1 there is QA
permanent
}
aux Available_design_time {
autotype Real
autounit da
def MAX(1<<da>>,(Contractual_design_time-Time_to_solve_extra_problems
+Time_free_unused-Time_for_extra_activities)*
AVERAGE(Time_fraction_to_communicate,Time_fraction_to_Coordinate
2
,Time_fraction_to_review,Time_fraction_to_Work))
)
}
aux Average_time_for_each_interaction {
autotype Real
autounit da/(person*doc)
def Contractual_design_time/Total_no_of_interaction
}
aux Briefing_to_team {
autotype Real
def GRAPHLINAS(Rate_of_Communication,0<<1/da>>,.02<<1/da>>,{0,.1,.2,.3,.4,.5,.6,.7,.8,.9,1//Min:0;
Max:1;Zoom//})
}
aux Capacity_to_solve_problem {
autotype Real
autounit da^-1
def Rate_of_interaction_actual/Probability_of_error
}
aux Carrying_capacity {
autotype Real
```

## Appendix A: Full List of the Model's Equations

---

```
def Total_no_of_interaction/Total_no_of_errors/1<<person*doc/error>>
}
aux Change_of_phases_effect {
autotype Real
def GRAPH(Design_process_steadiness,0,1,{0,.1,.2,.3,.4,.5,.6,.7,.8,.9,1//Min:0;Max:1;Zoom//})
}
aux Clear_deliverable {
autotype Real
def GRAPH(Procedure_of_producing_documents,0,1,{0,.1,.2,.3,.4,.5,.6,.7,.8,.9,1//Min:0;Max:1//})
}
level Communication {
autotype Real
init 0
doc the total infuence of communication is calculated based on the average influence of all factors on
communication
}
aux Concurrent_activities {
autotype Real
def No_of_designer_pressure
*Pressure_of_design_time
/Design_fee_pressure
}
const Contractual_design_time {
autotype Real
autounit da
init 270<<da>>
//either the contractactual design time has to be decided
//or the no of designers need to be fixed
}
level Coordination {
autotype Real
init 0
inflow { autodef Rate_of_coordination }
}
aux Copy_of_interaction_communicated {
autotype Real
autounit da
def (Total_no_of_interaction/Coordination)*Time_to_do_an_interaction
}
const Culture_of_team {
autotype Real
init 1
permanent
}
aux Design_fee_available {
autotype Real
autounit USD
3
def (Design_fee_factor+(Reputation_of_designer-1))*Design_fee_required
}
aux Design_fee_factor {
autotype Real
def Reputation_of_designer
// As the fess is an output of the reputation of designer in education.
//experience, previous experience, etc
}
aux Design_fee_pressure {
autotype Real
def Design_fee_required/Design_fee_available
}
aux Design_fee_required {
autotype Real
autounit USD
def Contractual_design_time*Designer_salary*No_of_designers_required
*((Amount_of_work_with_designer+1)/Amount_of_work_with_designer)
*Reputation_of_designer
```

## Appendix A: Full List of the Model's Equations

---

```
//when percentage of amount of work increase the fees are highy and vise versa
//may be we need to include the Profit and OverHead expenses
zeroorder
doc the design fee is the multiplication of the no of designer with salary and the period
}
aux Design_management {
autotype Real
def Design_office_ingredient*Reputation_of_designer
//when it is more than 1 it show noise at the end of the project
}
aux Design_office_ingredient {
autotype Real
def AVERAGE (Factor_of_designer_education
,Expereinced_designer
,Previous_designer_expereince
,availability_of_information
,Availability_of_QA_procedure)
//may be we have to add the cumulative experience of the designer
}
aux Design_process_steadiness {
autotype Real
def (Rate_of_interaction_actual/Rate_of_interaction_original)
*Effect_of_no_of_phases*Design_management*Culture_of_team
}
aux Designer_salary {
autotype Real
autounit USD/(mo*person)
def Salary_standard
*Factor_of_designer_education
*Previous_designer_expereince
}
aux Difference_of_interaction {
autotype Real
def (Rate_of_interaction_actual-Rate_of_interaction_original)/Rate_of_interaction_original
//this variables calculate the number of interaction which do not take place due
//to actual situation of the project
}
aux Document_review {
autotype Real
def Design_office_ingredient+
DELAYINF(Availability_of_QA_procedure,QA_start_date)*(1+Difference_of_interaction)
//QA review will deduct the interaction which did not take place
//due to the actual situation of the project
//1 is added because all the interaction are reviewed plus all the difference of interaction
}
aux e1 {
autotype Real
autounit error
def Total_no_of_errors*.8
4
}
aux e2 {
autotype Real
autounit error
def Total_no_of_errors*.2
}
aux e3 {
autotype Real
autounit error
def Total_no_of_errors*.4
}
aux Effect_of_no_of_phases {
autotype Real
def GRAPH(No_of_phases,1,1,{1,0.59,0.34,0.16,0.08,0.05,0.1,0.18,0.57,0.7,0.73//Min:0;Max:1//})
}
aux Effective_design_team {
```

## Appendix A: Full List of the Model's Equations

---

