CASE-BASED REASONING MODEL FOR THE MANAGEMENT OF DESIGN RELATED CHANGES IN DESIGN-BUILD CONSTRUCTION PROJECTS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

AYDIN ÖZGÜNEŞ

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
BUILDING SCIENCE
IN
ARCHITECTURE

JANUARY 2016

Approval of the thesis:

CASE-BASED REASONING MODEL FOR MANAGEMENT OF DESIGN RELATED CHANGES IN DESIGN-BUILD CONSTRUCTION PROJECTS

submitted by **AYDIN ÖZGÜNEŞ** in partial fulfillment of the requirements for the degree of **Master of Science in Building Science in Architecture Department, Middle East Technical University** by,

Prof. Dr. Gülbin Dural Ünver ____________________
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. T. Elvan Altan ____________________
Head of Department, **Architecture**

Assoc. Prof. Dr. Ali Murat Tanyer ____________________
Supervisor, **Architecture Dept., METU**

Examining Committee Members:

Prof. Dr. M. Talat Birgönül ____________________
Civil Engineering Dept., METU

Assoc. Prof. Dr. Ali Murat Tanyer ____________________
Architecture Dept., METU

Prof. Dr. İrem Dikmen Toker ____________________
Civil Engineering Dept., METU

Assoc. Prof. Dr. Rıfat Sönmez ____________________
Civil Engineering Dept., METU

Assist. Prof. Dr. Timuçin Harputlugil ____________________
Architecture Dept., Çankaya University

Date: 13.01.2016

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name : Aydın ÖZGÜNEŞ

Signature :

ABSTRACT

CASE-BASED REASONING MODEL FOR THE MANAGEMENT OF DESIGN RELATED CHANGES IN DESIGN-BUILD CONSTRUCTION PROJECTS

Özgüneş, Aydın
M. S. in Building Science, Department of Architecture
Supervisor: Assoc. Prof. Dr. Ali Murat Tanyer

January 2016, 162 pages

Project changes constitutes to an important problem in construction projects which are unavoidable and may appear at any stage of the construction. Most of the time, project changes cause conflicts between the parties and end with change orders or claims that lead to time and money losses. Moreover, design related changes, which can be defined as variations related with the design process of the construction project, are referred as one of the most frequently seen project change types in construction projects. Especially in the design-build procurement type, design related changes lead to conflicts between contractor and architect because of the direct relationship between contractor and architect based on the contract. In this research, a knowledge-based decision support model for the management of the design related project changes is proposed. The model is based on case-based reasoning approach. It will be used by the contractor to identify the conflicts with the architect because of project changes that may occur in the design-build projects. The aim of the model is to present the contractor possible effects of the change on time and cost, responsible party in the situation and related contract information depending on standard type of contract between contractor and architect defined in the model. The database of the model consists of 227 architectural changes which were collected via a survey conducted with professionals of 6 large-sized housing projects in Turkey. At the end, the model was tested with the help of a usability measurement survey.

Keywords: Case-based reasoning, project changes, change management, conflict, claim management

ÖZ

TASARIM EVRESİNE BAĞLI PROJE DEĞİŞİKLİKLERİNİN YÖNETİMİ İÇİN DURUM TABANLI ÇIKARSAMA MODELİ GELİŞTİRİLMESİ

Özgüneş, Aydın
Yüksek Lisans, Yapı Bilimleri, Mimarlık Bölümü
Tez Yöneticisi: Doç. Dr. Ali Murat Tanyer

Ocak 2016, 162 sayfa

Proje değişiklikleri, inşaat projeleri için önemli bir sorun teşkil etmekte ve tasarım evresinden yapım sürecine kadar farklı zamanlarda ortaya çıkabilmektedir. Bu değişikliklerin etkileri, zamanlama ve türlerine göre değişkenlik gösterip, çoğu zaman yüklenici tarafından yapılan değişiklik talimatları veya hak talepleri ile sonuçlanmaktadır. Ayrıca, projelerde meydana gelen değişiklikler arasında tasarım süreci ile ilgili olanlar etkisi en dikkat çekici ve en sık görülen türlerden birini oluşturmaktadır. Mimari değişiklikler olarak da tanımlanabilen tasarım evresine bağlı olan proje değişiklikleri özellikle tasarla-inşa et tipi projelerde değişiklik talimatlarının ve hak taleplerinin ana sebebini oluşturup, tasarımcı ile yüklenici arasında anlaşmazlıklara neden olmaktadır. Bu çalışmada, tasarım evresine bağlı proje değişiklikleri için bilgi-tabanlı değişiklik yönetimi modeli önerilmiştir. Modelin geliştirilme sürecinde durum-tabanlı çıkarsama metodu kullanılmıştır. Projede bir değişiklik meydana geldiğinde yüklenici model yardımıyla tasarımcı ile arasındaki ilişkisini yönetebilecektir. Bu model tasarla inşa-et yöntemi ile inşa edilen konut projeleri için özelleşmiştir. Modelin amacı yükleniciye projede meydana gelen bir değişikliğin bütçe ve süreye etkilerini, diğer proje elemanları üzerindeki etkilerini, değişiklik sebebiyle oluşan anlaşmazlıklardaki sorumlu tarafı ve ilgili sözleşme maddesi hakkındaki bilgileri sunmaktır. Modelin veri-tabanında Türkiye'deki büyük ölçekli 6 konut projesinden elde edilen 227 proje değişikliği örneği bulunmaktadır. Son aşamada model kullanılabilirlik anketi ile test edilmiştir.

Anahtar kelimeler: Durum-tabanlı çıkarsama, proje değişikliği, değişiklik yönetimi, anlaşmazlık, hak talebi yönetimi

ACKNOWLEDGEMENTS

Firstly, I would like thank my advisor Assoc. Prof. Dr. Ali Murat Tanyer for his support and criticism in my research process. I'm thankful for his guidance in my graduate education and my professional life. I'm also grateful to him for his contribution to the publications related with my research in conferences in Antalya and Thessaloniki and project management magazine. Furthermore, I would like to express my gratitude to the professors of Civil Engineering Department for their attention in the classes through my graduate program.

I'm also thankful to my colleagues and superiors in Design Group of Mesa Construction Co. Their contribution to the research process is very significant. I would like to thank all my classmates from department of architecture for their participation in my research process and in my life.

Finally, I want to admit my thankfulness to my beloved family my mother, my dad, my aunt and my wife. Including this research, no success I achieved in my life would be possible without their endless support and encouragement.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

CHAPTER 1

INTRODUCTION

In this section, introduction about the research is presented in five parts; background information, research argument, aim and objectives of the research, contribution and disposition of the research.

1.1 Background Information

Changes in construction projects constitute to an important problem for contractors. They are unavoidable and may have several substantial effects on the construction projects. After the occurrence of a change situation in a construction project, change orders are made which are the adjustments to the existing contract documents and scope of the project. Most of the change orders cause time and cost overruns, disruptions and disputes between the parties of the construction work. In this process, contractors usually try to make use of different interpretation of clauses in the contract or lacking points in design drawings in order to enhance their profits (Alnuaimi *et al.*, 2010). According to Finke (1998), contract values increase between 5-10% as a result of the variations in construction projects. Furthermore, in most of the cases, agreement about change situation cannot be made within the borders of the contract and results in claims. Claim can be defined as a request of compensation of expenses of one of the parties which is resulted from the actions of other parties in the contract (Semple, Hartman, & Jergeas, 1994).

According to Diekmann and Nelson (1985), problems related to design constitute to the most important factors that bring changes in construction projects. These problems can be depicted as defects and omissions in the project drawings, delays in the delivery of design documents by designer to the construction site, changes due to the conflicts or misunderstandings between designer and client and inaccuracies between drawings and specifications (Sun & Meng, 2009).

1.2 Argument

Many researches exist on the management of changes and claims in construction projects. Types of changes were classified and relationship between causes and effects of changes were analyzed with respect to different construction sectors. In some of the studies, methods and tools were proposed for the management of changes in construction projects such as prediction models, knowledge based models, change effect calculation models etc. Moreover, there exist researches that aim to identify the claims in the construction works in which types of claims, causes and results were analyzed. However, majority of the researchers focused on the management of the process of a claim. Several methods are proposed in these researches about the management of claims such as negotiation process simulations, delay analysis methods or information management systems.

According to the background information, it can be concluded that changes constitutes to an important cause of claims in construction projects. Changes related with design process correspond to one of the most frequently seen and most influential type of change. Consequences of a change in the architectural design can bring about other various variations in a construction project which causes time and money losses for the contractor. As corresponding to the starting point of a construction project, the extent of the effect of a small variation related with the design can be easily estimated. In this case, the question of how a contractor can manage this kind of process arises. Faults and errors in design cannot be totally avoided in construction projects. Hence, assistance to the contractors about this issue can be in the form of a guide for the management of unforeseen project changes in their projects.

Another problem of the existing studies can be summarized as the general scope. Many of the existing researches about changes and claims focused on general type of changes. These studies cannot be easily adapted to the construction projects and used by the contractors as a tool. The reason of that can be different from the generalized type of changes, the contractors have to cope with more specialized and complicated type of changes in their projects. Therefore, the results of the researches should be easily adapted to the practical life and the ways of totally adaptation of this kind of models to the construction projects must be analyzed.

There exist several construction procurement types in construction sector such as design-bid-build, design-build or PPPs. Project changes in the construction works are generally resulted with conflicts between parties. So that, a change issue in a project directly related with the contracts and there are various contracts implemented for each procurement type. Specialization of the change management models for one type of contract and procurement type can bring about better adaptation of the models to the practical works.

As a result, existing methods about the management of claims and changes must be diversified. Change management methods should be studied for specific type of changes. At this point, project changes related with the design must be focused on because of corresponding to the most problematic type of changes in the construction projects. Furthermore, most of the researches about claim management in the literature focused on the negotiation process between the client and the contractor. In these studies claim situations were analyzed according to the contractual relationship between those parties. Therefore, rather than focusing on the contractual relationship between the contractor and the client, same kind of relationship between the designer and the contractor must be studied specifically in order to analyze contractual consequences of project changes related with the design.

Responsibilities of the contractual parties about project changes related with design differs according to procurement type of the construction project. For example, in design-bid-build type, responsibility of design works belongs to the owner

(American Institute of Architects, 2014). In this procurement method, the contractor and the designer has no direct relationship so that there isn't any possible claim situations arisen between these parties (AnCor Inc., 2010). However, there is a direct relationship between the designer and the contractor in design-build procurement method (Cushman & Loulakis, 2001). The contractor has a direct responsibility of contractual issues related with the works of the designer (Cushman & Loulakis, 2001). Hence, the consequences of project changes regarding the design process could be harmful if they were not managed adequately in design-build procurement type. Therefore, projects constructed with the design-build procurement method are selected in order to study the contractual relationship between the designer and the contractor.

Moreover, the variety and the number of the design changes can be connected with the level of inclusion of a designer in a construction project. The role of the designer differs with respect to the type of the project such as housing projects, office buildings or industrial complexes. According to Dluhosch (2006), the role of the designer in large-sized housing is very significant. For this reason, large-sized housing projects are selected in order to collect a large variety of project change examples.

Finally, it is argued that project changes related with design constitute to one of the most significant problems of the contractors. Especially in design-build construction projects, the effects of this kind of project changes are very high and the professionals are in need of establishing a model for management of project changes in their projects.

1.3 Aim and Objectives

The main aim of this research is to propose knowledge-based decision support model for project changes regarding the design process. This model is going to be used by contractors in their construction projects procured by design-build method. When a project change appears in the construction phase of the project, the model will provide assistance about the management of related project change event. In this stage, information about possible effects of the project change and potential contractual consequences will be shown to the contractor. At the end, the contractor will be able to manage the process of change event better with the help of this model.

The objectives of the research are;

- Collection of the examples of project changes related with the design process in the large-sized housing projects in Turkey,
- Analysis of types, causes and impacts of these project changes,
- Transformation of collected examples of project changes to a database in which information about each event are divided into several features,
- Formation of a model based on this database in which case-based reasoning approach is employed,
- Testing of the model with a usability measurement survey at the end of the research process.

1.4 Contribution

In the literature, there exist studies that analyzing causes, types and effects of changes together with the status of change and claim management in the related construction sector. There are also several researches which aim to suggest new methods for change and claim management processes, most of which implemented IT tools such as prediction methods, knowledge-based decision support systems, simulation models for phases of the process and change monitoring systems etc. The main point of these researches is that the models were focused on general type of changes that can occur in the construction projects. They generally take account of the contractual relationship between the contractor and the client when dealing with the conflicts related with these changes. Specification of the studies with respect to one specific type of change can bring about more effectual outputs for the professionals of the construction sector. Classifying the project changes with respect to their resources can bring about analyzing more complex relationships between various parties in the construction works. As a result more detailed tools or systems which are specific for the relationships between all kind of parties in the contracts will serve as a more suitable assistance for the professionals of the construction sector. For instance, design related changes, which can be defined as the most problematic type of changes for the claim situations should be investigated by focusing on the relationship between the designer and the contractor.

This research contributes to the area of change management in the construction projects. The significance of the research is that it will serve as a new model for the management of design related changes in design-build construction projects. At the beginning, a semi-structured survey was conducted with the professionals of several construction projects located in Turkey and project change examples were collected. Thereafter, a decision support model for management of project changes were formulated based on the findings of this survey. The model is going to be used by contractors in their project procured by design-build method. The model will be used when a project change related with the design process appears in the construction stage. With the help of the model, the contractor will be able to manage project changes in his or her construction project more effectively.

1.5 Disposition

The current dissertation is composed of five chapters; introduction, literature review, research methodology and material, development of the decision support model and conclusion.

The first chapter is the introduction section. In this chapter, background information about the changes which can be referred as additions, deletions or adjustments to the project drawings in construction projects is given. Thereafter, it is argued that changes related with design corresponds to one of the most significant problems of the contractors and they are in need of assistance for management of this type of project changes. Afterwards, the aim of the research is stated as the suggestion of a knowledge-based decision support model for management of design related changes. The model will be used by the contractors in the construction of housing projects procured by design-build method. Finally, the contribution of the research to the literature is presented.

The literature review section contains three parts. In the first part, researches about change management is presented as; definition of change and change order, types of changes, causes of changes, effects of changes and change management models. In the second part, the studies about claim management is organized in a similar outline as; definition of claim and claim management, categorization of causes of claim, parties of claim, phases of claim management, problems in the process of claim management and methods for claim management. In the final part, design-build procurement method is summarized together with the definition of contracts and responsibilities of the parties.

Methodology of research is depicted in the third chapter with topics of material of the research, method of the research, questionnaire design, semi-structured interview and results of the research process. In the research material section, the selection of the sample of the research is presented which consists of six large-sized housing projects located either in Istanbul or Ankara. Thereafter, the method of the research is defined; Semi-structured interviews conducted with the related professionals worked in those projects and the design of the questionnaire is presented.

The fourth chapter includes the generation of the decision support model which is formulated by using case-based reasoning approach. At the beginning, the case-based reasoning(CBR) method is analyzed together with the main principles and areas of use. Then the CBR model generating tool which was used in the research is presented. The process of formation of the model is depicted in sections of definition of features, definition of similarity measurement function, retrieval of the results and reuse. Thereafter, the testing process of the CBR model is represented. The model was tested in two stages. Firstly the results of the retrieval was analyzed according to the similarity measurement values. In the second stage, a usability measurement survey was conducted.

CHAPTER 2

LITERATURE REVIEW

In this chapter, studies about change management, claim management and design-build procurement type are summarized in two sections. In the first section, 50 published materials about change management are reviewed. These published materials are divided into two main streams. The first stream examines the types, causes and effects of changes in construction projects which were conducted in various regions and countries. On the other hand, the second stream examines several methods, models and systems that were proposed for the management of changes in construction projects.

The second part is dedicated to the claim management and 41 publications about claim management were analyzed. These publications are categorized in three main sections. In the first part, the aim was to investigate types and causes of the claims in construction projects. In the second part, the purpose was to focus on the process of the claim management and problems in this process. In the third part, new methods and models for management of claims in construction projects were analyzed.

The final section explains the design-build procurement methodology. The liabilities of the contractor and designer are introduced. Then, standard form of contracts implemented in design-build construction works were presented.

2.1 Change and Change Management Practices in the Construction Industry

Construction works have complex phases which are prone to changes that cannot be avoided and generally occur more than one, affecting each other (Ijaola & Iyagba, 2012). Changes during execution of construction work are common and inevitable in construction projects which leads to change orders. Change orders can be defined as corrections, additions or deletions to project documents such as contract and design drawings emerging because of the complex relationships and processes in construction works (Alnuaimi *et al.*, 2010; Hwang & Low, 2012).

2.1.1 Definition of Change and Change Order

Change is identified by Sun and Meng (2009) as an alteration to design, building work, project program or other project aspects caused by modifications to preexisting conditions, assumptions or requirements. Changes are common in every construction project and they can be caused by various situations, can appear at any phase of the work and have substantial effects on schedule and budget (Karim & Adeli, 1999; Motawa, Anumba, Lee, & Pena-Mora, 2007).

A change in a construction project is generally identified with its sources, causes, timing of appearance in the project cycle and possible effects (Motawa *et al.*, 2007). Karim and Adeli (1999) also mention elements of a project change as its time of occurrence, causes and impacts. Furthermore, Molly (2007) analyzed changes by establishing cause-effect relationships in his research with linking the source party and the resultant damages. In addition to the cause-effect relationship, Motawa *et al.* (2007) investigated the impacts of changes with respect to various project parameters.

Change orders are issued after occurrence of a change event in construction projects. It was defined by American Institute of Architects (2007) as a written order to the contractor signed by the owner and architect, issued after execution of the contract, authorizing a change in the work or an adjustment in the contract sum or the contract time (Alnuaimi *et al.*, 2010).