```
autotype Real
def AVERAGE(
GRAPH(Designer_salary,0<<USD/person/mo>>,1<<USD/person/mo>>,{0,.1,.2,.3,.4,.5,.6,.7,.8,.9,1//
Min:0;Max:1//})
,Factor_of_designer_education
,Previous_designer_expereince
,Match_of_goals
,Procedure_of_producing_documents
)
}
aux Efficiency_of_production {
autotype Real
def Factor_of_designer_education*Previous_designer_expereince*Effective_design_team
//how to calculate the rate of production is it
//doc per time ??
note dimensionless
}
level Erroneous_action {
autotype Real
autounit error
init 0<<error>>
inflow { autodef Rate_of_erroneous_action }
outflow { autodef Rate_of_discovered_error }
outflow { autodef Rate_of_discovery_of_erroneous_action }
doc it includes all the action which has been solved wrongly in the first place and whihc will increase the
amount of error
}
level Erroneous_action_discovered {
autotype Real
autounit error
init 0<<error>>
inflow { autodef Rate_of_discovered_error }
}
level Erroneous_action_undiscovered {
autotype Real
autounit error
init 0<<error>>
inflow { autodef Rate_of_discovery_of_erroneous_action }
}
aux Error_discovered {
autotype Real
autounit error
def Erroneous_action_discovered+Skipped_error_discovered
}
level Error_solved_correctly {
autotype Real
autounit error
init 0<<error>>
inflow { autodef Rate_of_correctly_solving_problems }
doc it includes all the action which has been solved wrongly in the first place and whihc will increase the
amount of error
5
}
aux Error_undicovered {
autotype Real
autounit error
def Erroneous_action_undiscovered+Skipped_error_undiscovered
}
aux Errors_discovered {
autotype Real
autounit error
def Erroneous_action_discovered+Skipped_error_discovered
}
aux Errors_skipped {
autotype Real
autounit error
```

## Appendix A: Full List of the Model's Equations

---

```
def Auxiliary_4-Total_no_of_errors
}
level Errors_solved_assumed {
autotype Real
autounit error
init 0<<error>>
outflow { autodef Rate_of_erroneous_action }
outflow { autodef Rate_of_correctly_solving_problems }
inflow { autodef Rate_of_problem_solved }
}
const Expeirnced_designer {
autotype Real
init 1
permanent
}
aux External_variables {
autotype Real
def 0
}
aux Extra_activities {
autotype Real
autounit person*doc
def ((Total_no_of_errors*Probability_of_error/Factor_of_error_due_to_interaction)
-Total_no_of_interaction)
}
const Factor_of_designer_education {
autotype Real
init 1
//1 for proper education
//0 for no education
permanent
}
const Factor_of_error_due_to_interaction {
autotype Real
autounit error
init 1<<error>>
//person*doc/wk
permanent
}
const Factor_of_reuption {
autotype Real
init 1
// 1 he is normal reputed designer where their intention is to work as per the standard practice
// more than 1 he is reputed proportionally and he try to minimize error to maintain
//his reputation
}
aux Fator_of_concurrent_activities {
autotype Real
unit %
def (Contractual_design_time/Available_design_time)-1
//the percentage of the amount of conrrent activites
}
aux Free_interaction {
6
autotype Real
autounit error
def Erroneous_action_undiscovered+Skipped_error_undiscovered
}
aux group_organisation {
autotype Real
def Design_management
}
aux Initial_rate_of_errors {
autotype Real
autounit error/da
def MAX(0<<error/da>>,
```

## Appendix A: Full List of the Model's Equations

---

```

((Rate_of_interaction_actual-(Rate_of_interaction_actual*(Concurrent_activities-1)))
/Probability_of_error)
*Factor_of_error_due_to_interaction)
}
aux Interaction_communicated {
autotype Real
autounit da
def (Total_no_of_interaction/Communication)*Time_to_do_an_interaction
}
aux Interaction_communication {
autotype Real
autounit person*doc/da
def Total_no_of_interaction*Rate_of_Communication
}
aux Interaction_coordinated {
autotype Real
autounit person*doc/da
def Total_no_of_interaction*Rate_of_coordination
}
aux Interaction_extra {
autotype Real
autounit error
def Remaing_interaction
}
level Interaction_has_communicated {
autotype Real
autounit person*doc
init 0<<person*doc>>
inflow { autodef Interaction_communication }
}
level Interaction_has_coordinated {
autotype Real
autounit person*doc
init 0<<person*doc>>
inflow { autodef Interaction_coordinated }
}
aux Internal_approval {
autotype Real
def GRAPH(Clear_deliverable,0,.1,{0,.1,.2,.3,.4,.5,.6,.7,.8,.9,1//Min:0;Max:1//})
}
aux Internal_variables {
autotype Real
def 0
}
level Knowledge {
autotype Real
init availability_of_information+Knowledge_pre_exist
inflow { autodef Tranfer_of_knowledge }
}
aux Knowledge_pre_exist {
autotype Real
def AVERAGE (Factor_of_designer_education
,Expereinced_designer
,Previous_designer_expereince
,availability_of_information)
7
}
const Match_of_goals {
autotype Real
init 1
permanent
}
aux Motivation {
autotype Real
def
GRAPH(Designer_salary,0<<USD/person/mo>>,.1<<USD/person/mo>>,{0,.1,.2,.3,.4,.5,.6,.7,.8,.9,1//

```

## Appendix A: Full List of the Model's Equations

---

Min:0;Max:1//})  
}  
**level** no of error occured due availability of QA {  
**autotype** Real  
**autounit** error  
**init** 0<<error>>  
}  
**level** no of error occured due effective team {  
**autotype** Real  
**autounit** error  
**init** 0<<error>>  
}  
**level** no of error occured due to amout of work {  
**autotype** Real  
**autounit** error  
**init** 0<<error>>  
}  
**level** no of error occured due to availibility of information {  
**autotype** Real  
**autounit** error  
**init** 0<<error>>  
}  
**level** no of error occured due to communication {  
**autotype** Real  
**autounit** error  
**init** 0<<error>>  
}  
**level** no of error occured due to deign time {  
**autotype** Real  
**autounit** error  
**init** 0<<error>>  
}  
**level** no of error occured due to design-management {  
**autotype** Real  
**autounit** error  
**init** 0<<error>>  
}  
**level** no of error occured due to design-process {  
**autotype** Real  
**autounit** error  
**init** 0<<error>>  
}  
**level** no of error occured due to designer eeducation {  
**autotype** Real  
**autounit** error  
**init** 0<<error>>  
}  
**level** no of error occured due to designer fee {  
**autotype** Real  
**autounit** error  
**init** 0<<error>>  
}  
8  
**level** no of error occured due to designer salary {  
**autotype** Real  
**autounit** error  
**init** 0<<error>>  
}  
**level** no of error occured due to no of design fees {  
**autotype** Real  
**autounit** error  
**init** 0<<error>>  
}  
**level** no of error occured due to no of designers {  
**autotype** Real  
**autounit** error



## Appendix A: Full List of the Model's Equations

---