2.1.2 Types of Changes

Types of changes in construction projects can be classified according to their nature and impacts. Arain and Pheng (2005) indicated in their study that there are two types of changes, beneficial and detrimental. The former corresponds to the variations that improve the quality standard, reduce schedule or degree of difficulty in the project, optimize benefits of the client by eliminating unnecessary expenses. The latter comprises of variations that negatively affects performance of the project or value of the client (Ibbs, 2005; Mohammad, Che Ani, Rakmat & Yusof, 2010). Moreover, depending on the results of their survey conducted in Taiwan and Taipei, Hsieh, Lu and Wu (2004) categorized variation orders into two main divisions, technical and administrative.

2.1.3 Categorization of Changes by Causes

Changes can also be classified with respect to their sources as client-related, consultant-related, contractor-related, designer-related and external factors (Ndihokubwayo & Haupt, 2009; Sun & Meng, 2009).

Table 2.1 Categorization of Causes of Changes

Categorization of Causes of Changes
• Client-Related • Contractor-Related • Designer-Related • Consultant-Related

- **Client-Related**

Client-originated changes are quite prevalent in construction projects especially in the design phase. They generally result from variations in expectations of the client such as demand of acceleration, deductions in budget and requirement of updates (Sun & Meng, 2009). Moreover, unrealistic and unfair contract durations imposed by the client or delays in approval in project documents and drawings are another examples of problems that leads to a change which is mostly related with the level of experience of the client (Hsieh *et al.*, 2004).

Ndihokubwayo and Haupt (2009) stated in their research that variations in client's expectations is the most frequently seen cause of change. It is followed by unclear briefs in project documents which is also related with the definition of project scope in contract and satisfaction of the client from the services accordingly.

Furthermore, the significance of changes due to intervention of the owner into the design stage was also mentioned by Al-Jishi and Al-Marzoug (2008). According to their study based on a questionnaire conducted in Saudi Arabia, factors such as change of plans, schedule and budget by the client, problems in borders of project scope, conflicts in the contract documents and financial conditions of the client were mentioned as the most important causes that lead to a change in a construction work. This situation is also compatible with the same in Oman (Alnuaimi *et al.*, 2010).

- **Contractor-Related**

Contractor-related changes comprise of causes related with the works which is in the responsibility of main contractor (Sun & Meng, 2009). Kumaraswamy and Chan (1998) defined issues related with the contractor which lead to changes in the construction works as poor site management, inadequate managerial skills and experience of contractor, improper control over site resource allocation, faults of the contractor in planning and contract stages and delays in works of subcontractor in their study. Because of these situations, the contractor should forecast and should be aware of the potential changes or request instructions in the construction works. As a result, change orders that caused by contractors were rated as 73% of the total change orders (Ndihokubwayo & Haupt, 2009).

Furthermore, according to Alnuaimi *et al.* (2010), some malevolent activities of the contractor like misusing variation provisions and grey areas in contract also conduce to substantial change orders in construction works. Also, defects of the contractor in workmanship and unavailability of materials or equipment are other causes that lead to change orders in construction works (Mohammad *et al.*, 2010).

- **Designer Related**

Errors and omissions in design which is in the responsibility of architects or structural engineers corresponds to one of the main important causes of change orders in construction works. There are several types of changes related with designers. These are misunderstanding of needs of the client, human-originated faults in drawings, changes in the conditions of site that generate problems in the later stages giving rise to several revisions in drawings and changes in the requirements of the client (Sun & Meng, 2009).

In addition, design errors can be classified as incomplete design information, insufficient site investigation that leads to differences between design documents and real conditions, errors in quantity estimations and delays in approval of the drawings (Hsieh *et al.*, 2004; Kumaraswamy & Chan, 1998). Moreover, as mentioned by Alnuaimi *et al.* (2010), the most important problem related with design is unrealistic and inefficient periods for design which is the reason of all of the causes that mentioned above together with the communication problems between contractor and client in the initial stages.

- **Consultant Related**

In construction projects, the consultant may directly initiate variations or change orders may occur because of the actions of him which are similar to causes in the related phase where the consultant interferes. These causes can be defined as incompleteness in the contract documents, undefined roles and services in the contract, corrections to the design work, inadequate details in drawings, lack of consultant's knowledge and lack of communication of the consultant with parties of the construction work (Mohammad *et al.*, 2010; Ndihokubwayo & Haupt, 2009).

Moreover, experience level of the consultant is another important determinant for change orders. To illustrate, unfamiliarity of the consultant with specifications and regulations or type of the construction work corresponds to causes of change orders in Oman with relatively lower ranting than contractor or designer related causes (Alnuaimi *et al.*, 2010).

- **External Causes**

External causes consist of natural disasters, social unrests in the host country or financial and governmental instabilities. Sun and Meng (2009) stated that external factors that affect construction works and cause change orders are generally unpredictable and difficult to plan for in advance at the contract stage. These factors can be illustrated as climate and weather conditions which are cited as the main causes of project delays and unplanned variations. Furthermore, changes related with site and ground conditions which are resulted by inefficient analysis of geological conditions usually cause revisions in design drawings and delays in the construction site. However, Al-Jishi and Al-Marzoug (2008) admitted in their study that change orders due to these environmental factors correspond to the least influential determinants which can bring about variations in construction works. In addition, changes in government legislation and regulations, social problems in the country such as political unrests, war, terrorism or economic crisis can be cited as other factors related with external situations.

2.1.4 Effects of Changes

In this section several effects of the changes are depicted. These effects were summarized in four headings.

- **Increases in Cost**

Increases in the budget can be referred as one of the most important impacts of the changes in the construction works. Arain and Pheng (2005) stated in their study that increase in the project cost corresponds to the most frequently seen impact of variation orders. The reason of this the project's indirect and direct expenses can be influenced due to any additions or changes in design, in other words scope of the project. Also, Al-Jishi and Al-Marzoug (2008) pointed out that increase in the project cost was ranked as the major effect of changes according to their survey conducted in Saudi Arabia.

As a natural consequence of variation orders in construction projects, additional works are requested from the contractor which brings about additional payments to the contractor who usually conceives it as an opportunity for acquiring higher profits or achieving his desired profit margins (Arain & Pheng, 2005). However, in this situation, terms for valuing variations and additional works should be agreed upon by the parties of the contract at the beginning of the project.

Effects of the changes on the budget can be analyzed in several headings in a detailed way. These headings were defined by Bower (2000) as increases in overhead, losses in the earnings of the contractor, changes in cash flows and financial conditions of the contractor in his research. Because of implementation of change orders in construction projects, the expenses of all of the related parties and participants remain which results with unpredicted exceeding in head office or site overheads.

According to Mazlum (2015), reworks, revision woks according to the data provided by other disciplines and architectural decision alterations are the most important factors that cause cost overruns in the construction projects.

- **Delays in Project Schedule**

Although exceeding in time and project cost are often inter-related, many of the researchers identified these effects separately (Sun & Meng, 2009). Major changes in the scope of the project or frequently seen minor changes based on their timing of the occurrence can affect the construction work adversely that leads to delays in completion time. For example, the impacts of design related changes emerged during the execution of construction work is more than those appeared in the design stage (Arain & Pheng, 2005).

The importance of impacts of the changes on the project schedule was analyzed in several studies. Al-Jishi and Al-Marzoug (2008) mentioned that delays in project completion corresponds to the second main effect of variation orders in construction projects which is parallel with the research conducted by Haseeb, Xinhai-Lu, Bibi, Rabbani, and Dyian (2011) who emphasize the influence of change orders made by the contractor on project schedule. Alwi and Hampson (2003) investigated the causes of delays in their research conducted among worldwide contractor companies. Changes in design, slow revision processes in drawings, defects in design documents and change orders due to conditions of site are depicted as main determinants of project delays in this research. Apolot, Alinaitwe, & Tindiwensi (2011) acknowledged that change orders in public construction projects of Uganda correspond to the main factor for project delays, which is similar with the situation in the construction industry of Oman (Alnuaimi *et al.*, 2010). The effects related with project delays consist of delays in payment, delays in equipment and material procurements, delays in transportation, delays due to reworks and demolitions, delays because of standing time for subcontractors etc (Arain & Pheng, 2005; Bower, 2000).

- **Decrease in Productivity**

Productivity is defined as the measurement of speed and efficiency in the execution of a particular work. It is generally admitted that projects with high level of change experiences fall in productivity (Sun & Meng, 2009).

Generally, there is a negative relationship between changes in the construction works and productivity. According to Thomas and Napolitan (1995), there occurs 30% loss of productivity as average if any change is performed in a construction project which can differ with the time of appearance of the change. Because of rework, disruptions and variations, the most critical factor that affects productivity is lower labor performance. Ibbs (2005) also specified similar conclusions in his study that changes in the project have disruptive effects on project performance and there exists specific impacts of each different type of variation on labor productivity. In addition, it is important to encourage early beneficial changes and discourage late changes during execution of a construction work which can have more detrimental effects as a proper contract management strategy. Arain and Pheng (2005) also stated the negative correlation between change and labor productivity in their article and focused on the effects of reworks and demolitions on the construction site because of variations in design drawings with respect to productivity. Hanna, Russell, Gotzion, and Nordheim (1999) studied the impact of change orders on project productivity and efficiency in a more detailed way with respect to size, timing, type and complexity of variations. They concluded that the decrease in project performance is caused by schedule compression, overtime, multiple-shift and accelerated work, loss of morale in staff, problems in resource, site congestion, loss of rhythm in production and out-of-sequence work (Bower, 2000).

- **Risk-Related Effects**

Except from the immediate impacts that depicted before, changes in construction projects may also increase the risk of further damages (Sun & Meng, 2009). Due to variations, floats in project schedule is lost and progress of project must be reorganized. This can bring about increased sensitivity to delays and possible accelerations, because of which possible coordination problems may occur between the staff (Hanna, Taylor, & Sullivan, 2005). Furthermore, beside the impacts on a particular construction project, reputation of the construction company can also be affected negatively because of the impacts of changes that may appear in the further stages (Arain & Pheng, 2005).

2.1.5 Definition of Change Management

Change Management, which corresponds to an important section of project management, is defined as the process of forecasting possible changes in a construction project, identifying variations appeared in the previous construction works and generating plans in order to prevent possible detrimental impacts and coordination of changes across the entire project with all of the parties (Motawa *et al.*, 2007).

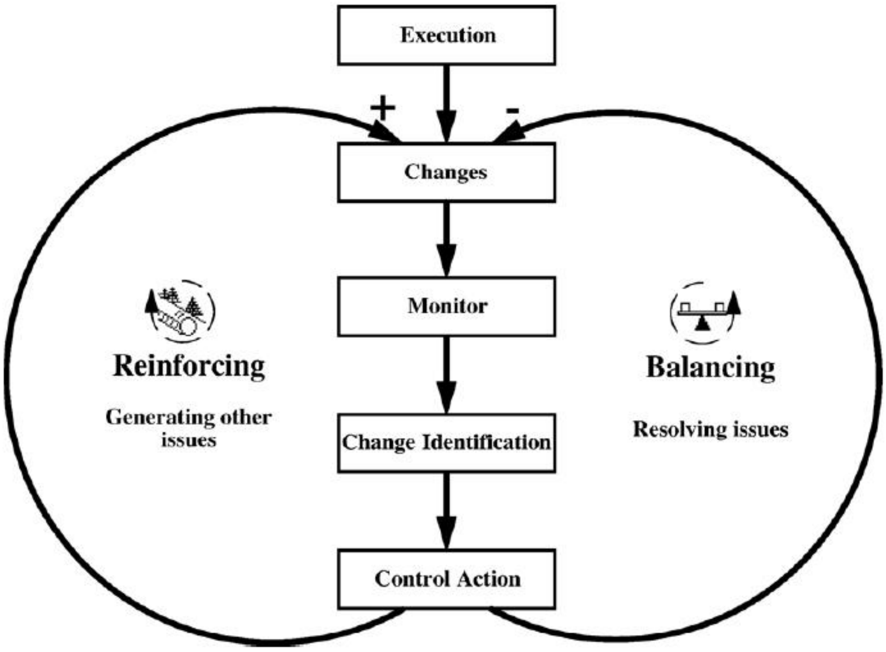

Figure 2.1 Feedback Processes Caused by Changes (Motawa *et al.*, 2007)

2.1.6 Change Management Models

Change management systems were designated in literature by various researchers, the main and most inclusive of which are generic models that defines the process of change management. To begin with, objective of setting up a comprehensive model for change management emerged with the study of Ibbs *et al.* (2001) who proposed five basic principles in order to achieve an effective change management system. These are (1) promotion of a balanced change culture, (2) recognizing change, (3) evaluating change, (4) implementing change and (5) learning from past experiences. Motawa *et al.* (2007) presented a more extensive change management framework with four main sections, (1) start up comprised of proactive requirements, for instance plans to respond an unpredicted change or to prevent possible variations, (2) identifying and evaluation process which includes definition of a change with respect to its type, causes and effects and analysis of change options that helps decision takers to select optimum solutions, (3) approval and propagation which consist of taking the final decision with client, design of updated change management plans and briefing related parties about the change, (4) post-change phase which includes monitoring the actual effects and dispute resolution (see Figure 2.2). Furthermore, Arain (2008) again came up with the same sections and suggested an addition of monitoring phase which is comprised of documentation and plans for controlling of a change. Moghaddam (2012) also proposed an updated version of this generic process model altered for specific change orders in the Iranian construction industry.

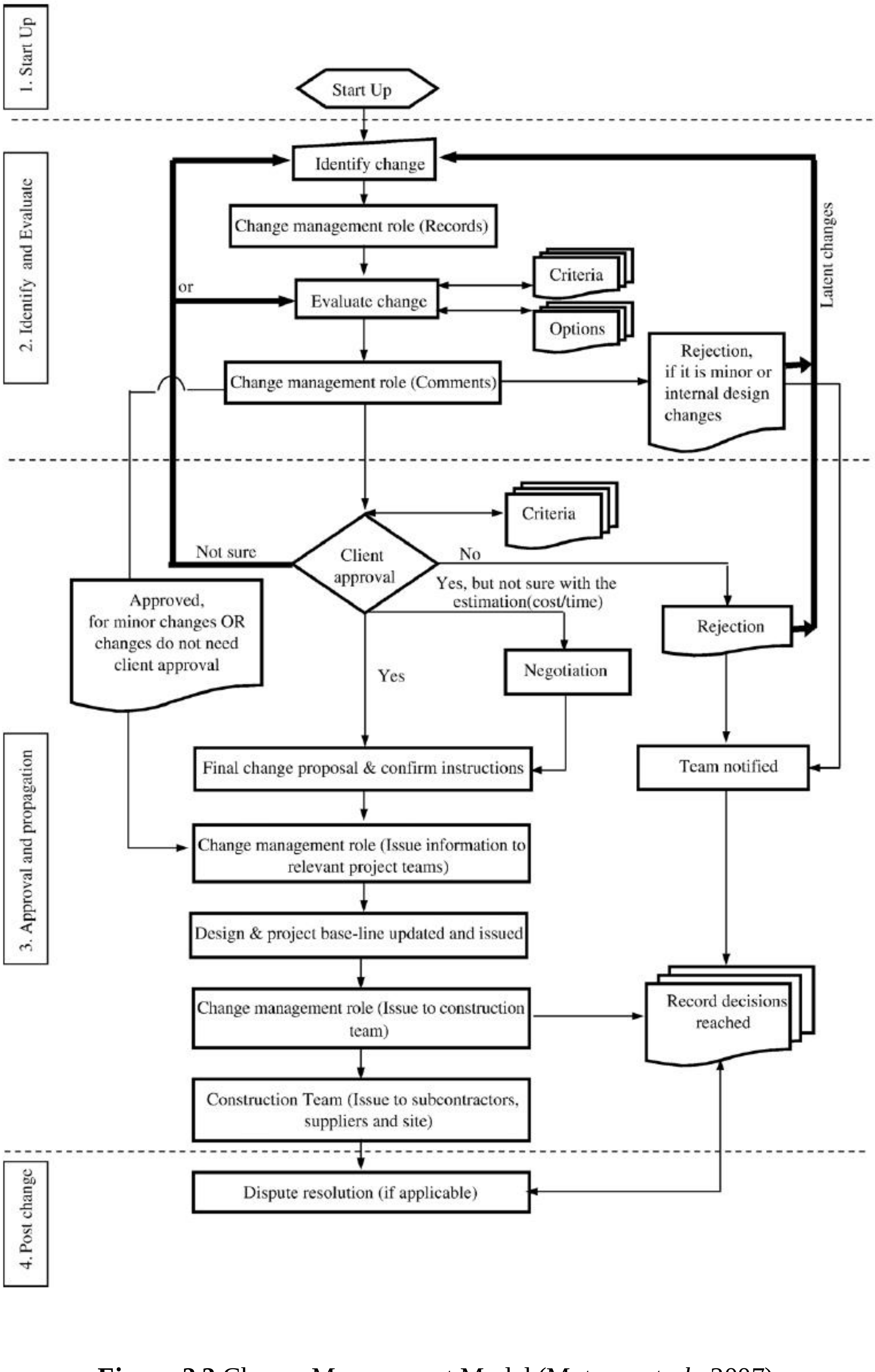

Figure 2.2 Change Management Model (Motawa *et al.*, 2007)

- **Prediction-Based Decision Support Models**

Systems for the foresight of possible variations in the further stages of construction projects correspond to the most important section of researches about decision support. Firstly, Bower (2000) proposed a prediction model based on the analysis of indirect and direct costs of variations in contract with the help of influence curves, so that the contractor can bid more accurate prices and take financial risks.

Another prediction system related with the determination of the relationships between causes and effects of changes was studied by Motawa *et al.* (2007) who used fuzzy systems in this method and collected data from 20 change events. The correlation between factors that lead to causes of change, causes and impacts were defined by dependency diagrams for each variation case. Fuzzy rule-based system was formed by linking these facts with If-Then format. The probability of each change event with respect to their occurrence was calculated at the beginning of the project in order to obtain more accurate schedules and change prevention plans which corresponds to also a measure of project stability and through which the impact of changes on different project parameters can be examined.

There also exist studies for the analysis of relationships between changes in the construction works. As can be seen in Figure 2.3, Zhao, Lei, Zuo and Zillante (2010) proposed an activity-based dependency structure matrix in order to allocate the relationships between change events. It was based on the analytical design planning technique. With the help of interdependencies between tasks in the design process, a more logical and structured planning approach was provided. The system works as an integrated design solution system (Austin, Baldwin, Li, & Waskett, 2000). At first, various relations between tasks in the Gantt graph was modeled on dependency structure matrix from dependent relationships to overlapped activities. Then, for each change event, the correlation of factors, causes and activities was defined on dependency diagram. Thereafter, by using Monte-Carlo simulation, risk levels of each change event were obtained and required procurements for events or tasks possessing high risk were determined (Hwang & Low, 2012).

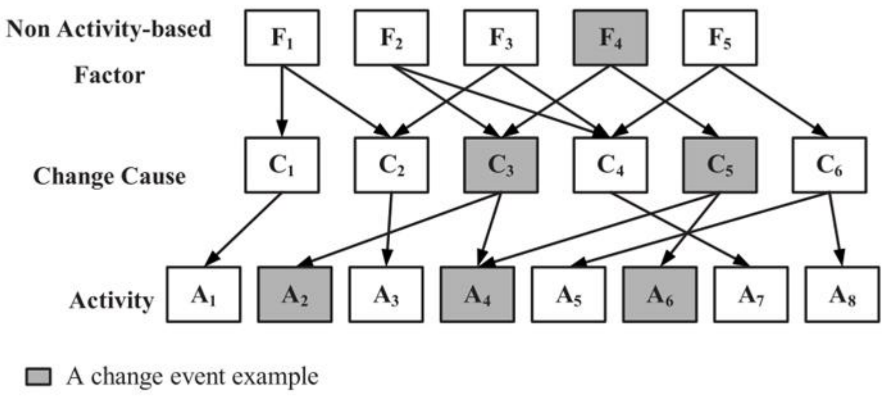

Figure 2.3 Activity-Based Dependency Diagram for a Change Event Example (Zhao *et al.*, 2010)

Stare (2011) suggested a model that combines risk management and change management which was formed by a quantitative research conducted between 137 Slovenian enterprises. In this method, risk factors correspond to change events. Possible problems and errors were identified at the beginning of the project and ideas about related solutions, direct or indirect impacts were connected to these events. As a result, by foreseeing the consequences of possible change events with the help of this risk allocation method, proactive approach can be taken in a quicker and easier way.

- **Knowledge Based Decision Support Systems**

Knowledge based decision support systems aims to provide opportunity for professionals to learn from past experiences which corresponds to the last phase of generic change management system. The objective of these systems is to supply supportive information.

Arain (2008) developed a Knowledge Based Decision Support System (KBDSS) as a unique system for education projects which provides an effective strategic management of variations. Firstly, the system consists of two main sections the knowledge-base and the controls selection shell in order to select proper controls.

The database was developed by collecting data from 80 educational projects in Singapore with a questionnaire survey. KBDSS supplies display of changes and their relevant details about causes, a variety of filtered knowledge about each variation case and analysis of possible impacts. Moreover, with the help control selection part, the user is able to forecast possible consequences of each solution, providing a decision support. At the end, the proposed model was tested with the same sample and it was concluded that variations in educational projects can be reduced by 30-35% when the model was used.

- **Control Management Systems**

Researches about control management systems focus on strategies for dealing with the changes that occurred in a construction projects together with planning and scheduling operations. Park and Pena-Mora (2003) introduced a dynamic change management model for construction by taking into consideration of both strategic level and operational level. As can be seen in Figure 2.4, it consists of a generic process model and four supporting structures for project scope, resources, performance in which quality of work, progress and productivity. The model consists of policies which correspond to the most important section regarding change management where managerial change ratios for each construction project are stored. In particular, generic process model is comprised of generic parameters which were converted from the most common influential construction dynamics. Characteristic and activities of the project is defined in this process model with related feedbacks for measure of quality management. Moreover, with the application of simulations, the impacts of specific variation tasks can be monitored by focusing on the control of aspect of change management at the operational level. Together with project planning, the user is also able to update the system with different variables at each specific stage of a construction project.

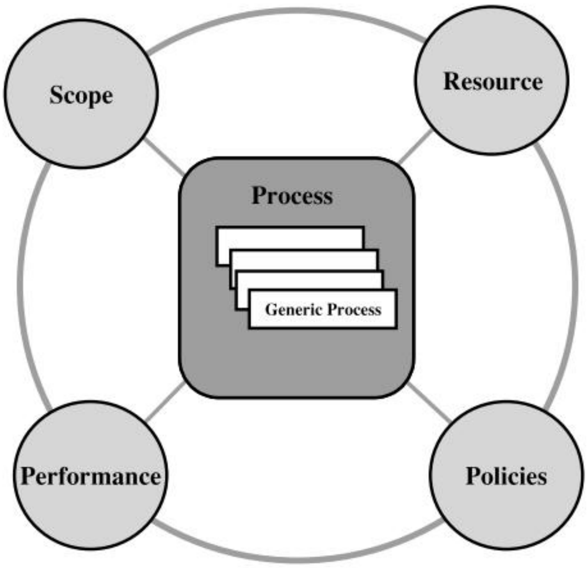

Figure 2.4 Schema of Dynamic Construction Project Model (Park & Pena-Mora, 2003)

Dynamic Planning and Control System (DPCM) was proposed by Motawa *et al.* (2007) with taking into consideration of overcoming the uncertainties and complexities caused by the changes in design and construction processes. Motawa *et al.* (2007) also make use of generic process model with iterative cycles resulted by impacts of variations. However, the stability level of construction project, a ratio that was achieved by change prediction system working in collaboration with DPCM, was incorporated into the model which brought about more realistic consequences in this example.

- **Models That Calculate Effects of Changes**

The productivity and performance rates in a construction project can be strongly influenced by the variations as mentioned above as "impacts of changes". There exist systems developed in order to acquire the quantities effects of changes in construction projects.

To begin with, a statistical labor productivity model was developed by Hanna *et al.* (2005) with data collected from 88 construction projects located across the United States. The model takes account of whole process of construction while regarding the impact of variations. By generating quantitative relationships between variables such as project size, overtime and productivity; decreases in the labor productivity can be obtained in the format of number of hours worked per week increase or project duration increases.

Another model was proposed by Hanna, Lotfallah, and Lee (2002). It was based on a different methodology for quantifying impacts of change orders in construction projects by using fuzzy logic. The methodology was formed by statistical data linked with if-then sets. The objective of the methodology is enhancing the accuracy of prediction with respect to traditional statistical approaches.

Finally, Artificial Neural Network Model was developed by Yitmen and Soujeri (2010) which is based on a survey conducted with the contractors working in the Cyprus construction industry. The aim of the ANN Model is to estimate the effects of change orders more accurately and to avoid probable disputes before a litigation occurs. The model is comprised of two main sections, the first of which is identifying different factors that define adverse impacts of variation orders on project performance and the latter is procurement of the probability value of dispute.

2.2 Claim and Claim Management Practices in the Construction Industry

In most of the time, changes in construction projects are resulted with claims which correspond to one of the greatest challenges that contractors are facing. Construction projects are becoming more susceptible to various factors that can lead to time overruns or cost exceeding because of the complex relationships and difficulties in the construction contracts (Kululanga & Kuotcha, 2001).

2.2.1 Definition of Claim and Contract

According to Cambridge Dictionaries Online (2013), contract is defined as a legal document which indicates a formal agreement between two or more different people or groups. A construction contract is a legal agreement conducted between several parties in construction project such as owner, contractor, subcontractor, consultant, designer etc. and basically a promise by one party to supply construction services or building activities for an another party who promises to pay the work according to specified obligations and rules. Generally, construction contracts possess a complex and long structure and high-risk sharing relationships between parties, which can result in disagreements and disputes (Semple *et al.*, 1994).

Claim is defined by Oxford Dictionaries Online (2013) as a demand or request for something that is considered as someone's responsibility. For the field of construction industry, Hughes and Barber (1992) explained term of claim as “a request, demand, application for payment or notification of presumed entitlement to which the contractor, rightly or wrongly at this stage, considers himself entitled with respect to a contract has not yet been reached”. According to American Institute of Architects (2007), claim is, as a matter of right depended upon the terms of the contract, an assertion by one of the parties seeking payment of money or other relief. Therefore, it can be concluded that a claim appears when one party believes that the other does not perform its part of bargain which is stated in contract (Levin, 1998).

Moreover, term of claim is also defined with emphasis of change. Diekmann and Nelson (1985) identified claim as "the seeking of consideration or change, or both, by one of the parties to a contract based on an implied or express contract provision." When a change situation occurs, it can result with an agreement between owner and contractor which is called change order in other words modification of contract. This situation can also result with a claim which refers to seeking of the solution methods out of the borders of the contract; or in the worst case with a disagreement, disputes and arbitration.

2.2.2 Parties of Claim

In almost all of the construction projects, while the contractor continues his execution of work, there occur some situations can appear that require compensation of the parties by means of money or time because of predictable or unpredictable problems (Yıldız, 2010).

Majority of the claim situations in construction works appear between the owner and the contractor, even though construction contracts are conducted between various parties like architects, consultants etc. For this reason, most of the standard types of contracts used in construction industry contain contractual procedures or clauses for compensating the losses of the contractor in case of the practices of the owner and his agents which induce extra works or expenses for the contractor (Vidogah & Ndekugri, 1998). While most of these claims situations which contributes additional costs to contractor is caused by the designer, claim management process is generally between the owner and the contractor.

2.2.3 Causes of Claim

A claim document contains the causes and impacts of the change situation, quantification of the cost impacts together with the calculation method and statement of its legal basis together with related contractual provisions and entitlements (Semple *et al.*, 1994). In the literature, there exist various studies which aims to identify the causes of claims in the construction industry, to categorize these causes and to analyze frequencies together with importance weights. In these studies, questionnaires or surveys were implemented as the research methodology. These studies were selected according to the diversity related with their research materials. Both of them focused on different kinds of locations and construction sectors such as United Arab Emirates, United States, Canada, Egypt, etc.

Hassanein and Nemr (2008) analyzed 21 construction projects built by Egyptian contractors with appreciable experience in the construction industry ranging from middle to large size. The status of claim management was investigated with detailed penetration on changes in the construction project which constitutes to the major factor of construction claims.

Diekmann & Nelson (1985) conducted their research on 22 federally administered Governmental Projects in United States with contract prices of which range from $200.000 to $20.000.000 and in total 427 claim situations were analyzed.

Another study focused on the construction works in Western Canada. This research was conducted between 24 construction projects containing civil, industrial, high-rise and housing projects by Semple, Hartman and Jergeas (1995).

Another questionnaire survey was carried out between professional individuals of the construction sector such as owners, consultant's engineers, quantity surveyors, architects and civil engineers by Vidogah and Ndekugri (1997) in order to identify the shortcomings of the claim management process from viewpoint of contractors. Interviews were made with contracting and consulting firms for clarifying the reasons of the results of the survey.

In addition, the attitudes of engineers working in construction projects from different views such as agent of owner, consultant or employees of contractor were analyzed by Lee, Choi and Kim (2010). In this study, major causes of claims and behaviors of engineers that resulted in claim were classified.

Lastly, Zaneldin (2006) conducted a questionnaire survey which constitutes to one of the recent researches in this field. The aim was to investigate construction claims in United Arab Emirates.

With the analysis of these studies which were conducted with different samples, the causes of claim situations can be categorized as;

Table 2.2 Categorization of Causes of Claims

Causes of Claims
• Change Orders • Contractual Causes • Delays • Design Errors • Force Majors • Scheduling / Planning Errors • Site Conditions

- **Change Orders**

Change orders in construction projects correspond to the major cause of the claim situations which are comprised of additional works, deletion of works, change of plan and methods both brought about by the needs of the owner.

According to Hassanein and Nemr (2008), claims related with change orders constitute to approximately 54% of total number of claims in the Egyptian construction industry. They emphasized that further studies must be conducted specifically on change order claims. Diekmann and Nelson (1985) also mentioned the importance of the impacts of change orders. They stated that 30% of total claims were caused by change orders in their study. When it's come to United Arab Emirates, change orders are also referred as the main cause of the claims, constituting approximately 40% of total claim situations (Zaneldin, 2006).

- **Contractual Causes**

Almost in all of the other factors that generate claims, there is a major role of the contract provisions. If the contract contains specific clauses about those factors such as design errors, change orders, unforeseen conditions or delays, claims may not occur. Yıldız (2010) stated that any omissions, misunderstandings, errors, unclear terms in contract clauses may cause several disputes. Such clauses that can generate claims is listed as,

- Clauses related with changes; which comprises any variations made by one party in architectural or engineering design can affect other party, such as changes in quantities and execution of work.
- Clauses of extension of time; which comprises additional delay and acceleration costs of one party that caused by other; simply actions of other parties that may affect one's planned schedule.
- Clauses related with definition of scope of work
- Clauses of quality of work; defective workmanship or wrong execution of defined work by one party may affect other party's work or costs
- Clauses related with the liabilities of parties; any misunderstanding in the liabilities can cause entitlement problems in claims that may appear in the future
- Clauses of administration and managerial requirements of partners; especially in joint venture projects managerial faults of one partner can affect other partner's work.
- Clauses related with violation of contract terms

As parallel with the research of Yıldız (2010), Semple *et al.* (1994) also depicted the most frequently pointed out clauses in contracts in the process of claim entitlement as delays, extra works, responsibilities, changes and scheduling. Owner-favorable contract mechanisms can be referred as the alerts of potential claim situations which will most likely occur in the later stages of the project. These mechanisms consist of low prices of contract and unfair terms with advantage of the owners in the contracts due to high competition (Lee *et al.*, 2010; Zaneldin, 2006).

- **Delays**

In some of the researches, delays in the construction projects are included as another specific cause of construction claims although other factors in the Table 2.2 can be considered as determinants leading to delay. For example, Kartam (1999) indicated that delays correspond to the most common and costly cause of construction claims.

In their questionnaire based research conducted in Nigeria among 102 contractor firms, Aibinu and Jagboro (2002) analyzed the status of claims that caused by delays. They admitted that most of delays in construction projects are related with the client which bring about significant impacts on expenses generally resulted with claims. Odeh and Battaineh (2002) also came into a similar conclusion in their survey. They stated that client corresponds to the main source of delays in the construction projects with the actions of late payments, slow decision making processes, unrealistic contract durations which was followed by improper planning, site management, inadequate experience by contractors, late preparation and approval of drawings, inadequate contract management by consultants and lack of communication between those parties. In addition, Lee *et al.* (2010) also highlighted the effect of late approvals by owner and his consultants on delays and classified these actions as failures in documentation, long review stages by consultants and late submission of reports by contractors.

- **Design Errors**

Inadequacies and defects found in the drawings, inaccuracies between drawings and specifications and problems related with the delivery methods of the design drawings by the architect to the construction site correspond to design errors in the construction projects (Diekmann & Nelson,1985). Lee, Choi and Kim (2010) stated that design errors are mostly resulted by the omissions in drawings and disputes between the contractor and the designer.

Design errors correspond to the one of the most frequent causes of claim situations. Diekmann and Nelson (1985) specified in their study that design errors constitute to the cause of 39% of the total claim situations in other words claims are related with the relationship between designer and contractor. Hassanein and Nemr (2008) indicated that nearly 15% of the total claims were due to the design errors in the

Egyptian construction industry. According to Zaneldin (2006), claim situations resulted by design errors in United Arab Emirates correspond to 5% of total claims. Consequently, the weight of the design errors as causes of claims are variable which may be related with the differences between research domains such as location, type and size of the projects.

- **Force Majeure**

Force majeure are comprised of unexpected weather conditions, natural disasters and unpredicted social conditions in the host country such as political conflicts, changes in governmental regulations, social unrests, wars or terrorist events which may results with the suspension of the construction work. Claim situations related with these issues are usually come up from wrongly interpretations of “force-majeure” clauses in the construction contracts.

The weights of claim situations due to force majors were depicted as 3% of total claims in the Egyptian construction industry, 2% in the United Arab Emirates and 6% in Canada (Diekmann & Nelson, 1985; Hassanein & Nemr, 2008; Zaneldin, 2006). Consequently, claims caused by force majeure constitute to relatively the lowest weight when compared with the other factors.

- **Scheduling / Planning Errors**

Faults of the contractor about planning at the beginning of the construction project such as inaccurate scheduling estimations may bring about wrong contract strategies which can result in agreeing upon irrelevant contractual terms related with timescale and extension of time.

Chester and Hendrickson (2005) investigated inaccuracies of initial scheduling performances of contractor which cause claims and used critical-path method analysis for depicting the differences between estimated and actual schedules. They concluded that it's important to make nearly correct estimations at the contract stage in order not to enter into obligations of inappropriate clauses related with completion date. Furthermore, Zaneldin (2006) concluded in his research that scheduling and estimating errors conduce to 4% of total construction claims in United Arab Emirates.

- **Site Conditions**

Differences between the physical conditions of the construction site and design drawings lead to problems related with the site conditions. This type of problems can also be referred as 'Restricted Access', which means that conditions at the particular work area is not available for the construction work.

The weight of site conditions as cause of claim situations is not significant as design errors. Semple, Hartman and Jergeas (1995) remarked the weight of claims due to the site conditions in Western Canada as nearly 15% in their study. Also in the United States, 15% of the total claim situations are due to that kind of problems, mentioned by Diekmann and Nelson (1985). In contrast, according to Zaneldin (2006) this weight is only 1.5% when it's come to United Arab Emirates.

2.2.4 Claim Management

Claim Management can be defined as the process of establishing plans for preventing potential claim situations in a construction project and forming procedures in order to solve the problems caused by them. Kumaraswamy (1997) designates the practice of claim management as identification of claim situations, focusing on avoidable ones and minimizing negative impacts of them. Cox (1997) indicated in his article that claim management corresponds to management of risks and it starts with the selection of construction method, then continues with contract preparation phase, negotiations with subcontractors and consultants. Therefore, a project manager should be able to cope with risks during these periods in order to prevent claims.