```
init 0<<error>>
}
level no of error occured due to procedure {
autotype Real
autounit error
init 0<<error>>
}
level no of error occured due to reputation of designer {
autotype Real
autounit error
init 0<<error>>
}
level no of error occured due to transfer of knowledge {
autotype Real
autounit error
init 0<<error>>
}
aux No_of_designer_available {
autotype Real
autounit person
def No_of_designer_availability_factor*No_of_designers_required
//1 mean it is as required no of designer
//less than 1 mean it is understaffed
//more than 1 mean it is over staffed
}
aux No_of_designer_availability_factor {
autotype Real
def Design_fee_factor*Reputation_of_designer
//the designer available depend on the design fee and the reputation of design
}
aux No_of_designer_pressure {
autotype Real
def No_of_designer_available
/No_of_designers_required
}
aux No_of_designers_required {
autotype Real
autounit person
def (Required_hours*Efficiency_of_production/Working_hour_per_Week_per_designer)
/Contractual_design_time
}
const No_of_disciplines {
type Integer
init 10
permanent
}
aux No_of_free_interaction {
autotype Real
autounit person*doc
def MAX(0<<person*doc>>,(
(Total_no_of_interaction/Probability_of_error)
-(Total_no_of_errors/Factor_of_error_due_to_interaction)
)*Probability_of_error)
}
9
const No_of_phases {
autotype Real
init 5
permanent
}
aux Pace_of_change {
autotype Real
def (Rate_of_interaction_actual/Rate_of_interaction_original)
*GRAPH(Rate_of_Communication,0<<1/da>>,.02<<1/da>>,{0,.2,.4,.6,.8,1//Min:0;Max:1//})
//1 represent the pacing of changes minus
//the other factor increase or decrease the pace of change
```

## Appendix A: Full List of the Model's Equations

---

```
//as communication increase the pace of change decrease which has been taken in consideration
//by using the graph
}
aux Planning_of_work {
autotype Real
def Design_management+Design_process_steadiness
doc influence of design management on planning is propopotinal, proper design management force
planning to be implimented
}
level Potential_error {
autotype Real
autounit error
init 0<<error>>
outflow { autodef Rate_of_skipped_action }
inflow { autodef Initial_rate_of_errors }
outflow { autodef Rate_of_problem_solved }
inflow { autodef Rate_of_errors_discovery }
doc considering every interaction in the process as a potential error
}
aux Pressure_of_design_time {
autotype Real
def Workload*(No_of_designer_available*Available_design_time)/
(Contractual_design_time*No_of_designers_required)
//when the value is 0 it means there is no pressure
//and as the value is increasing the pressure is increasing till
//it reach 1 which means that the pressure is at peak value.
}
const Previous_designer_expereince {
autotype Real
init 1
//enough expereince to handle project
//1 for full knowldge about the project
//0 for nill knowldge about the project
permanent
}
aux Probability_of_error {
autotype Real
autounit person*doc
def 1<<person*doc>>*Reputation_of_designer
//the possibility of an error due to every person
//in every document, as reuption of designer increase
//it decrease his possiblities of making errors and vise versa
}
const Procedure_of_producing_documents {
autotype Real
init 1
//1 there is a procedure
//0 there is no procedure
permanent
}
aux Project_Completed {
autotype Logical
def STOPIF(TIME=STARTTIME+Contractual_design_time)
doc This is a stop control, which is used for creating an event that alerts the user when the project is
finished.
}
10
aux Proper_analysis {
autotype Real
def AVERAGE(Factor_of_designer_education
,Knowledge
,Previous_designer_expereince
)
}
aux QA_start_date {
autotype Real
```

## Appendix A: Full List of the Model's Equations

---