Claims are generally occurred in lump-sum contracts between the employers and the contractors in the construction industry where fixed-price is defined for specific works. In this case, several unforeseen events can affect these works with respect to increase in time and budget (Yıldız, 2010).

2.3 Design-Build Procurement Method

There exist two popular procurement methods in the construction works which are design-bid-build and design-build. The implementation of design-build method in construction projects has increased in the last years which consists of integration of design and construction in the process of construction project different from the traditional design-bid-build procurement method (Arditi & Lee, 2003; Lam, Chan, & Chan, 2008). In design-build, the barrier between architect and contractor is removed and these two parties work in a joint effort in order to procure the project to the client. Therefore, the owner doesn't need to get involved in the situations of delays, deficiencies, injuries or property damages (Winkler & Chiumento, 2009). However, most of the risks are taken by the contractor who is liable to submit a turnkey project to the client and responsible for both design and construction phases where traditional lines between designer and builder blurs. In conclusion, the concept of "master builder" in the medieval ages evolved as contractor who is authorized to contract and implement design-build ventures which contains all aspects of design and construction (Castro, 2013). There exist various needs and complexities in the construction sector and traditional procurement methods cannot meet these needs entirely. In this case, design-build method evolves as an alternative method with advantages such as single-point responsibility, acceleration in the project delivery process, financial certainty, reduced claims and improvements in the productivity (Palaneeswaran & Kumaraswamy, 2000).

2.3.1 Liabilities of Design Builder

Contractor is liable for both design and construction activities in the contract between the owner, in other words works are not separated and connected to the one party in design-build type (Deniz, 2012). It is stated in the design-build contracts that the contractor must have required architectural and engineering skill in order to perform these works with a reasonable care and without neglect. Moreover, Castro (2013) defined the duties of the contractor responsible to the owner as;

- Preparing plans and specifications at the design stage which contributes to the duty of design professional
- Supervision of the implementation of these plans and specifications as corresponding to another duty of design professional
- Supervision of conduct of construction work which is the duty of contractor

2.3.2 Liabilities of Design Professional

Design professional which referred as design subcontractor is liable to the contractor for the design works implied in the contract between contractor and design subcontractor. According to Taylor (2000), the architect corresponds to the lead design professionals in design subcontracting works who is the coordinator of all of the design works such as electrical, mechanical, structural, landscaping, quantity surveying and interior design.

2.3.3 Contribution of Design-Build Method to the Project Success

The contribution of the design-build (DB) method to the project success is summarized in this section. According to Chan, Scott and Lam (2002), time and cost correspond to the most important factors when analyzing the effects of DB procurement method on the project success. The contribution of DB method is summarized within these two headings in this section.

- **Cost**

According to Songer and Molenaar (1997), completion of the construction projects without exceeding the limits of the budget is an important success criteria for design-build projects. The positive contribution of the design-build procurement type to the cost was mentioned in the various researches in the literature. In his research comparing the effects of design-bid-build (DBB) and design-build (DB) methods on the budgets of the military construction works, Roth (1995) admitted that costs related with design and construction processes significantly decrease in the projects procured with DB method. Konchar and Sanvido (1998) analyzed 351 construction projects in United States in order to compare the impacts of DBB and DB procurement methods on the cost. They investigate several variables such as unit cost, construction speed, delivery speed, increases in the cost and increases in the duration. They admitted that it's most likely that DB method provide a reduction in the overall cost. Hale, Shrestha, Jr. and Migliaccio (2009) investigated several public construction works in order to compare performances of DBB and DB with respect to cost. They concluded that DB method diminishes the duration of the construction process and public buildings must be procured by using DB procurement method.

- **Schedule**

According to Songer and Molenaar (1997), completion of the construction projects without exceeding planned duration of the project is another important success criteria for design-build projects. In design-build procurement type the owner awards the contract to one entity who is responsible to deliver the project to the owner by compensating all of the requirements. Therefore, there is only one procurement step different from the design-bid-build which diminishing the schedule of the project (Hale *et al.*, 2009). According to Ibbs *et al.* (2003), the main advantage of DB type when compared with DBB method is decreasing the duration of the construction process. However, they admitted that the experience level of the project team has more effects on the duration rather than the procurement method. Uhlik and Eller (1999) analyzed various construction works related with health care facilities in order to compare DBB and DB procurement methods. They specified that DB provides time reduction in design and construction processes. According to Songer and Molenaar (1996), time savings is the most important factor for the owners in selection of DB as the procurement method. Other factors mentioned in this research are establishing cost, reducing cost, establishing schedule and reducing claims.

2.3.4 Success Factors in Design-Build Projects

There are several factors which bring about success in the construction projects procured by design-build method. These factors are defined in the various researches in the literature. Factors are summarized in Table 2.3 with respect to the authors.

Table 2.3 Success Factors in Design-Build Projects

Authors	**Project Success Factors in Design-Build Projects**
Pinto and Slevin (1988)	Most important factor is establishing the project goals clearly. Others are the contractor's experience related with the building technologies and contractor's experience related with the design process which can shorten the duration of the project cycle.
Mohsini and Davidson (1992)	Most important factor is proper communication among the project members. It is crucial for decreasing the time consumption in the decision making processes. Proper communication brings about mutual trust and cooperation between the project participants which correspond to key factors for the success in DB projects.
Mo and Ng (1997)	According to the results of their research, most important factor is clearly definition of the client's brief. Other factors can be stated as client's and contractor's experience related with DB method and proper communication between the participants of the project.
Ashley and Laurie (1987)	Most important factor is the definition of the project scope by the client properly. Others are experiences of the contractor and the client in the DB projects. Commitment of the project members to the project goals and effective monitoring for

	coping with the design related changes can be depicted as the other success factors.
Deakin (1999)	Definition of the needs of the client, comprehensive and clear inputs of the client to the project at the beginning of the project are most critical factors for the success of the project.
Chan, Ho and Tam, (2001)	Commitment of the project participants, experience and knowledge of the contractor and the client related with DB method are among critical factors for the success of the project.

2.3.5 Design-Build Contract Types

There are several form of agreements used in the design-build construction works. In this section, publications of American Institute of Architects (AIA), Associated General Contractors of America (AGC) and Design Build Institute of America (DBIA) are depicted.

- **AIA Design-Build Contracts**

AIA design-build documents consist of four separate contracts which were published in 2005. The structure of the relationships in the design-build procurement type and related contracts issued by AIA can be seen in Figure 2.5. According to Friedlander (2005), AIA design-build contracts are very practical, detailed, well-written and generally in favor of the owner in the conflict situations. These contracts are,

- A 141: The contract between the owner and the contractor
- A 142: The subcontract between the contractor and the general contractor
- B 142: The contract between the owner and its architect working as the consultant
- B 143: The subcontract between the contractor and the designer

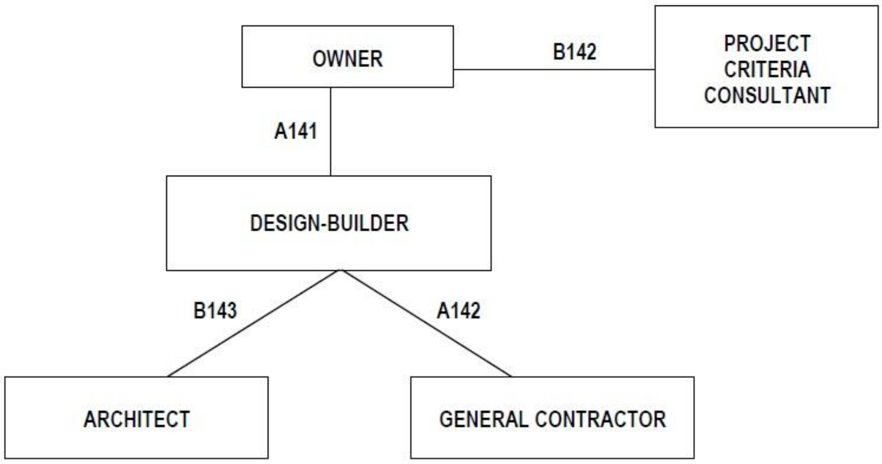

Figure 2.5 AIA Design-Build Contracts (Friedlander, 2005)

- **AGC Design-Build Contracts**

Associated General Contractors of America (AGC) was established in 1918 consisting of contractors and industry related companies. AGC Contract documents were prepared and published by AGC's Contract Document Committee (Associated General Contractors of America, 2002). AGC 400 series of contract documents are used for design-build construction works. There are several documents which are summarized below**.**

- AGC 400: Preliminary Design-Build agreement between owner and contractor
- AGC 410: Standard form of contract between owner and contractor based on cost of the work plus a fee
- AGC 415: Standard form of contract between owner and contractor based on lump sum price
- AGC 420: Standard form of contract between contractor and designer
- AGC 450, AGC 455, AGC 460 and AGC 465: Standard form of agreements between contractor and subcontractors with varying degrees of risk sharing and payment type.

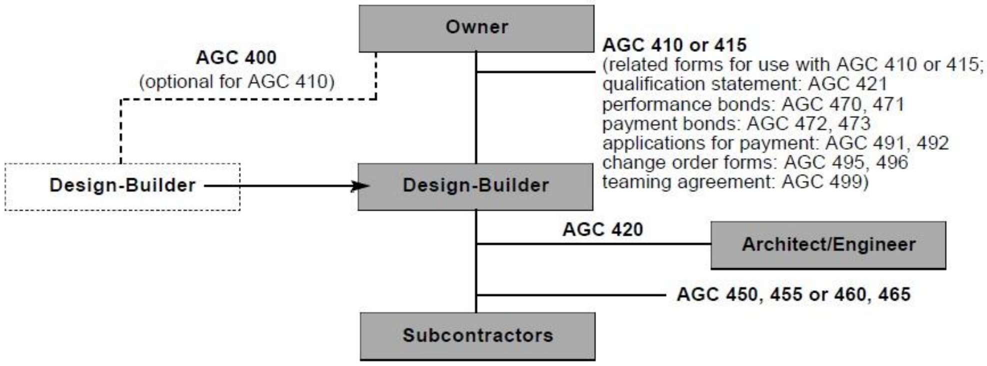

Figure 2.6 AGC Design-Build Contracts (Associated General Contractors of America, 2002)

- **DBIA Design-Build Contracts**

Design-Build Institute of America (DBIA) was established in 1993 and serves as a forum for participants of design-build process, contractors, clients and related professionals. DBIA publishes form of contracts for design-build works which are demonstrated as the most balanced forms of contracts in the industry ("Design-Build Institute Of America (DBIA) Releases Revised Contract Documents," n.d.). In 1980 DBIA released a team of agreements for design build projects. In 2010, several revisions were made in these forms of contracts with respect to the changes in the relevant case law and needs of the professionals. These contracts are depicted below, (Design-Build Institute of America, 2015)

- DBIA Document No: 501, contract for design-build consultant services
- DBIA Document No: 520, standard form of preliminary agreement between owner and contractor
- DBIA Document No: 525, standard form of agreement between owner and contractor based on lump-sum price
- DBIA Document No: 530, standard form of agreement between owner and contractor based on cost of the work plus a fee

- DBIA Document No: 535, standard form of contract between owner and contractor
- DBIA Document No: 540, standard form of agreement between contractor and designer

2.4 Inferences Drawn from Literature Review

Contribution of the studies analyzed in this section to the literature of change order/claim management can be summarized in several points;

- Researches about investigation of types, causes and effects of changes and claims in construction projects serve as a determination of local problems which were conducted particularly in various regions and countries. The samples of these researches generally includes one construction sector, so that the results of these studies can differs from each other. Several of them propose simple guidelines or change management models in order to deal with changes in construction. Some of the claim analysis studies investigated data related with the occurrence of the claim situation such as frequency, severity etc.
- Changes in the construction projects are presented as the one of major reasons that leads to delays and cost overruns in the construction works. It was stated that in most of these cases, claims appear at the end of the construction projects.
- In some of the researches, efficiency and applicability of change management and claim management methods were examined. These studies provide a knowledge about the problems in process of change order/claim management and lacking points in the management models together with actual demands of the construction industry related with this field.
- Some of the researches focused on the analysis of the effects of changes on project performance, productivity, cost and schedule. Several models and

methods for calculating the impacts of changes in construction projects were presented in these studies.

- Models for prediction of the occurrence of any possible changes in a construction project and control of these changes were generated in some of the researches with the aim of proposing practical tools for construction professionals.
- There exist knowledge-based decision support systems for management of changes in the construction projects. However, these systems can only be used in a particular region and they are limited with respect to the size of their samples.
- There exist researches about calculation of cost of the claim situations. Several methods and tool were provided for calculation of expenses related with claim situations in order to be used by the contractors in their claim management practices.
- Some of the researches proposed IT based models for claim management process which serve as mediums for the documentation phase and simulation based agents for the negotiations.

The main inference drawn from the literature review is that most of the researches about change order/claim management have a general perspective of all types of changes in the construction projects rather than a detailed investigation of specific types of changes such as design related changes as the major factor of the occurrence of change situations. Researches about claim management generally focused on the relationship between the contractor and the owner when dealing with the conflicts related with claims. Conflicts which are occurred due to the claim situations were analyzed according to the contracts between the client and the contractor. However, there are different kind of causes which are resulted with claim situations in the construction works and different kind of parties in the construction contracts can be responsible from these issues. For instance, conflicts which are resulted from design related changes in the construction works must be analyzed with focusing on the relationship between the designer and the contractor depending on the procurement type of the construction work. Therefore, models and systems related with the negotiation process of claim management should be specialized by focusing on contracts between the designer and the contractor.

Furthermore, another conclusion drawn from this review is the status of change management differs from region to region in terms of weights and importance of causes of changes, awareness of practitioners in the construction sector and impacts of the change situations. The frequency of various causes and effects of changes can differ depending on the characteristics of the related construction sector. For example, a particular factor can conduce to 70% of the total change events in a one country. However, according to the results of same kind of research conducted in a different country, it can be seen that this particular factor is not important as the others like in the previous sample. So that, investigation of the causes and effects of changes with respect to the specific construction sectors is important.

In addition, methods that aim to define the relationship between causes and effects of changes are based on the limits of the investigated samples, so that interrelations of changes should be identified for specific type of projects in particular regions. The factor of designer faults can have different impacts on the cost and duration of the construction project depending on the function of the project. For instance, the designer can have different responsibility in an industrial plant project and in a housing project. So that, the faults of the designer will bring about different kinds of damages to these projects.

In conclusion, there is a gap in the literature about management of design related changes in the construction projects especially concerning the role of the architect and structure of the relationship between the architect and the contractor in claim situations. The relationship between the contractor and the architect can be analyzed rather than the one between the client and the contractor for the management of design related changes in the construction works. The methodology of the management of design related changes can also be specific for a particular construction procurement type. For example, design-build procurement type can be selected as the target because of the importance of design related claims for the contractor. Logics in knowledge based change management models and relationship structures in the cause-effect analysis methods can be implemented while generating a model for solution of the design related change situations in the construction projects. Therefore, case-based decision support model for management of design related changes can be formed for design-build construction works with the aim of providing assistance for the contractors in management of design related changes by proposing solutions at the moment of occurrence of a change event. The model will be formed with the data drawn from the Turkish construction industry. Rather than studying the relationship between the owner and the contractor, the main focus is on the contractual relationship between the contractor and the designer. So that, standard form of agreements used between those parties will be selected for the model.

CHAPTER 3

RESEARCH MATERIAL AND METHODOLOGY

In this section, the material and methodology of the research are presented in three sections as introduction, material of the research and method of the research.

3.1 Introduction

The aim of this research is to propose a knowledge based decision support model for management of project changes regarding the design process in design-build construction projects. The most important assumption in this research is that significant amount of change order/claim situations are resulted from project changes depending on the design process in the construction projects (Diekmann & Nelson, 1985). Firstly, design changes that lead to change orders/claims will be investigated with respect to their causes and impacts via semi-structured interviews in this research. Thereafter, the knowledge-based model based on case-based reasoning approach will be generated.

3.2 Research Material

Large-sized mixed-used housing projects, possessing nearly 30.000 m2 construction area, consist of several functions, housing as main, commercial, recreational, entertainment etc. There exists a significant rise in the large sized housing projects since 2000s. According to Turkish Statistical Institute, the percentage of the housing projects in the construction permits equaled to 53% (Erdem, 2015). The percentage of the large sized housing projects in this statistical result is also important. According to the Turkish Statistical Institute, the number of the housings for sale was nearly 400.000 by 2009 in Istanbul. 70% of these constitutes to the large-sized housing projects (Tüfekçi, 2009).

In this research, 6 large-sized mixed-used housing projects constructed in 5 years were analyzed. They were chosen according to their accessibility. The housing projects are located in either Istanbul or Ankara.

Table 3.1 Definition of the Projects

Projects	Location	Number of Housing Units	Approximate Construction Area (m^2)	Number of Blocks	Number of Floors
Project 1	Istanbul	304	70.000	1	32
Project 2	Istanbul	298	75.000	46	3-5
Project 3	Istanbul	251	55.000	2	26
Project 4	Istanbul	476	90.000	11	6
Project 5	Ankara	530	120.000	10	15-25
Project 6	Ankara	420	100.000	8	20-32

First project is located in Istanbul. It has 32 floors and 304 housing units in total. The construction area is approximately 70.000 m^2. There are several social facilities in the project such as outdoor swimming pool, trekking road, open sport courts, fitness center, playgrounds and hobby area. The construction of the project has been finished in 2014.

Second project is located in Istanbul. There are 46 blocks and 298 housing units in total. The floor levels are varying between 3 and 5. The land area is 100.000 m^2 and the area of the green zone is 80.000 m^2 in the project. The construction area is approximately 75.000 m^2. The project includes outdoor swimming pool, several social facilities and playgrounds in the green area. The construction of the project has been finished in 2011.