```
autounit da
def Contractual_design_time/No_of_phases
//normally the QA take place at the end of each phase
}
aux Rate_of_Communication {
autotype Real
autounit da^-1
def (Rate_of_interaction_actual/Rate_of_interaction_original)
*aa_Discovery_of_error*Knowledge*Pressure_of_design_time
*Design_management*Planning_of_work*Workload*Work_product_procedure
*group_organisation*Concurrent_activities*
Effective_design_team
//all the variables as they increase help in reducing the rate of interaction
doc the total influence of communication is calculated based on the average influence of all factors on
communication
multiplied by the no of disciplines and the no of designers
}
aux Rate_of_coordination {
autotype Real
autounit da^-1
def Design_management*(Workload*Rate_of_interaction_actual/Rate_of_interaction_original)
*Pace_of_change*Change_of_phases_effect*Concurrent_activities*Document_review
*Rate_of_Communication*Planning_of_work
//may be interaction rate should be added to this coordination and communication
}
aux Rate_of_correctly_solving_problems {
autotype Real
autounit error/da
def MAX(0<<error/da>>,DELAYINF(aa_Quality_of_work*Errors_solved_assumed,QA_start_date))
//the dicovery of error start when the QA start
}
aux Rate_of_discovered_error {
autotype Real
autounit error/da
def aa_Discovery_of_error*Erroneous_action
//the dicovery of error start when the QA start
}
aux Rate_of_discovered_skipped_error {
autotype Real
autounit error/da
def DELAYINF(Skipped_error*aa_Discovery_of_error,QA_start_date)
}
aux Rate_of_discovery_of_erroneous_action {
autotype Real
autounit error/da
def MAX(0<<error/da>>,
(Erroneous_action-Erroneous_action_discovered)/Available_design_time)
}
aux Rate_of_erroneous_action {
autotype Real
autounit error/da
def MAX(0<<error/da>>,(Errors_solved_assumed-Error_solved_correctly)/Available_design_time)
//the dicovery of error start when the QA start
doc the action which it is not solved will be consider as errornous action which has to will might be
discovered by disovery_of_error factor
}
aux Rate_of_error_occurance {
autotype Real
11
autounit error/da
def Factor_of_error_due_to_interaction*(
((aa_Designer_experience+aa_Share_of_knowledge+aa_Discovery_of_error+aa_Solving_problem)
*(aa_Input_to_team+aa_Flow_of_information+aa_Production_of_documents))
-(aa_Quality_of_work))
}
aux Rate_of_errors_discovery {
```

## Appendix A: Full List of the Model's Equations

---

```
autotype Real
autounit error/da
def Rate_of_discovered_error+Rate_of_discovered_skipped_error
}
aux Rate_of_interaction_actual {
autotype Real
autounit person*doc/da
def Amount_of_document_produced*No_of_disciplines*No_of_designer_available DIVZO
Available_design_time
//availability of QA if 1 will mean that all interaction will happen
// if QA is less than 1 will mean less interaction happening
}
aux Rate_of_interaction_original {
autotype Real
autounit person*doc/da
def Amount_of_document_produced*No_of_disciplines*No_of_designers_required/
Contractual_design_time
}
aux Rate_of_problem_solved {
autotype Real
autounit error/da
def MAX(0<<error/da>>,
(Potential_error)*aa_Solving_problem
+Auot_error_solving)
*(Rate_of_interaction_actual/Rate_of_interaction_original)
}
aux Rate_of_skipped_action {
autotype Real
autounit error/da
def MAX(0<<error/da>>,
Potential_error*(Rate_of_interaction_actual/Rate_of_interaction_original)
/Available_design_time)
}
aux Rate_of_undiscovered_skipped_error {
autotype Real
autounit error/da
def (Skipped_error-Skipped_error_discovered)/Available_design_time
}
aux Remaing_interaction {
autotype Real
autounit error
def (Rate_of_interaction_actual*Available_design_time/Probability_of_error
*Factor_of_error_due_to_interaction)-Total_no_of_errors
}
aux Reputation_of_designer {
autotype Real
def AVERAGE (Factor_of_designer_education
,Expeirenced_designer
,Previous_designer_expereince
,Factor_of_reuption)
}
aux Required_hours {
autotype Real
autounit hr
def Amount_of_document_produced*Required_time_to_produce_a_document
}
const Required_time_to_produce_a_document {
autotype Real
autounit hr/doc
init 50<<hr/doc>>
12
permanent
}
aux Resource_allocation {
autotype Real
def Planning_of_work
```

## Appendix A: Full List of the Model's Equations

---

```
doc planning shows when resources is needed
}
aux Resources {
autotype Real
def Amount_of_work_with_designer
*Design_fee_factor
*No_of_designers_required/No_of_designer_available
}
const Salary_standard {
autotype Real
autounit USD/(mo*person)
init 1<<USD/person/mo>>
permanent
}
aux Share_of_understanding {
autotype Real
autounit da^-1
def aa_Share_of_knowledge*Rate_of_coordination/Rate_of_Communication
}
level Skipped_error_discovered {
autotype Real
autounit error
init 0<<error>>
inflow { autodef Rate_of_discovered_skipped_error }
}
level Skipped_error_undiscovered {
autotype Real
autounit error
init 0<<error>>
inflow { autodef Rate_of_undiscovered_skipped_error }
}
level Skipped_error {
autotype Real
autounit error
init 0<<error>>
inflow { autodef Rate_of_skipped_action }
outflow { autodef Rate_of_discovered_skipped_error }
outflow { autodef Rate_of_undiscovered_skipped_error }
doc it include all the interaction which did not take place in the production process
}
aux Technical_knowledge_availability {
autotype Real
def Breifing_to_team*Resource_allocation
}
aux Time_comulitive_used {
autotype Real
autounit da
def Available_design_time-Time_unused_to_date
}
aux Time_for_extra_activities {
autotype Real
autounit da
def ABS(Extra_activities)*Time_to_do_an_interaction
}
aux Time_fraction_to_communicate {
autotype Real
def 1
}
aux Time_fraction_to_Coordinate {
autotype Real
def 1
}
13
aux Time_fraction_to_review {
autotype Real
def 1
```

## Appendix A: Full List of the Model's Equations

---