Third project is located in Istanbul. It has two blocks with 26 floor levels and 251 housing units. The construction area is approximately 55.000 m^2. There exist outdoor swimming pool and several social facilities such as fitness center, playgrounds in the green area and sports courts. The land area of the project is 20.000 m^2. The construction of the project has been finished in 2010.

Fourth project is located in Istanbul. It has eleven blocks all of which has six floors. The land area is 41.000 m^2 and the construction area is approximately 90.000 m^2. The total number of the housing units is 476. There exist several social facilities such as outdoor swimming pool, kindergarten, playgrounds, fitness center, commercial areas etc. The construction of the project has finished in 2013.

Fifth and sixth projects are parts of a master plan which is a grand multi-functional housing project expected to be constructed within ten years. The master plan is divided into several parts and these parts were constructed separately. The design and construction processes were conducted as independent projects by the same contractor. This grand housing project is located in Ankara. Because of its enormous scale, two parts of the project are taken into account in this research in order to be harmonious with the scale of the other projects in the research. These parts are handled as independent projects. Fifth project has 10 blocks with floor levels varying between 15 and 25. The construction area is approximately 120.000 m^2. The number housing units are 530. There is a small pond for recreational in the landscape together with several social facilities such as playgrounds, sport courts etc. There exist also commercial areas consisting of 44 shops. The construction of this project has been finished in 2015. Sixth project has 8 blocks with floor levels varying between 20 and 32. There are 420 housing units and the construction area is approximately 100.000 m^2. It consists of two social facilities, playgrounds in the landscape and a commercial area.

Design-build procurement model was implemented in all of these housing projects. The construction companies are responsible about the design and the construction of the projects. These companies awarded design firms with a contract for the preparation of the design documents such as architectural, static, mechanical, electrical and landscape projects. The contracts between design and contractor were formed by each construction company separately. Standard form of contracts which were explained in the section 2.3.5 were not used in these stages. The project coordination during the design and construction processes were handled between the project offices of the construction companies and design firms. The design documents were prepared with CAD programs.

3.3 Research Methodology

The method of the research contains two sections. First of which is the questionnaire survey made for gathering information about the changes in the selected construction works and for gathering information about the status of change management in these construction works. The second one corresponds to the generation of the knowledge-based model by using these data depending on the results of the survey.

A semi-structured interviewed questionnaire has been conducted as the first step with the aim of acquiring information about the issues mentioned above. These interviews were carried out with project managers, project coordination architects and site architects of related construction projects.

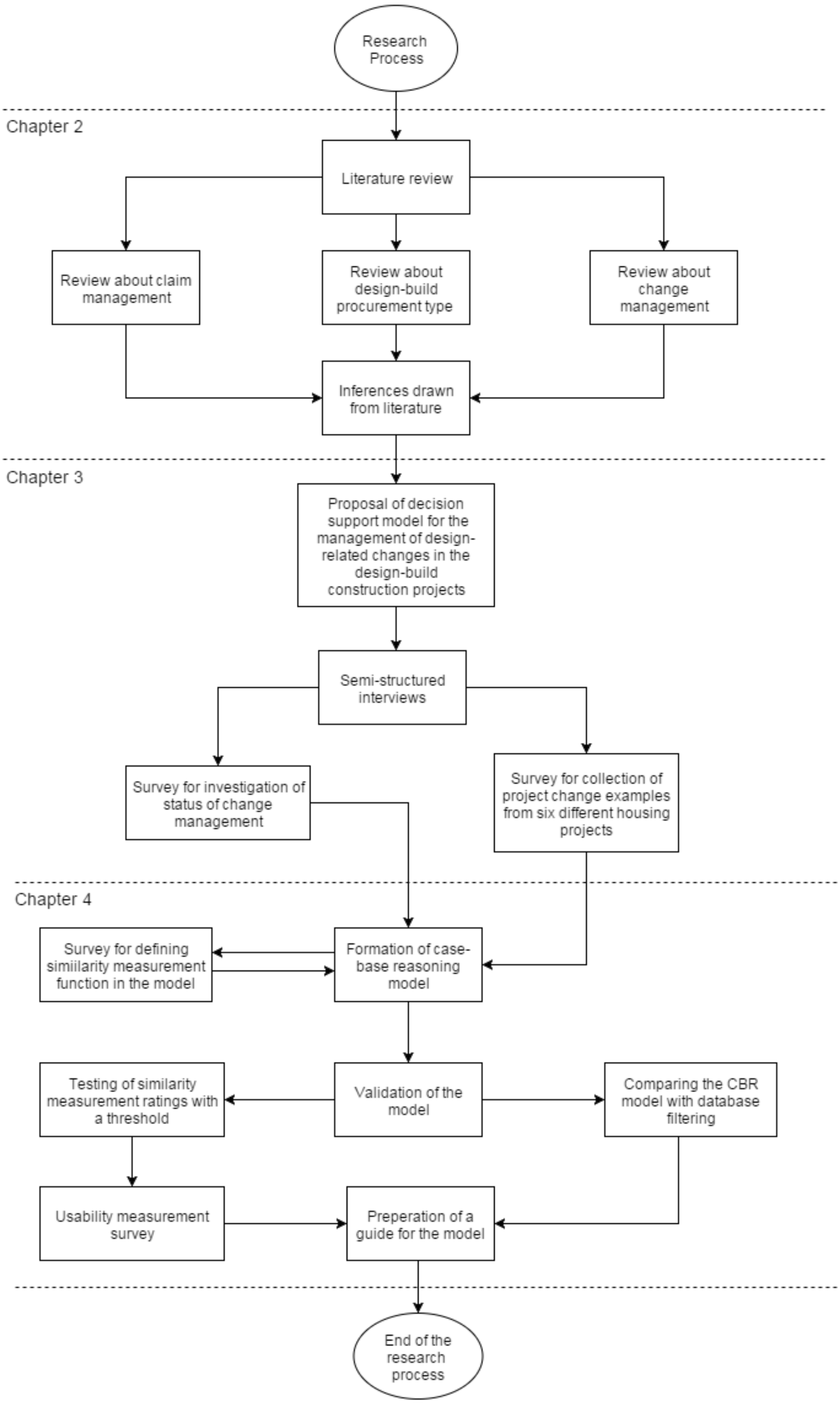

Figure 3.1 Chart of the Research Process

3.3.1 Questionnaire Design

The aim of the questionnaire was to investigate the status of change management in the construction works and to collect data in order to generate the model. In the first stage, a survey was conducted with the respondents in order to acquire information about their attitude towards change management, their experiences about change and claim management, existence of any change management methods used in their project and their expectations from the CBR model. The main aim is to investigate any need of a model for the management of project changes in the construction projects as argued in the introduction chapter.

In the second stage, examples of project changes were collected from six housing projects. These data were gathered in a textual format based on a form given to the respondents. With respect to the definition of the change in the construction projects in the literature review, the questionnaire includes four sections, i) The type of the change which corresponds to the general information in other words the name of the change event, ii) Causes of change, iii) Effects of change on project parameters which are impacts on project office of the construction company and the construction site, iv) impacts on other changes for setting up cause-effect relationships between changes which must be analyzed separately from the effects related with the project parameters. As a result, the form of the questionnaire survey which was filled in the interview is depicted below.

Table 3.2 The Form of the Questionnaire Survey

Type of Change	Causes of Change	Effects of Change	Effects on other changes

3.3.2 Semi-Structured Interview

Semi-structured interview corresponds to a verbal interchange between the interviewer and a respondent based on a list of specified questions. There is a conversational manner in this type of interviews where respondents can also mention different topic from the pre-determined questions if they feel as important (Clifford, French, & Valentine, 2010). Therefore, information gathering in the semi-structured interview has a less imposing, natural and spontaneous structure (Grindsted, 2005).

In this research, semi-structured interviews were made with the project managers of the related construction projects. Depending on the format of the questionnaire that was mentioned in the previous section, information about project changes was collected by asking questions to the respondents. These questions corresponded to the sections in the questionnaire and verbal information taken from the answers was written by the interviewer to the table.

Semi-structured interviews were made with the respondents in three sections. Firstly, the respondent was informed about the interview that was going to be conducted in order to provide him or her with enough time to gather all kind of information about project changes of the related project. During this period, the respondent collected related documents like drawings and tables, and gathered any missing information about the project changes. After that, semi-structured interview was conducted with the respondent according the questionnaire and initial information was taken about project changes of the related housing project. Lastly, the answers were analyzed and summarized by the interviewer, and any missing or incomprehensible parts were identified. Then, another meeting was organized with the respondent in order to complete the missing parts and confirm the analyzed version of the questionnaire. After that, the last version of the questionnaire was acquired, transformed into a MS excel© file and stored.

Questions that asked to the respondents can be presented generally as:

- The type of change,
- The causes of change,
- The effects of change,
- Any effects on other changes

In the "Effects of Change" section, the respondents were asked to rank impact of each event on project office and construction site according to the scale presented in the survey. In this section, selection of all kind of possibilities was presented to the respondents in which the effect is categorized into duration effect and cost effect. To illustrate, duration impact of a change event is divided into two parts, impact on project office and impact on construction site. The respondent selected the degree of effect between “No, Low, Medium, High” for each part separately. Furthermore, cost impact of a change event was ranked by implying the direction of the effect as, 'negative' if the change increases the project budget, 'positive' if the change decreases the budget and lastly 'neutral' if the change has no effect on the budget.

3.3.3 Results of the Questionnaire Survey

To begin with, all of the respondents are in a consensus about the need of establishing a plan for management of project changes for the success of the construction projects. They indicated that the impact of the changes to the construction process is significant with respect to duration and cost. Most of them didn't experience a model for the management of changes in their construction projects and they are in a need of assistance in management of changes. Finally, they admitted that the expectation from the model is high.

In the second stage, information about design related changes in six construction projects was collected in textual format with semi-structured interviews conducted with the respondents. During these interviews, the respondents defined each project change event depending on the design process in their construction project by filling the sections under “Type of Change”, “Causes of Change”, “Effects of Change” and

“Effects on the other Changes” headings. The initial version of these answers was in textual and handwritten format, so that they must be structured according to the features in the decision support model in order to be transformed into the database of the model. Because of this, two phases were employed in order to analyze the results of the semi-structured interviews.

In the first phase, the aim was to summarize the definitions of the project changes and transforming this information into electronic environment. The textual format of these definitions was summarized into several items and represented with keywords under these items. Then, an MS Excel© file was created in which all project change examples were listed according to their related construction project. In this file, project change examples were presented with their summaries.

In the second phase, the aim was to transform the MS Excel© file into a data format which can be adapted to the decision support model. In this stage, information about the project changes was structured according to the features of the model. This file corresponds to the database which is more specifically explained in the section 4.8.1.

To summarize, 227 project change examples were collected from the interviews. In the Table 3.3, breakdown of the number of changes with respect to the projects is depicted. The results of the survey are summarized specifically in section 4.5.1. The categorization of the changes are depicted in various tables according to the features of the model.

Table 3.3 Breakdown of the Number of Changes Collected during the Interviews

Project Name	Number of Changes
Project 1	36
Project 2	25
Project 3	36
Project 4	45
Project 5	52
Project 6	33

CHAPTER 4

DEVELOPMENT OF THE DECISION SUPPORT MODEL

After the questionnaire survey, a knowledge based decision support model for project changes regarding the design process was created which is going to be used by the contractor in his relationship with the designer. It provides strategies for the contractor in order to deal with design related project changes at the moment of occurrence. Case-based reasoning approach was used in the development process of the model.

Assistance for the contractor about the solution of a conflict related with the project change suggested by the model is based on a specific form of contract. This contract is AGC 420 between designer and contractor which was formed by Associated General Contractors of America (AGC). This specific from of contract should be used between the contractor and the designer in the related project. The model can only be used if the user implements this contract in his or her construction project. Information about a specific project change situation consists of the responsible party of the situation, related contract clauses in AGC 420, potential impacts on the other facts, possible effects on the cost and the duration of the project. With the help of the model, the user can decide on rejection or implementation of the project change. The user can also decide on what can be requested from the designer according to the contract provisions in order to minimize delays and extra costs.

The contractor will also be able to judge the conditions of the contract. The contractor can examine the responsible parties of each change situation and can develop a more contractor-favorable contract for the agreements with designers in the other construction projects.

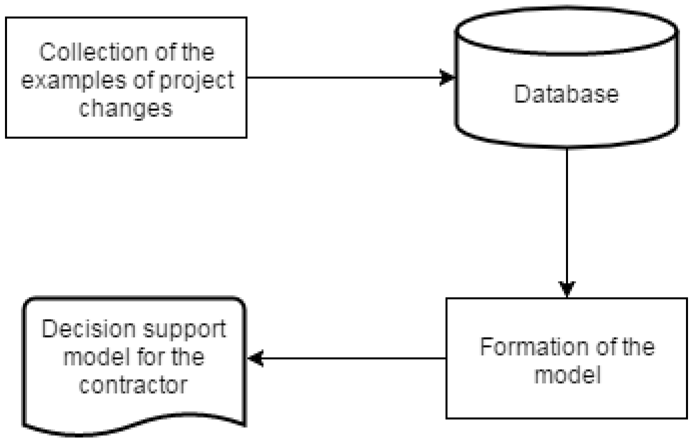

Figure 4.1 Formation of Decision Support Model

4.1 Review of Case-Based Reasoning Approach

Case-based reasoning (CBR) is a method of problem solving which depends on the use of past solutions in order to deal with a new situation (Li, 1996). By contributing to a useful technique in the artificial intelligence domain, it provides suggestions to the user for solving problems by comparing the new situation with the existing cases in the database and retrieving similar results (Yau & Yang, 1998b). The process of dealing with new problems by utilizing the specific knowledge is associated with how people use their experiences and make inferences for emergent situations (Choy & Lee, 2002). Because of the experience-oriented nature of the construction sector, CBR is used in the various stages in construction such as negotiation, bidding, cost estimation, planning, design and litigations.

4.2 Development of the Case-Based Reasoning Model

Case-based reasoning approach includes mainly three sections; *retrieval*, *adaptation* and *retain* (Chua, Li, & Chan, 2001). Furthermore, Yau and Yang (1998b) define the process of CBR by adding three more stages; case collection, case base, target case entry, case retrieval, case adaptation and case validation. Beside this wide categorization, CBR systems can be generally summarized with 4 "R"s, retrieve, reuse, revise and retain (Choy & Lee, 2002).

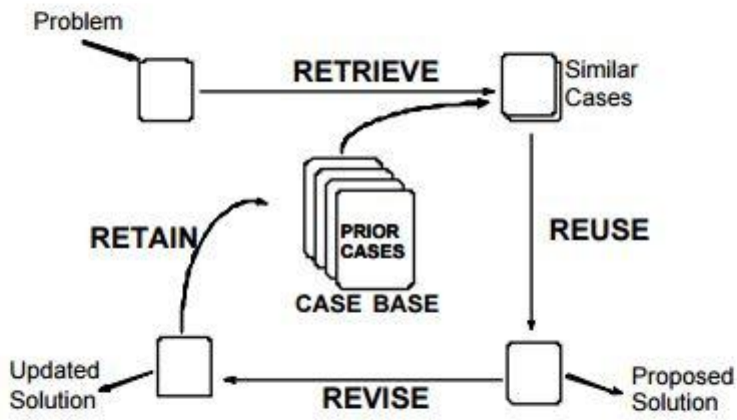

Figure 4.2 The Process of Case-Based Reasoning (Aamodt & Plaza, 1994)

The knowledge is represented in CBR in a formulation like "object-attribute-value" form as in the expert systems. In this formulation, a case is separated into various fields and each field is filled with specific values which corresponds to the structure of the case. Then, cases are stored in a database with these particular values which corresponds to the case-base (Yau & Yang, 1998b). At the initial stage, the structure of the case-base, in other words the features of the cases must be defined and then cases are collected in the database. Each feature in CBR can have different kind of features in various forms like numerical, logical, alphabetical and strings (Yau & Yang, 1998b).

When a new case is entered, the CBR model selects the most similar and appropriate case in the database by matching the features of the two cases in the retrieval stage (Perera & Watson, 1998). This matching is conducted according to the similarity measure established in the model and most similar cases are ranked for the next stage (Chua *et al.*, 2001). Then, the selected cases are reused in order to generate a solution for the new problem which is the output of the proposed solution (Choy & Lee, 2002). At the revise stage, the solution from the reused cases is adapted to the current problem case which is based on the differences between the values of new case and retrieved cases (Kim, An, & Kang, 2004). The adapted case is analyzed and validated as the final solution (Perera & Watson, 1998). In the last stage, this solution is added to the existing case and retained in the knowledge for the future usage (Choy & Lee, 2002).

4.3 Case-Based Reasoning Systems in Construction Field

CBR systems are adopted in the construction industry in various fields. These fields are design phase, bid decision making, negotiation, cost estimation, construction planning and dispute resolution.

For the design phase in the construction, Pearce *et al.* (1992) proposed ARCHIE which supports architects in the conceptual design stage of the office buildings with design proposal and critiquing. Flemming and Woodbury (1995) also suggested a system for the early design phase called SEED. It is capable of helping the architects with computational support such as architectural programming, schematic design and three-dimensional forming of a structural system. CASTLES which was developed by Yau and Yang (1998a) provides information for the user in the process of retaining wall selection. The case-base of CASTLES contains 254 different types of retaining walls. The most proper one is selected from the case-base when the user enters needs of the project.

For the bid decision making process, Chua *et al.* (2001) developed a case-based reasoning bidding system called CASEBID. The system supplies the user with dynamic information for various bid cases in which there exists two goals; risk and competition. Dikmen, Birgonul and Gur (2007) suggested a case-based decision support tool for bid mark-up estimation in which 95 cases were collected from the Turkish contractor companies. The tool takes into consideration of three factors affecting the bid; level of risk, opportunity and competition. Ratings for each factor are estimated by the tool in order to calculate the risk and profit mark-up values at the end. Li (1996) proposed a case-based reasoning model, MEDIATOR, for assisting professionals in the construction negotiations. When the user enters a new case by clarifying his goals and issues in the negotiation, the model selects the most similar one and adapts to the current problem for providing support to the user until an agreement is reached.