```
}
aux Time_fraction_to_solve_problems {
autotype Real
autounit da/error
def Contractual_design_time/(Error_discovered+Skipped_error_discovered)
}
aux Time_fraction_to_Work {
autotype Real
def 1
}
aux Time_free_from_skipped_errors {
autotype Real
autounit da
def Free_interaction*Time_to_do_an_interaction*Probability_of_error
//Factor_of_error_due_to_interaction
//this time is due to time skipped from undiscovered skipped errors and undiscovered
//errors
}
aux Time_free_unused {
autotype Real
autounit da
def (No_of_free_interaction*Time_to_do_an_interaction)
+Time_free_from_skipped_errors
}
aux Time_needed_for_project {
def AVERAGE (
1+Time_fraction_to_communicate,
1+Time_fraction_to_Coordinate,
1+Time_fraction_to_review,
1+Time_fraction_to_solve_problems,
1+Time_fraction_to_Work)
}
aux Time_of_each_phase {
autotype Real
autounit da
def Available_design_time/No_of_phases
}
aux Time_spend_to_solve_problem_correctly {
autotype Real
autounit da
def Error_solved_correctly*Time_to_do_an_interaction*Probability_of_error/
Factor_of_error_due_to_interaction
}
aux Time_to_communication {
autotype Real
autounit da
def Total_no_of_interaction/Communication*Time_to_do_an_interaction
}
aux Time_to_coordinate {
autotype Real
autounit da
def Total_no_of_interaction/Coordination*Time_to_do_an_interaction
}
aux Time_to_do_an_interaction {
autotype Real
autounit da/(person*doc)
def Contractual_design_time
//(Amount_of_document_produced*No_of_designers_required*No_of_disciplines)
//no of designers required per disciplin
doc as the assumption is that an interaction is the multiplication of no of designer X no of discipline X
amount of document produced
then the time of doing an interaction is divided of contractual time by the no of interaction
}
aux Time_to_solve_extra_problems {
14
autotype Real
```

## Appendix A: Full List of the Model's Equations

---

```
autounit da
def Error_discovered
*Time_to_do_an_interaction
*Probability_of_error
/Factor_of_error_due_to_interaction
}
aux Time_unused_to_date {
autotype Real
autounit da
def (No_of_free_interaction*Average_time_for_each_interaction)
}
aux Total_no_of_errors {
autotype Real
autounit error
def Error_solved_correctly
+Skipped_error_discovered
+Erroneous_action_discovered
//these errors are either discovered errors or remained unsolved in the potential error stock
//undiscovered error are excluded from the total number of errors
//as they are undiscovered
}
level Total_no_of_interaction {
autotype Real
autounit person*doc
init 0<<person*doc>>
inflow { autodef Rate_of_interaction_actual }
}
aux Total_time_fractions {
autotype Real
def AVERAGE (
Time_fraction_to_communicate,
Time_fraction_to_Coordinate,
Time_fraction_to_review,
Time_fraction_to_solve_problems*1<<error/da>>,
Time_fraction_to_Work)
}
aux Total_time_to_communicate_and_coordinate {
autotype Real
autounit da
def Time_to_coordinate+Time_to_communication
}
aux Tranfer_of_knowledge {
autotype Real
autounit da^-1
def Rate_of_Communication/Knowledge
doc the total infulence of communication is calculated based on the average influence of all factors on
communication
}
aux Unsolved_error {
autotype Real
autounit error
def Erroneous_action_undiscovered+Skipped_error_undiscovered
}
const Wokring_hour_per_Week_per_designer {
autotype Real
autounit person^-1
init 208<<hr/mo/person>>
permanent
}
aux Work_product_procedure {
autotype Real
def Design_management
}
aux Workload {
autotype Real
def (Rate_of_interaction_original/Rate_of_interaction_actual)
```

## Appendix A: Full List of the Model's Equations

---

```
15
*No_of_designer_pressure
}

unit doc {
def ATOMIC
doc the unit is for the documentation count
}
unit error {
def ATOMIC
}
unit loc {
def __LOCALCURRENCY
doc Currency - locale currency unit
}
unit person {
def ATOMIC
doc People - here a Worker, or people working on the project
}
unit project {
def ATOMIC
}
unit USD {
def __CURRENCY("USD")
doc US Dollars
}
16
```



## **Appendix B**

Dear Sir,

This is a PhD research project which aims to investigate the cause of errors in the construction (design) documents, carried out at the **School of the Built Environment, Heriot-Watt University, Edinburgh, UK.**

The aim of this research is to improve the construction industry, through the development of a strategy for eliminating - or at least reducing the number of - errors generated in the construction (design) documents

The research will be based on the case study project, and the responses to the questionnaire would therefore be much appreciated and treated with confidentiality.

A brief synopsis of the completed study will be available upon request.

Thanking you in anticipation of your kind cooperation.

Yours faithfully,

Rukn Eldeen Mohammed

P.S.

For any clarification regarding any question, please feel free to contact me on

Mobile 0504475807

# Questionnaire No (      )

**Name and Telephone No (Optional):**

.....

**Type of project:** .....

(Residential, Offices, Shopping Centre, etc...)

**Type of Client:** .....

(Government, Semi Government, Private, Developer)

**Discipline:** .....

(Whole Project, Architecture, Structure, Electrical, and Mechanical)

**Estimated cost of project:**.....

**Nature of Contract:** .....

(Traditional, Design build, Construction Management, Fast Track, etc... )

---

**Please circle the appropriate answer(s) as applicable or the fill the gap**

1. What is the composition of the project team? (Please tick as appropriate)

- a Client/ client representative
- b Project manager
- c Architects / engineers
- d Other (please specify)

.....

2. Composition of client team (please tick as appropriate)

- a. Client himself
- b. Client representative
- c. Architects and/or engineers (separate from the client)

.....

3. Composition of design team

- a. Project director..... Number
- b. Project manager..... Number
- c. Senior architect(s)..... Number
- d. Senior engineers..... Number
- e. Technical..... Number
- f. Other (please specify)

.....

4. Experience of design team
  - a. Project manager
    - a. Less than 5 years
    - b. Between 5-10 years
    - c. More than 10 years
  - b. Architects
    - a. Less than 5 years
    - b. Between 5-10 years
    - c. More than 10 years
  - c. Engineers
    - a. Less than 5 years
    - b. Between 5-10 years
    - c. More than 10 years
  
5. Costs (In Saudi Riyadh)
  - a. Estimated cost of project .....
  - b. Cost of project at completion .....
  - c. Cost of design work.....
  - d. Or percentage of construction project
  
6. Duration of design work (In weeks)
  - a. Original agreed time
  - b. Final
  - c. If there is a difference, please explain
   
.....
   
.....
  
7. Content of the construction document
  - d. Drawings
  - e. Specifications
  - f. Bills of quantity
  - g. Form of contract
  - h. Schedules
  - i. Addenda
  - j. Other (please specify)
   
.....
  
8. How many phases do you have in your office for producing construction documents?
  - k. One phase
  - l. Two phase
  - m. Other (please specify)
   
.....

9. Can you please specify why you have that number of phases in your office
- n. Office practice
  - o. Municipality requirements
  - p. Contractual (client requirements)
  - q. Other (please specify)  
.....

10. Types of errors in the construction documents

**Nature of documents:** ..... (QA drawings set, variation order, tender queries)

	Types of errors in the construction documents	Number of errors occurring in the project				
		None (0)	Very Few (0-5)	Few (5-10)	Average (10-20)	More than 20
1	Does not conform to client's design criteria					
2	Does not conform to code					
3	Does not conform to design calculations					
4	Coordination problem (between discipline)					
5	Discipline coordination problems (within the same discipline)					
6	Operability problem					
7	Constructability problem					
8	Does not conform to vendor data (elevators, equipment,...)					
9	Dimensional error					
10	Callouts of the details are incorrect or missing					
11	CADD (Computer ) related problem					
12	Missing or incorrect notes on the drawings					
14	Additional views / details needed					
15	Does not conform to drafting standards					
16	Errors in capital cost estimating errors					
17	Designer error					
18	Does not confirm to the municipal regulations					
19	Does not confirm with the law (such as documents must specify Saudi products)					
20	Error in project contextual factors, (not compatible with survey or roads)					
21	Errors and omission in the bills of quantities					
22	Errors in symbols and abbreviations					
23	Errors in specifications					
24	Others ( please specify)					

## **Interview Questions**

## Question for Interview - Form No (      )

1. The literature revealed many factors which affect the number of errors generated in the design documents. In your opinion which one of these factors affects your project?

Factor	Percentage (total must be 100%)
Project influence	
Client influence	
Project management influence	
Designer influence	
<b>Total</b>	<b>100%</b>

2. The following factors should be drawn using causal diagrams (initial factors are drawn).

Classification	Factors influencing occurrence of errors in construction documents	Is this factor controlled by designers	Importance of Factors				
			Not important	Very low	Low	High	Very high
<b>Project Specifics Factors</b>	a. Time schedule pressure						
	b. Project budget cost						
	c. Project procurement						
	d. Size of the project						
	e. Quality demand of the project						
	f. Compatibility with consultant goals						
	g. Services provided						
	h. Authority approval						
	i. Type of construction (refurbishment, new)						
	j. Other (Please Specify) ..... .....						
	k.						
<b>Client Specifics Factors</b>	a. Type of client (private, developer, and government)						
	b. Client experience						
	c. Construction constraint time imposed by the client						



	d. Client point of contact (representative)							
	e. Planning the project							
	f. Identification of project risks							
	g. Attitude of client toward other members of the project team							
	h. Other (please specify) ..... .....							
<b>Project Management Specifics Factors</b>	a. Management organizational structure							
	b. Project manager's experience							
	c. Project brief							
	d. Project management fees							
	e. Other (please specify) ..... .....							
<b>Designer factors Specifics Factors</b>	a. Design process (nature of tasks or documents)							
	b. Design management experience							