NIRMANI was developed by Perera and Watson (1998) for the cost estimation stages in the construction works. This case-based reasoning system gives estimation of building cost when the user enters information about the design of the project in the format of specifications and design layout. By this way, alternatives of design can be judged according to their approximate cost. Tah, Carr, and Howes (1999) suggested a case-based reasoning model for construction planning called CBRidge. It was developed and tested with bridge construction projects and provides the user information about durations in the design stage.

CBR systems are also used in the field of construction dispute resolution. Tokdemir and Arditi (1999) presented a CBR model for prediction of the outcome of construction litigations in the USA. The case-base of the model was formed by collecting real court cases in the USA. The accuracy of the model was tested with several similarity measurement implementations.

In conclusion, CBR systems are used in the several fields of construction sector because of the experience-oriented nature of the industry. When it's came to the knowledge-based decision support model for the management of design related changes in the construction works, making use of previous examples is also very important. CBR corresponds to a functional and comprehensive technique to provide solutions for the current problems with the help of the past experiences. Therefore, CBR method is selected as the methodology of the knowledge-based decision support model in this research.

4.4 MyCBR Tool

MyCBR was developed by the Competence Centre CBR in Germany and the School of Computing and Technology in UK (MyCBR, 2012). It is an open-source similarity-based retrieval tool for creating CBR systems which is able to cover different types of tasks such as decision support, planning or presentation (Bach & Althoff, 2012). The user is able to model knowledge-intensive similarity measures and these measures can be integrated into applications with the software development kit (SDK) (Roth-Berghofer *et al.*, 2012).

The workbench of the tool provides a strong and user-friendly Graphical User Interface (GUI) for generating knowledge intensive similarity measures (Roth-Berghofer *et al.*, 2012). There are task-oriented structures in the tool for modeling of the system, extraction of information and editing of case-base. The tool also offers a similarity-based retrieval functionality for testing of the products (Bach, Sauer, Althoff, & Roth-Berghofer, 2014). The process of modeling can be summarized as creation of the case structure, definition of the vocabulary, generation of local similarity measures for each attribute and definition of the global similarity function (Roth-Berghofer *et al.*, 2012).

There are concepts and attributes in the vocabulary of the MyCBR tool. A concept in the model can be defined with one or several attributes which refers to the object-oriented case representation. Furthermore, an attribute can be defined with several data types such as double, integer, string, date and symbol. After identification of the data types, values are attended to the attributes by the user which corresponds to the definition a concept in the model (Bach *et al.*, 2014). In this research two data types were used. These are; string which refers to textual values and symbol in which several values are listed and can be selected by the user.

MyCBR contains two types of similarity measurement methods which are local similarity measurement and global similarity measurement. Local similarity measurement refers to the description of similarity functions for each attribute in the model. Moreover, each attribute consists of various similarity measures in which the user is able to experiment different methods and can analyze the variations (Bach *et al.*, 2014). For symbolic values, there exists two kind of local similarity functions editors, table editor and taxonomy editor. By using the table editor, the user is able to define similarity values for each value pair. Taxonomy editor is preferred when the size of the vocabulary is large. In this method, local similarity values of attributes can be defined with taxonomies. Finally, global similarity measurement is defined in the concept level in which importance weights must be attended to each concept (Roth-Berghofer *et al.*, 2012).

In conclusion, myCBR tool was preferred to be used in this research for several reasons. First of all, myCBR provides a simple model generating process with the advantage of user-friendly GUI. Moreover, the tool can be used for an academic research for free. It is also favorable for the large-sized vocabulary of this research because of enabling taxonomy editor for definition of local similarity measurement. Finally, the research can be transformed into a tradable product in the further stages by using the software development kit in myCBR.

4.5 Methodology of Case-Based Reasoning Modeling

This study aims to create a knowledge-based decision support model based on the case-based reasoning approach. Should a change event related with the design stage comes up in a design-build housing construction project, the professionals using this model will be provided strategies on how to manage the changes. When the user inserts current event into the model, the most similar case will be selected from the case-base and the most acceptable solution will be shown to the user. The development process of the model can be summarized in four sections such as,

- Determination of Features
- Similarity Measurement Function
- Retrieval

- Reuse

Cases which were collected from six large-sized housing projects in Turkey via semi-structured interviews were inserted into the case-base. The development process of the model is finalized with a testing.

4.5.1 Determination of Features

Cases in the case-based reasoning approach must be defined with several features which can be in the form of string, list or number. In this model, each change event is structured as a case and a case-base will be formed by inserting them into the model. In this stage, features are determined after the analysis of the data collected from the questionnaire survey.

As mentioned previously, the survey that was filled by the respondents in the research phase has three main parts: Type of the change, causes of the change, effects of the change and effects of the change on the change events. The interviewees provided information regarding the project change events based on these headings. For example, the respondent disclosed the name of the change event for a question regarding the type of change. Nomenclature used by the respondents contains the location of the change in the context of the project, project element and what was made during this change occasion. Furthermore, in the causes of change section, the respondents gave two kinds of information; the source party of the change event and the factors that lead to the change. When it's came to the effects of change question, interviewees presented their evaluations depending on the categorization in the questionnaire. The information about the impact was given in the form of qualitative ratings under three sections; duration effects on the project office, duration effects on the construction site and effects on the cost. In the effects on other changes part, the respondents specified the name of any influenced change event. According to these classifications under each heading, features of the CBR model are determined. These features are presented below.

Same classification in the survey is also used in the categorization of features of the model. These are “General Information” corresponding to the type of change section, “Causes” corresponding to the causes of changes section and “Effects” corresponding to the effects of changes section in the survey. “Effects on Other Changes” section in the survey is also included in the “Effects” category.

Moreover, the main aim of the model is giving information about the treatment of each change event. After determination of features related with the data taken from the respondents mentioned above, two extra features will be added to the case-base which are related with the treatment of each change event. These are the determination of the responsible party of the change event and explanation of the related contract clauses. As a result, the features are described in four categories, “General Information”, “Causes”, “Effects” and “Treatment”.

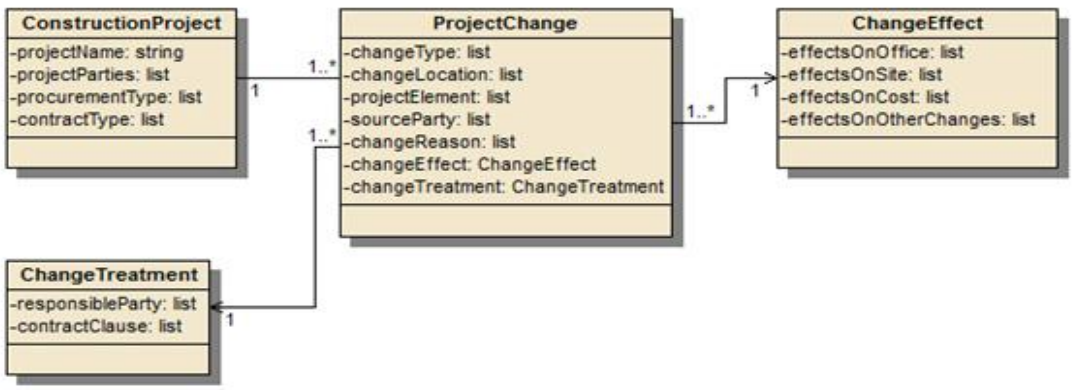

Figure 4.3 UML Class Diagram of the Model

- **General Information**

In the general information category, three features were defined depending on the responses from the interviewees. To begin with, location of the change and project element affected by the change event were defined with symbol. These features are represented with two OmniClass Tables from which the user can select the related item from the list. The OmniClass Construction Classification System constitutes to a new classification approach for construction industry which is used as the structure for electronic databases. It contains 15 tables demonstrating various sections of construction works (*OmniClass Introduction and User's Guide*, 2006). In the feature of change location, OmniClass Table 13 is used. Spaces of function in the built environment defined by either physical or abstract boundaries are categorized in this table. OmniClass Table 21 is utilized for the feature of project element. In this table, elements in the construction projects are classified which is identified as either a major component or an assembly.

Depending on the results of the questionnaire several missing points is added to the both tables. Firstly, some of the project changes were originated in general locations such as facade and whole building. However, OmniClass Table 13 only contains specific locations such as kitchen, entry lobby or car park. Therefore, locations of "Façade" and "Whole Building" were added to the table in order to be chosen while defining the feature of location of the change. Secondly, several minor or general project elements were added to OmniClass Table 21 which is used for defining the feature of project element in order to provide exact provisions to the responses which was taken from the survey. These are "Structural Elements", "General Plan", "System Details of Joineries" and "Skirting Details".

Types of changes are defined by Associated General Contractors of America as additions, revisions and deletions in the construction work (Callahan, 2005). American Institute of Architects (2007b) also presented construction changes in the special type of contracts in a similar manner. Because of this, the feature of type of change was represented with symbol and values of addition, deletion or revision can be chosen from the list while defining the type of change.

- **Causes**

When it's came to the causes section, the features were also created according to the responses in the survey. Firstly, the source party of the change event was described with symbol where one of the parties in the construction project can be selected from the list. The list of parties in the construction project was generated according to the generic contract in the model. These are contractor, designer, owner/client, electrical consultant, structural design consultant, mechanical consultant, landscape architect and governmental issues.

Table 4.1 Allowed Values for Source Party Feature

Source Party
• Designer
• Contractor
• Owner/client
• Electrical Consultant
• Mechanical Consultant
• Structural Design Consultant
• Landscape Architect
• Governmental Issues

Then, the reason of change was defined with symbol in which the user can determine the cause which leads to the change event. In this process, cases were categorized into several topics according to the taxonomy generated in the study of Babak (2012) for nomenclature of the causes of the changes in the construction projects. The purpose of Babak (2012) is to provide a comprehensive taxonomy for the causes of changes in the construction projects. Through extensive review of the literature, totally 1578 causes of changes were listed and grouped under several headings in this study. This classification leads to a general model which can provide a base for prospective claim management researches and can be used in the data base models.

The hierarchy in the taxonomy has three levels. The first one is composed of 13 general categories. "Design and specifications" constitutes to one of these categories and it was used in the case-based reasoning model. Causes of changes related with design documents and design process are included in this category with four sub-headings, "Accuracy of Design Documents", "Changes in Design and Specifications", "Design Process” and "Characteristics of Design".

Because of the inclusion of source party feature in the model, name of the agents of the contract were removed from some nomenclatures in the taxonomy. For example, names of agents such as designer, consultant, owner and client were subtracted from causes of “change / modifications in design by owner”, “change in design by consultant”, “change of plan by owner / client”, “late in revising and approving design documents by owner” and “design errors made by designers”. In the CBR model, the user is able to select the agent while defining the source party feature from a more extended list.

According to the results of the questionnaire survey there exist some missing nomenclatures related with causes of design related changes in the "design and specifications" section of the taxonomy. Depending on the results of the research, two change reasons were added to the list of this feature in the model. The first one is “Inconsistent with governmental regulations” which corresponds to the problems related with the design documents due to not being in accordance with the governmental specifications. The second is “Inconsistency between drawings” which corresponds to problems related with incompatibilities between several design drawings. As mentioned before, "design and specifications" section is used in the CBR model because the model is related with the changes regarding the design process in the construction projects. According to the results of the questionnaire survey, some of the project changes occurred due to the actions of governmental authorities such as alterations in the regulations or laws. Because of this, another nomenclature of cause “Changes in government regulations and laws” is also added to the model which is included in the “Macro Factors” section in the taxonomy. The final version of the list which is used in the change reason feature is depicted in the Appendix E.

- **Effects**

Depending on the results of the questionnaire survey, the impacts of a change event are presented as duration effects on the construction site and on the project office, effect on the cost and effects on the other change events. As mentioned before, duration impacts on the project office and the site was determined in the questionnaire survey with specified ratings which are "no, low, medium, high". By the way, effects on the cost was specified with values of positive, negative or neutral. The features of duration effects on the project office site, duration effects on the site and effects on the cost were defined with symbol in the model. The user can select these values from the list. The feature of effects on the other change events is depicted with string. Names of the effected change events can be written to this section.

- **Treatment**

Treatment constitutes to the last section of the case-base and the main output of the model by providing a support related with the contractual issues. There are two features in this category, the responsible party and the related contract clauses both of which are defined with symbol. The responsible party is selected from the list which contains parties in the contract, designer, contractor or client. Related contract clause with the change case is chosen from the list which includes clauses of the contract.

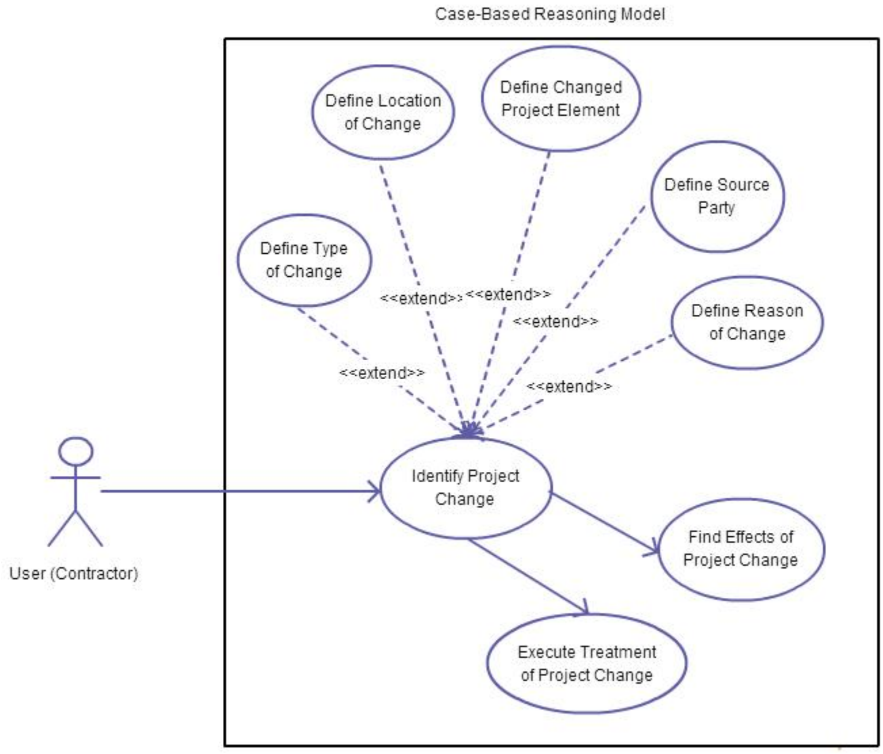

Figure 4.4 Use Case Diagram of the Model

After determination of the features, cases which are collected from the semi-structured interviews were entered into the model. The representation of an example case in the CBR model is depicted in Figure 4.5. These cases are design related change events collected from six different large sized housing projects in Turkey. At the end, the case-base of the model was settled up.

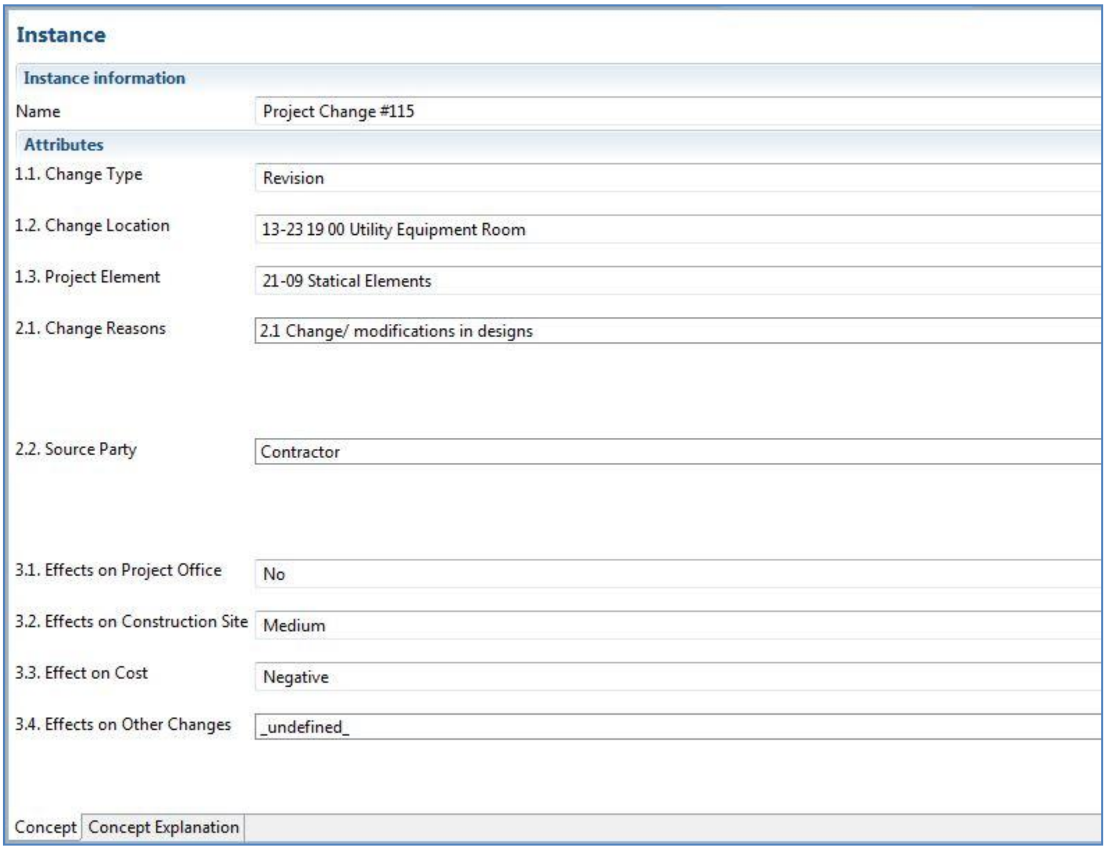

Figure 4.5 Representation of a Case in the CBR Model

The results of the interviews were organized according to the features of the model. As mentioned in the previous chapter, the information given by the interviewees in the research was structured with attributes in order to be used in the model. In this sense, several features were determined while designing the model. Firstly, a MS Excel© document was created in which information about each case was represented with several values corresponding to the features of the model. Then, this document was approved by the participants of the interview. They confirmed that the final document exactly meets with the information given by them in the semi-structured interviews. After approval of this document, 227 project change cases collected from six construction projects were entered into the model.