	c. Designer professional education							
	d. Designer experience							
	e. Design fees							
	f. Design team efficiencies							
	g. Design time schedule							
	h. Procedure for producing documents							
	i. Designer salary							
	j. Number of designers							
	k. Concurrent design activities							
	l. Amount of work with the designer							
	m. Reputed designer							
	n. Availability of quality control							
	o. Effective design team							
	p. Communication							
	q. Availability of information							
r. Transfer of knowledge and experience between designers								
s. Other (please specify) .....								

1. How many projects like this have you experienced?
  - a None
  - b One only
  - c Too many (please specify)
  - .....

**Project characters**

2. What is the level of pressure to finish the contract documents?
  - a No pressure
  - b Very low
  - c Low
  - d Normal
  - e Very high
  
3. What is the project budget?
  - a Up to 10 millions
  - b Between 10-20 millions
  - c Between 20 -50 millions
  - d Between 50 - 100 millions
  - e More than 100 millions
  
4. What is the method of procurement of this project?
  - a Traditional
  - b Design & Build
  - c Accelerated traditional
  - d Construction management
  - e Other (please specify)
  - .....
  
5. Would you please describe the size of the project?
  - a Build up area of the project  
 .....M<sup>2</sup>
  
  - b Number of floors
    - Single floor
    - Two floors
    - Two to five floors
    - Five to ten floors
    - More than ten floors
  
  - c Number of drawings
    - Architecture .....

- Interior design .....
- Landscape .....
- Structure .....
- Electrical .....
- Mechanical .....
- .....
- 

6. What was the demand of quality in this project?
  - a No demand for quality
  - b Low quality
  - c Normal
  - d High
  - e Very high, prestige project
  
7. Is the office interested in doing this project?
  - a No
  - b Normal job
  - c High
  - d Too much
  
8. How many services are provided for this project?
  - a Project management only
  - b One service only
  - c Services only
  - d All design services (architect, all services, structure, and BOQ)
  - e Full services (above services and including project management)
  
9. What is the level of constraint (authority law and regulations) on the project?
  - a No constraint
  - b Regular municipal regulations
  - c Very restricted municipality regulations
  
10. What is the type of construction?
  - a New construction
  - b Refurbishment
  - c Subcontracting ( for the main contractors)

**Client Factors**

11. What is the type of the client?
  - a Private
  - b Developer
  - c Semi- government
  - d Government

12. Does the client have experience of this type of project?
- a None
  - b Similar project
  - c One like this project
  - d More than one project
13. Does the client impose any time pressure on the consultant?
- a No
  - b Low
  - c Average
  - d High
14. Does the client have any established plan for carrying out the project?
- a No
  - b Primitive plan without control
  - c Plan with control
15. Who is the client's representative?
- a None
  - b From client organization without experience
  - c From client organization with experience
  - d Consultant
16. Does the client have knowledge about the risk management?
- a No
  - b Yes
17. What is the attitude of the client toward the design team?
- a Hostile
  - b Friendly
  - c Professional

**Project Management Characters**

18. Project management organization
- a Does the project management organization fit the project?
    - No
    - Yes
    - Partly
  - b What is the composition of the project team? (Please tick as appropriate)
    - Client/ client representative
    - Project manager
    - Architects / engineers
    - Other (please specify).....

- .....

19. Experience of project manager

a Does the project manager have previous experience in this type of project?

- No
- Yes

b Project manager experience

- None
- Between 1-5 years
- Between 5-10 years
- More than 10 years

20. Project brief

a What is the level of quality of the project brief?

- There is project brief
- Unclear
- Below average
- Average
- Good
- Perfect

b Is the project brief transferred to other members of the team?

- Yes
- No

21. Project management fees

a Are the project management fees fair?

- Yes
- No

b How are the project manager fees calculated?

- Not applicable
- On percentage basis
- Lump sum

c Do the project manager fees prevent them from doing their job properly?

- Yes
- No

22. Process of the preparation of the documents

a Do you have any variation order (regardless of the originator) during the process of preparing the construction documents?

- Yes
- No

- b How smooth was the process during the process of the preparing the documents?
  - Very difficult
  - Difficult
  - Easy
  - Very easy

23. Design management experience

- a Is there any design manager (or head of department)?
  - Yes
  - No
  
- b Do you have any plan for producing the documents and allocation of resources?
  - Yes
  - No
  
- c Does the design manager pass the information to the designer(s)?
  - Yes
  - No

24. Main designer education

- a What is the level of education of the main designer?
  - Diploma
  - University degrees
  - Higher degrees
  
- b Is he registered in an accredited organization or associations?
  1. Yes
  2. No

25. Main designer experience

- a Does the designer have experience in this type of project?
  - Yes
  - No
  - Partly
  
- b Is there any other person in the organization who has this particular experience?
  3. Yes
  4. No

**Designer Factors**

26. Design Fees

- a How do you calculate the design fees?
  - Lump sum

- Fixed rate per hour
  - Fixed rate per man/hour
  - Fixed rate per drawing
  - Actual cost plus profit
- b How do you compare your fees compared with others in the market?
- Very low
  - Low
  - Average
  - High
  - Very high
- c What is the level of profit in the design fees?
- Lost
  - Break even (no profit, cover all expenses)
  - Profitable
  - Generous profit
- d With reference to the previous question, why does that happen?
- Fees not fair
  - Fees is fair but estimation was wrong
  - Over spending
  - Generous fees
  - Public relations reasons
- e Are you going to work with the same client again at the same rates?
- Yes
  - No

27. Design team efficiencies

- a Is the design team cohesive?
- Yes
  - No
- b How do you describe the level of coordination between team members?
- No coordination
  - Very low
  - Low
  - High
  - Excellent
- c Do project team members change their goals to align with the team?
- Yes
  - No

- d Does your company have any quality control and assurance system in place?
  - International certification e.g. ISO
  - Quality control team
  - Quality control procedures

28. Design time

- a Did you finish the project on time?
  - Yes
  - No
  
- b With reference: to previous question, why?
  - Not enough time
  - Wrong estimation