- **Summary of the Changes**

In this section, summary of the changes which were collected from the interviews is depicted according to the features of the model. The changes are categorized according to the values in the features and percentage of these values are depicted in the various tables.

Table 4.2 Number of Changes Related to the Type of Change

Change Type	Number (Within the 227 total changes)	Percentage in the total changes
Addition	24	10,5%
Deletion	9	3,9%
Revision	194	85,6%

Firstly, number of changes related to the type of change and their percentage in the total changes are depicted in Table 4.2. According to the table, 85,6% of the total changes in the case-base is revision type. 10,5% of them is addition and 3,9% of them is deletion.

Table 4.3 Number of Changes Related to the Location of the Change

Location	Number (Within the 227 total changes)	Percentage in the total changes
General Housing Plan	48	21%
Kitchen	10	4,4%
Bathroom	16	7%
Corridor	7	3%
Entry Lobby	12	5,2%
Facade	14	6,1%
Fitness Center	12	5,2%

In the Table 4.3, number of changes related to the specific locations in which changes appeared are depicted together with their percentage in the total changes. General housing plan is the most common location with the percentage of 21% in the total changes. 7% of the changes appeared in the bathroom, 6,1% of them appeared in the facade, 5,2% of them are related with the entry lobby, 5,2% of them appeared in the fitness center, 4,4% of them appeared in the kitchen and finally 3% of them are related with the corridor.

Table 4.4 Number of Changes Related to the Source Parties

Source Party	Number (Within the 227 total changes)	Percentage in the total changes
Architect	55	24,2%
Contractor	128	56,4%
Client	5	2,2%
Governmental Issues	18	7,9%
Landscape Consultant	5	2,2%
Mechanical Consultant	21	9,2%
Structural Design Consultant	3	1,3%

In the Table 4.4, number of changes related to the source parties together with their percentage in the total changes are depicted. Contractor can be determined as by far the most popular party as the source of the changes with the percentage of 56,4%. 24,2% of the changes are related with the architect, 9,2% of the changes are related with mechanical consultant, 7,9% of them were are related with governmental issues, 2,2% of them are related with client, 2,2% of them are related with landscape consultant and finally 1,3% of them are related with structural design consultant. It has to be noted here that the respondents can select various source parties during the interview so that the total sum of the percentages is exceeding 100%.

Table 4.5 Number of Changes Related to the Duration Effects on the Office

Effect	Number (Within the 227 total changes)	Percent in the total changes
No	24	10,5%
Low	96	42,2%
Medium	74	32,5%
High	33	14,8%

In the Table 4.5, number of changes related to the duration effects of the changes on the project office is depicted together with their percentage in the total changes,4% of the changes have a low impact on the project office, 32,5% of the changes have a medium impact on the project office, 14,8% of them have a high impact and 10,5% of them have no impact on the project office.

Table 4.6 Number of Changes Related to the Duration Effects on the Site

Effect	Number (Within the 227 total changes)	Percent in the total changes
No	44	19,3%
Low	71	31,2%
Medium	75	33%
High	37	16,5%

In the Table 4.6, number of changes related to the duration effects of the changes on the site together with their percentage in the total changes is depicted. According to the table, 33% of the changes have a medium impact on the site, 31,2% of them have a low impact on the site, 19,3% of them have no impact and 16,5% of them have a high impact on the site.

Table 4.7 Number of Changes Related to the Effects on the Budget

Effect	Number (Within the 227 total changes)	Percent in the total changes
Negative (Implementation of the change increases the budget)	121	53,3%
No	62	27,3%
Positive (Implementation of the change decreases the budget)	44	19,4%

In the Table 4.7, number of changes related to the effects of the changes on the budget is depicted together with their percentage in the total changes. According to table, 53.3% of the changes have a negative impact on the budget, 27,3% of the changes have no impact and 19,4% of them have a positive impact on the budget.

4.5.2 Similarity Measurement Function

Similarity measurement function is the criterion of selection in the retrieval stage. The function of similarity contributes to the most important part of the case-base modeling (An, Kim, & Kang, 2007). It differs case-based reasoning from other knowledge models such as expert systems because the output of the model directly depends on this formulation.

- **Review about the Similarity Measurement Adaptation Methods**

There exist several methods for similarity measurement in case-based reasoning models such as feature counting, inferred-feature computation and weighted feature computation. Among these, most of the case-based-reasoning tools promote weighted feature computation which is performed by defining an importance weight for each feature. In the retrieval stage, the case with most higher-priority features matching with new case is selected from the case-base (Tokdemir & Arditi, 1999). For the weighted feature computation, there are three types of calculation methods in the case-based reasoning tools (Karancı, 2010). These are ID3, gradient descent method and manual adaptation method.

- **ID3**

ID3 is a learning algorithm based on decision trees which is used for classification problems (Smyth & Cunningham, 1998). In this approach, decision trees are constructed in which all of the attributes are classified under several categories (Quinlan, 1986). After formation of the decision tree, the algorithm selects one attribute at each step to be tested. After testing of the attributes, the optimum decision tree is constructed (Pantic, n.d.). At the end, the decision tree can be used for the classification of the attributes in the case-based reasoning models.

- **Gradient Descent Method**

The gradient descent method constitutes to a kind of optimization algorithm applied in CBR systems in which importance weight of each feature is determined automatically**.** Firstly, random cases are selected by the system. Then, importance weights of these cases are revised depending on the differences between them until the criteria defined by the user is reached (An *et al.*, 2007)**.** Therefore, the weights of each feature are calculated by the system accordingly.

- **Manual Adaptation Method**

In this method, the developer determines weights of each feature in the design process of the CBR system. There must be an appreciable research for specifying these weights which can be made with a survey in order not to reflect the bias of the developer (Tokdemir & Arditi, 1999). In myCBR, the user can assign the weights of each feature manually by using Global Similarity Function Editor (MyCBR, 2012).

In this model, manual adaptation method was preferred. For each feature of the case base, an importance weight was defined according to their influences on the similarity measurement. In order to designate these importance weights, a survey was conducted with the interviewees of the semi-structured interviews made in the first section of the research. According to the results of this survey, the global similarity function was defined. Later on, inner similarity functions were defined for the contents of each feature.

- **Global Similarity Function**

Global similarity function identifies the similarity rule between the features of the case-base reasoning model. Importance weights were given manually during the formation of the model by the developer. These features were ranked with the numbers from 1 to 10 by the respondents in the survey. Then, these values were summed up and the value of each feature divided with the summation in order to find relative weight of each feature. The output features which are located in the category of effects and treatment are not going to be used in the retrieval stage. So that, they were not given any importance weight and were not included in the survey. The process of the survey is defined in a more detailed manner in section 4.6.

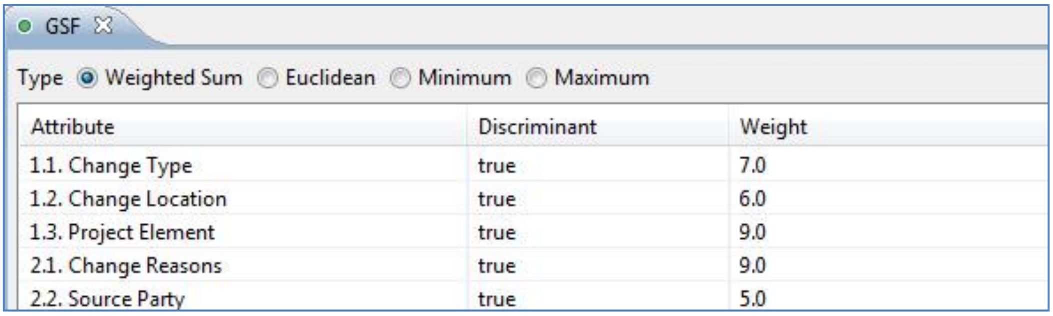

Figure 4.6 Global Similarity Function in the CBR Model

- **Local Similarity Function**

Local similarity function defines the measurement of similarity between values in the feature. For each feature in the CBR model determined with symbol format, several similarity measurement functions were designed. Two kinds of methods were used while generating these functions depending on the values and type of the feature. These methods are table editor and taxonomy editor.

Taxonomy editor was used in order to define inner similarity function for the features in which there exist taxonomies in the list of values. For instance, the taxonomy proposed by Babak (2012) was represented with this kind of function in the feature of "Change reason". Inner similarity functions of features which is based on OmniClass tables such as "Change Location" and "Project Element" was also defined by Taxonomy editor. The feature of “Source Party” was also defined with taxonomy editor as shown in Figure 4.7 according to the dependency of relationships between the parties in the AGC Design-Build contract. The structure of each inner similarity function is shown in the Appendix.

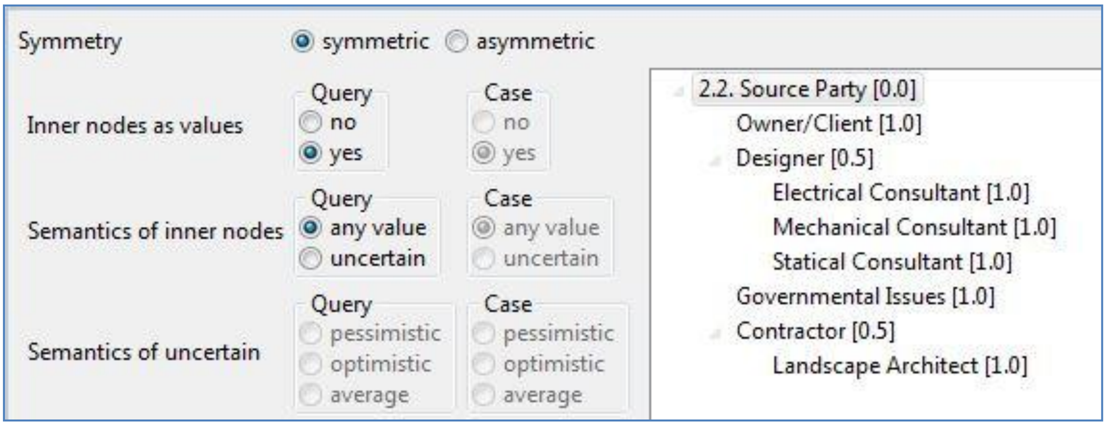

Figure 4.7 Local Similarity Function of Source Party in the Taxonomy Editor

Table editor was used for the features in which there are distant type of values and there isn’t any similarity or dependency structure between them. For instance, there exists three values in the feature of “Change Type” which were identified independently from each other. These are revision, addition and deletion. There isn’t any similarity or dependency relationship between each other; so that, Table editor was used in the formation of inner similarity function of “Change Type”. The structure of the inner similarity function can be seen in Figure 4.8.

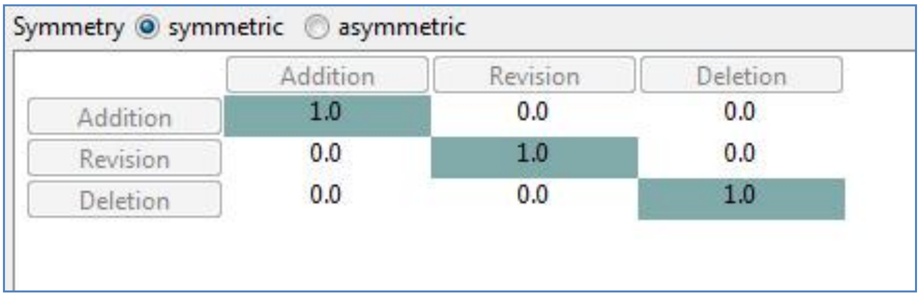

Figure 4.8 Local Similarity Function of Change Type in the Table Editor

4.5.3 Retrieval

In the retrieval stage, the user is going to define a new project change in the CBR model. The user defines the features related with general information and causes of the change event. In this case, values are given to five features which are location of the change, type of the change, project element, reasons of the change and source party as shown in Figure 4.9. Other features which belong to the effects and treatment section corresponds to the outputs of the model.

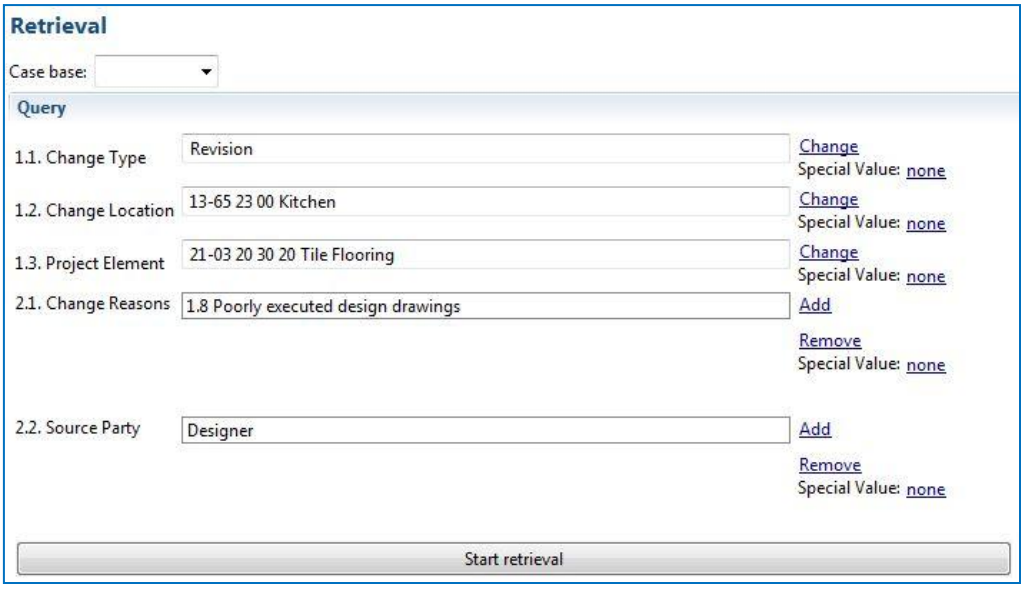

Figure 4.9 Definition of a New Case in the Retrieval Stage

When a new case is inserted into the model, the CBR model retrieves similar cases of the new case from its database according to the similarity measurement function. The results of the retrieval are shown to the user together with the similarity scores calculated between 0% and 100%. At the end, selected cases are sorted from highest to lowest according to their similarity score as shown in Figure 4.10.

Project Change #38 - 0.88
Project Change #108 - 0.79
Project Change #109 - 0.75
Project Change #98 - 0.75
Project Change #90 - 0.75
Project Change #37 - 0.75
Project Change #40 - 0.63
Project Change #184 - 0.63
Project Change #73 - 0.63
Project Change #113 - 0.63
Project Change #170 - 0.63
Project Change #201 - 0.63
Project Change #224 - 0.61
Project Change #129 - 0.61
Project Change #70 - 0.61
Project Change #176 - 0.61

Figure 4.10 List of Similar Cases

4.5.4 Reuse

In this stage, the user is shown the retrieved cases together with their similarity scores. The selected cases are arranged according to their similarity rankings. This output is in the form of a strip in which cases are sorted from left to right as depicted in Figure 4.11. The most similar case is located on the left. At the top left of the screen the user can also discover the similarity scores of other cases in the database. In this stage, the results of the model is used for the current project change event. The way of use of this output in order to reach the final solution is decided after a survey is conducted with the same audience. The method of use of these results is explained in the testing section together with a guide for the users.

	Project Change #38	Project Change #9	Project Change #108	Project Change #109
Similarity	0.88	0.83	0.79	0.75
1.1. Change Type	Revision	Revision	Revision	Revision
1.2. Change Location	13-65 00 00 Private Residential Spaces	13-25 11 11 Corridor	13-65 13 00 Bathroom	13-65 00 00 Private Residential Spa...
1.3. Project Element	21-03 20 30 20 Tile Flooring	21-03 20 30 20 Tile Flooring	21-03 20 30 20 Tile Flooring	21-04 50 Electrical
2.1. Change Reasons	1.14. Poor design quality – improper/ wrong ...	1.8 Poorly executed design drawings;	1.14. Poor design quality – improper...	1.8 Poorly executed design drawin...
2.2. Source Party	Designer;	Designer;	Mechanical Consultant;	Designer;
3.1. Effects on Project Office	Low	Low	Medium	No
3.2. Effects on Construction Site	Medium	Low	Medium	Medium
3.3. Effect on Cost	No Effect	Negative	No Effect	Negative
3.4. Effects on Other Changes	Project Change #37;	_undefined_	_undefined_	_undefined_
4.1. Responsible Party	Designer;	Designer;	Designer;	Designer;
4.2. Related Contract Clause	3.2;3.2.3;3.2.6;5.1;	3.2.3;5.1;	3.6;5.1;	3.2;3.2.2;5.1;

Figure 4.11 Results of the Retrieval

4.6 Survey for Definition of the Similarity Measurement Function

Global similarity measurement is based on relative importance weights given for each attribute in the model. In order to designate these importance weights, a survey was conducted with the interviewees of the questionnaire survey made in the first section of the research. The audience consists of professionals responsible for each housing project.

4.6.1 Design of the Survey for Determination of the Similarity Measurement Function

In the retrieval stage of the model, the user will define five attributes related with general information and causes categories. These are type of change, location of change, project element, reasons of change and source party. These attributes will be used for identification of a new case to the model. Measurement of similarity will be calculated according to these five attributes when sequent comparisons are conducted between new case and current cases in the case-base.