  - Relaxed time
  
- c How do you calculate the design time?
  - Fixed time per drawing
  - Time management breakdown
  - As per the constraints of the client
  
- d If you do the same project again are you going to
  - Use different time estimation technique
  - Use the same time estimation
  - Reduce the time
  - Increase the time?

29. Procedure for producing documents

- a What type of procedure do you have for producing the documents?
  - None
  - Company custom procedure
  - Client custom procedure
  - International recognized procedure (such as AIA, RIBA)
  
- b With reference: to the previous question, are you satisfied with your current procedures?
  - No, looking for alternative
  - Yes, but need adjustment
  - Completely satisfied
  
- c Why did you adopt your present system?
  - Individual initiative
  - Company policy
  - Quality certification requirements
  - Client requirements



- d Do you have a company drafting standard for producing the documents?
- No
  - Yes
  - Depends on the project

- e Do you have CADD procedure for producing the documents?
- No
  - Yes
  - Depends on the project

### 30. Designer salary

- a How do you compare the designer salaries with competitors in the market?
- Very low
  - Satisfactory
  - High
  - Very high

- b Is there a policy for deciding the level for salaries?
- No
  - Yes

- c Does your company have any system for the regular review of salaries?
- No
  - Yes
  - Incentive bases

- d Have you been paid on time at the end of the month?
- No
  - Yes
  - Sometimes

### 31. Number of designers

- a What is the composition of the design team?
- Designer (in the same discipline).....
  - Senior architects
  - Architects
  - Senior engineers....
  - Engineers

- b How did you decide the composition of the design team?
- Fee based

- Availability of designers
- Nature of project
- Client requirement

32. Concurrent design activities

- a What is the procedure of producing the documents?
- Sequential from general to specific
  - Most of the activities together
- b When you have many design activities concurrently, what do you do?
- Nothing, normal procedure
  - Increase the level of coordination and communication
  - Increase number of staff
- c Why you are doing the design activities concurrently?
- Time pressure to finish the project quickly
  - Fees pressure, to reduce the expenses
  - Quality procedure, to reduce errors and mistakes in the documents
  - Shortage of designers and increased work load.

33. Amount of work with the designer

- a Which of the following systems do you use to produce the design documents?
- Project specific team
  - Project team working on different project at the same time.
- b How many other projects were carried out during this project?
- None
  - Only one
  - Two to five projects
  - More than five projects

34. Reputation of the design office

- a How do you describe your office?
- Small design office.
  - Medium design office.
  - Outstanding design office.
- b What is the impression of the client about the project documents?
- Negative impression, with too many errors and mistakes
  - Positive impression.

35. Availability of quality control

- a What type of quality control do you have in place?
  - None
  - Company custom quality control procedure.
  - Internationally recognized quality control procedure.
  - Third party review
  
- b Why do you use quality control procedure?
  - Defensive
  - Company custom quality control procedure.
  - Internationally recognized quality control procedure.
  
- c How much you are paying as a percentage of design cost for the quality control procedure?
  - None
  - Less than 1% of design fees
  - Between 1% - 2%
  - Between 2% - 3%
  - Between 3%-5%
  - More than 5%

36. Effective design team

- a Does every member of the team have specific roles in the process of preparing the contract documents?
  - No
  - Partly
  - Yes
  
- b Do you understand what other peoples roles are in the team?
  - No
  - Partly
  - Yes
  
- c Do you have specific goals to achieve?
  - No
  - Partly
  - Yes
  
- d Do you have any tools or procedures to measure the progress in the project?
  - No
  - Partly
  - Yes

37. Communication

- a What type of communication is in place?
  - None
  - Informal communication
  - Company custom procedure
  - Internationally recognized quality control procedure (e.g. ISO)

38. Availability of information

- a Do you have all the information needed for the project?
  - None
  - Unaware
  - Some information
  - All the information
  
- b Why do you do not have all information?
  - We do not know that we need this information
  - The client refused to give us this information
  - The information needed time to get it, and we cannot wait until we get it.
  - We do not have a budget for it.
  
- c Do you get all the information correctly?
  - No
  - Partly
  - Yes

39. Transfer of knowledge and experience between individual designers

- a Is there a difference in experience between designers?
  - No
  - In some areas only
  - Completely different experience
  
- b If you lack experience in a particular area in the project, do you refer to
  - Another member of the design team
  - Standards and design manuals
  - Project manager
  - Combination of the above?
  
- c If you encounter a mistake made by a colleague, what do you do?
  - Ignore the mistake
  - Tell your colleague, and explain the correct solution
  - Report to the project manager

40. Out of the following team members, would you please rank the following as per their influence on generating errors in the construction documents?

(1 is the highest, 5 is the lowest)

- a .....Project characters
- b .....Client
- c .....Project manager
- d .....Designers
- e .....Other (please specify and rank)
- f .....

41. Change of key personnel

a Does the change of the key personnel in your team influence the quality of the documents?

- No
- Partially
- Yes

b If yes to the above question, why?

- He has the experience in the company
- He can deal better with the client
- He has experience in this type of project
- He can manage the team
- Other (please specify)
- .....

c Does the change of the key personnel in the client organization influence the quality of the documents?

- No
- Partly
- Yes

d If yes to the above, why?

- He is the only one in the client organization who has the knowledge
- He has a good relationship with the designer
- He is the project sponsor
- Other (please specify)
- .....

e Do you have personnel in your team who cannot be replaced?

- No
- Yes

42. Group organization

- a How do you describe the level of cooperation between the project team members?
  - Hostile
  - Professional
  - Friendly
  
- b Do you think you have the right organization structure?
  - No
  - Partly
  - Yes

43. How in your opinion can we improve the process of producing the construction documents to minimize the number of errors generated?

- a -
- b -
- c -
- d -
- e -
- f -