In the survey, the respondents evaluated these five attributes according to their importance in the definition of a project change. Each attribute was rated with numbers from 1 to 10. At the beginning of the interview, the respondents were informed about the criteria of the evaluation which is the importance in the definition of a project change. In this session, a guide for decision making process of evaluating the importance of each attribute was represented to the respondents. Three steps was introduced in this guide. The guide for decision making process was depicted below. In this example, the importance of location of the change is going to be evaluated.

Suppose that the definition of the project change is "Revision of suspended ceiling in kitchen because of changes in design by the contractor".

1- Change the location of change while the other attributes remaining same.
2- Compare the two examples according to their effects on the project in form of time and budget.
3- Decide on the importance of location of the change with the help of the difference between impacts of these two examples.

Table 4.8 Comparison of Two Examples

Attributes	**Actual Case**	**Compared Cased**
Type of Change	Revision	Revision
Location of Change	Kitchen	Entry Lobby
Project Element	Suspended Ceiling	Suspended Ceiling
Change Reason	Change in design	Change in design
Source Party	Contractor	Contractor

4.6.2 Results of the Survey for Determination of the Similarity Measurement Function

The evaluation of five attributes according to their importance in the definition of project change was made with six interviewees responsible for each housing project. The respondents rated each attribute. The final ratings of attributes were determined by taking average of the ratings given by each respondent. The final results are depicted in Table 4.9. These ratings correspond to the importance weights of each attribute in the CBR model.

According to Table 4.9, it can be seen that the most effectual features are project element and change reason. The respondents of the survey thought that the effects of the change highly depend on the cause of the reason and the effected element in the project. By contrast, source party has the lowest importance weight. Whether the source party of the change is designer or the contractor, the respondents admitted that the effects of the change on budget and duration does not differs significantly.

Table 4.9 Results of the Survey

Attributes	Ratings for Importance Weights
Change Type	7
Change Location	6
Project Element	9
Change Reason	9
Source Party	5

4.7 Validation of the Model

At the final stage of the development of the CBR model, the model was validated in two phases. In the first phase, the results of retrieval process of the model were tested by using a threshold. In the second phase, the way of use of the results was tested by conducting semi-structured interviews with the same audience.

4.7.1 Testing the Results of the Model

The case-base of the model consists of 227 project change cases collected from six different housing projects. As mentioned in the previous chapters, when the user inserts a new case into the model, similar cases are retrieved and sorted depending on their similarity measurement values. In the first step of the validation process, the model was tested according to these values.

- **Selection of the Cases**

At this stage, cases which were used in the testing process were selected from the case-base. In the literature, generally two kinds of case-bases were prepared for the validation stage. These are actual base and testing base. In their model providing estimation of total construction cost based on CBR approach, Kim *et al.* (2004) divided the case-base into two parts. 40 examples from 530 total cases were randomly selected for the testing base. At the end, 8% of the total cases were used in the validation process.

In this research, 23 out of 227 cases were randomly selected from the database for the testing of the model which corresponds to 10% of the total cases. The testing set was formed by simple random sampling method in MS Excel©. The testing process is different from the method of creating two different sets for the validation of the model. In this model, there are six different case-bases. These case-bases are related with six different housing projects from which cases were collected in the research phase. In each case-base, cases collected from one housing project were excluded. The aim was the validation of a case by using cases of other projects. Therefore, each case in the testing set was tested according to a case-base containing cases collected from other housing projects.

The formation of the case-bases which are used in the testing process is depicted with an example. According to Table 4.10, suppose that the case which is going to be used in the testing process is a_2. In this stage, information about a_2 is going to be defined in the model and the model will show similar cases of a_2. This case will be tested with a case-base in which cases collected from Project A are subtracted. Therefore, the case-base which will be used in the testing process can be defined as "Total-Project A". Suppose that, c_1 is the other case in the testing set. This case is going to be tested by using another case-base. In this moment, cases collected from

Project C must be excluded from the total cases. Therefore, the case-base which will be used in the testing process can be defined as "Total-Project C". The example is depicted in Table 4.10.

Table 4.10 Selection of Cases and Case-Bases

	Case Base	**Cases in this Base**
Project 1	A	a_1, a_2, a_3
Project 2	B	b_1, b_2, b_3
Project 3	C	c_1, c_2, c_3
Project 4	D	d_1, d_2, d_3
Project 5	E	e_1, e_2, e_3
Project 6	F	f_1, f_2, f_3
Total	A+B+C+D+E+F	

Selected case for testing = a_2

Case-base used in the testing process = Total-A = B+C+D+E+F

- **Threshold Value**

The similarity measurement values have numerical values between 0 and 100 depending on the similar features that appear as a result of the retrieval process. For the reuse process of the model, retrieved cases should be eliminated depending on their similarity measurement values in order to provide more accurate results.

In this stage, similarity measurement values of the cases in the testing set were tested according to a similarity threshold. Similarity threshold was identified by analyzing the previous researches. In his bid markup estimation model, Gür (2005) determined the threshold value as 75%. In this model, cases with similarity measurement ratings equal or more than 75% were used for solution after the retrieval stage. Tokdemir and Arditi (1999) also specified this value as 75% in their model for estimation of the outcomes of the construction litigations. Furthermore, threshold value was determined as 70% by Özorhon (2004) in his CBR model for organizational learning.

According to this review, 75% and 70% are generally used in the case-based reasoning models as the threshold value. Both values were tested with the cases in the testing set. It can be seen that the model can give nearly 5 similar cases when the threshold value determined as 70%. When the threshold value is determined as 75%, generally 3 similar cases can be selected for the testing process. Therefore, 70% was selected as the threshold value in this research. While cases in the testing set are introduced into the model, retrieved cases with similarity measurement ratings above or equal to 70% are utilized for the second phase of the validation process. If there is no retrieved cases suitable for this criterion, testing of the related case will fail in the first phase of the validation process.

4.7.2 Testing the Use of the Results

In the previous phase of the testing process, cases in the testing set were selected and the results of the model were validated according to the quantitative values of them. In this phase, qualitative values of these cases were tested with the help of a survey. In this survey, the way of use of the retrieval results was experienced. In the first stage, two methods which are proposed for making use of the retrieval results of the model are introduced. Then, preparation of the survey is presented. In the final part, the results of the survey are discussed.

- **Methods to be Tested**

After the retrieval process, similar cases are listed together with their features and similarity measurement scores in the CBR model. Procedure of using this output was determined by conducting a survey. In this stage, two methods were presented to the respondents. One of them was chosen by the respondents.

Tokdemir and Arditi (1999) proposed a CBR tool for estimating results of construction litigations. In this tool, one output is shown to the user after the retrieval process which is the responsible party of the litigation. In the generation process of the model, three methods were experienced for determining the way of use of the model. After the testing process, one of these methods was presented as the procedure of using retrieval results. These methods are;

- Taking the most similar case,
- Taking average of 10 cases possessing highest similarity measurement scores,
- Taking average of 5 cases possessing highest similarity measurement scores as the result of the model.

Özorhon (2004) generated a CBR model in order to be used by construction companies as an organizational learning tool. Information about construction markets with respect to features of attractiveness and competitiveness are given to the user by the model. Values of attractiveness and competitiveness are calculated and presented to the user as the output. In the adaptation process, five methods were proposed by Özorhon (2004) as prediction models. These methods are;

- Taking the most similar case,
- Taking average of the values of all cases in the retrieved cases list,
- Taking mode of the values of all cases in the retrieved cases list,
- Taking average of the values of top 10 cases in the retrieved cases list,
- Taking mode of the values of top 10 cases in the retrieved cases list as the result of the model.

In this model, the first method is the presentation of the most similar case as the result the model. In this method, the interviewee evaluated the results of model according to the most similar case selected in the retrieval process. The second one is the presentation of top five cases in the retrieved cases list. These cases are sorted according to their similarity measurement ratings. In this method, the interviewee evaluated results of the model according to the outputs of top five cases in the retrieval list.

Table 4.11 Methods to be Tested

	Description
Method I	Output of the most similar case
Method II	Outputs of top five cases in the retrieved cases list

- **Design of the Research for Evaluation of Usability of the CBR Model**

The aim of the research is to determine the way of use of the model. The research was conducted with semi-structured interviews based on a survey. The audience of the survey was same with the previous research. Professionals who are responsible for six different housing projects were selected as the respondents. As mentioned in the previous chapter, the testing set contains 23 cases which are located in the case-base of the model. Semi-structured interviews were conducted for each case in the testing set. Each case in the testing set was tested by the responsible of the related project. By this way, each professional was asked to validate the results of the model related with his or her project.

In the first phase of the semi-structured interview, general information about the CBR model was given to the participants. Methodology of the model and process of the development of the model were presented. Thereafter, the respondents experienced the CBR model and the retrieval process was presented to them. This process was conducted for all cases in the testing set. At the end, the respondents had an idea about the usability of the model before answering the questions in the usability measurement survey. At the end, evaluation about two methods and the CBR model was made based on a survey by the respondents. The semi-structured interview was conducted in Turkish which is the native language of the participants.

The survey which is used in the semi-structured interviews was designed according to a literature review conducted for usability evaluation. There exist various methods for evaluation of usability and experiences of user (Bevan, 2008). International Organizational Standardization (ISO) developed a measurement method for usability of products, ISO 9241. In this method, usability is identified as the product's capability of allowing user to accomplish his or her work effectively, efficiently and with satisfaction which correspond to three attributes of usability (Abran, Khelifi, Suryn, & Seffah, 2003). These attributes are defined as (as cited in Joo, Lin, & Lu, 2011):

- Effectiveness: Accuracy in the accomplishment of the work
- Efficiency: Resources used in the accomplishment of the work
- Satisfaction: Attitude of the user towards the system

Several adjustments were introduced to the definition of the usability in some of the researches. For instance, Nielsen (1994) represented five attributes while referring to the term of usability which are learnability, efficiency, memorability, errors and satisfaction. In this case, learning refers to the easiness in the implementation of the system by the user. Memorability refers to the easiness in remembering the system after a period of a time. With a similar attitude, Shackel (1991) describes the usability with four attributes; efficiency, effectiveness, learnability and satisfaction. Several usability measurement models were developed depending on these studies. Joo *et al.* (2011) generated a usability evaluation system for library website systems. The model was based on the attributes of efficiency, effectiveness and learnability. Satisfaction was included to the context of learnability attribute in this system.

In order to test the results of the CBR model, a semi-structured survey was designed based on the usability evaluation. In this survey, usability of the model and methods which are proposed as the output of the model were evaluated by the respondents. The usability of the CBR model was tested based on the three main components. These are effectiveness, efficiency and satisfaction as presented in the ISO 9241.

Therefore, the questions for the evaluation of the usability of the model were structured within these three sections in the survey.

The aim of the effectiveness part was the evaluation of the model with respect to the accuracy in the results given to the user. Firstly, the respondents were asked to choose the method which is going to be used as the output of the model. The respondents can select either Method I or Method II which are depicted in Chapter 5.2.1. The respondents also indicated the reason of this selection. Then, questions about the accuracy in the results of the model were asked to the respondents with respect to each attribute in the CBR model. These attributes are time effects on the project office and the site, effects on the budget, effects on other changes in the project, related contract clauses and the responsible party. In the efficiency part, the aim was to evaluate the model according to its contribution to diminishing the period of decision making about the project changes. The period of decision making was divided into several parts in the management of project changes depending on the attributes in the model. These parts were evaluated by the respondents separately. In the last part, the respondents indicated their satisfaction about the model in terms of several criteria such as learnability, adaptability, easiness and presentation.

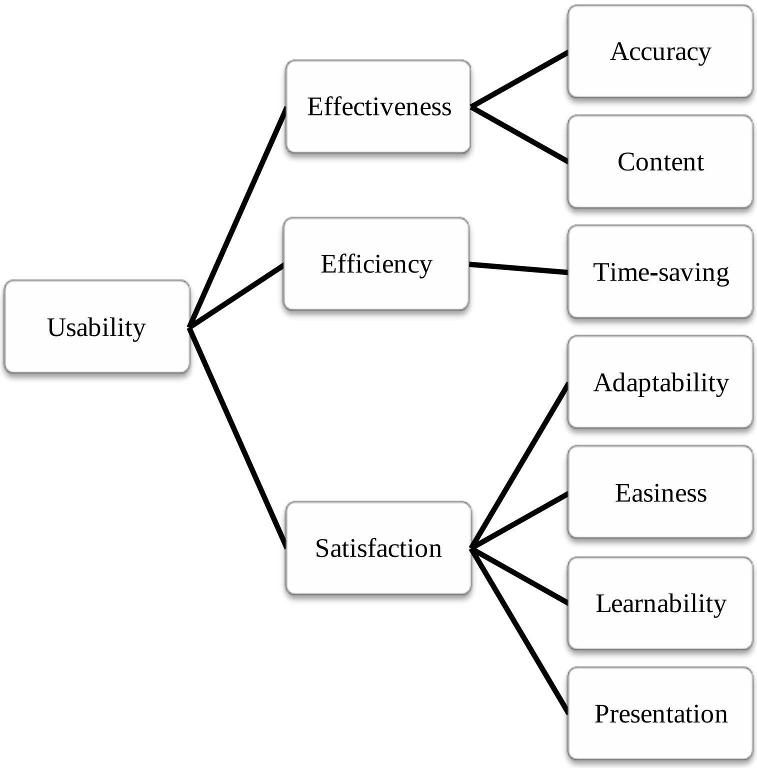

Figure 4.12 Usability Measurement Methodology

4.7.3 Results of the Testing Process

In this section, results of the testing survey are summarized and presented with respect to the sections in the survey which are effectiveness, efficiency and satisfaction. As a general opinion, the model was validated for the ability of showing results of legal impacts of a project change. Moreover, the performance of the model in finding effects of the change on time and cost was evaluated as fairly well. There is also a consensus about the positive contribution of the model to the acceleration of the decision making process about the project changes. Consequently, general satisfaction of the participants about the CBR model is acceptable.

- **Effectiveness**

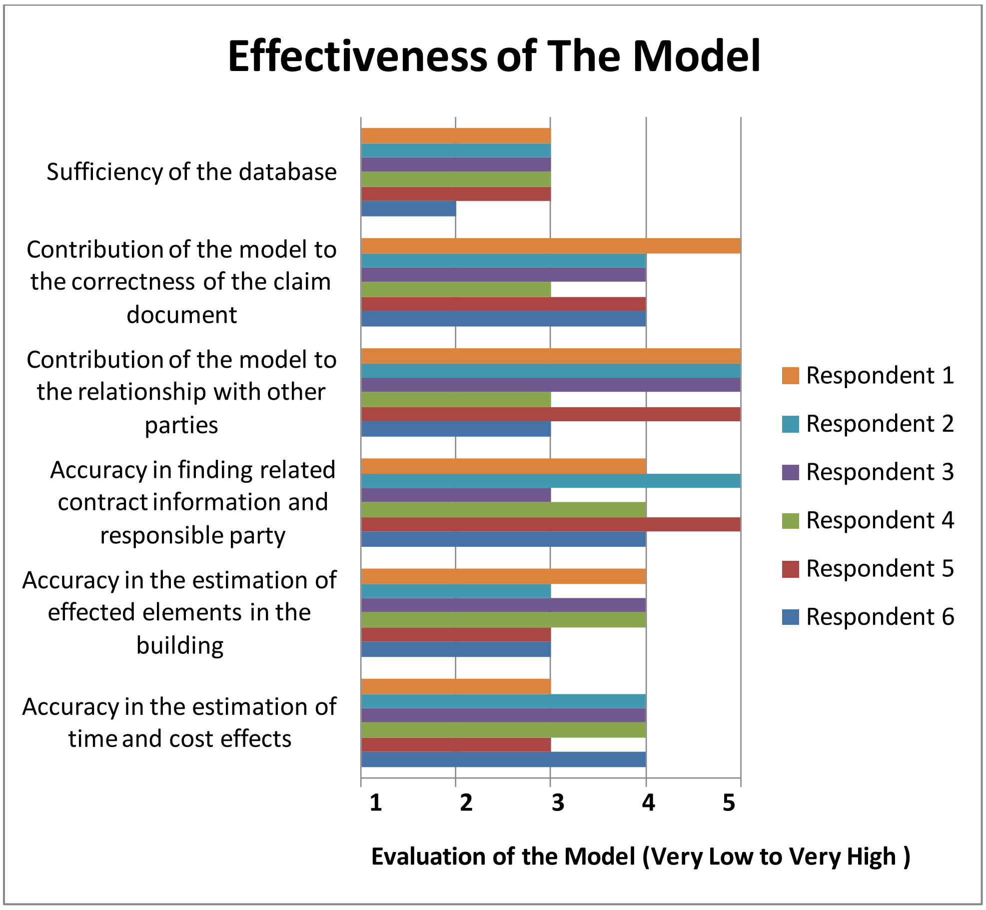

Figure 4.13 Results of the Model with respect to the Effectiveness Section

Firstly, the respondents selected either method 1 or method 2 as the output of the model in the effectiveness section. Thereafter, the performance of the model according to the accuracy in the results given to the user was tested. As mentioned before, method 1 refers to the presentation of the most similar case as the output of the model. Method 2 refers to the presentation of five top ranked cases in the retrieved cases list as the final result. All of the respondents chose method 2 as the output of the model. In this process, the participants stated several considerations related with their selection. These are;

- Aim to reach the accurate result,
- Need of checking all of the examples,
- Aim to become confident about the result of the model.

The performance of the model in finding effects of a project change was evaluated by the respondents with several questions. According to the results of the survey, the performance of the model in finding time and cost effects of a project change and effects of the change on the other elements in the building was evaluated as relatively high. When it has come to finding related contract clauses and the responsible party of the occasion, the performance of the model was evaluated as very high. The contribution of the model to the relationship between the contractor and the architect was evaluated as positive. Generally, a claim document needs to be prepared after a conflict arises between parties of the contract because of a project change. The contribution of the model to the accuracy of the claim document was evaluated as very high. Likewise, the performance of the model in finding the responsible party and related contract clause was evaluated as very high. However, sufficiency of the database of the model was evaluated as relatively poor. The analysis of these results are depicted in Chapter 4.7.4.

- **Efficiency**

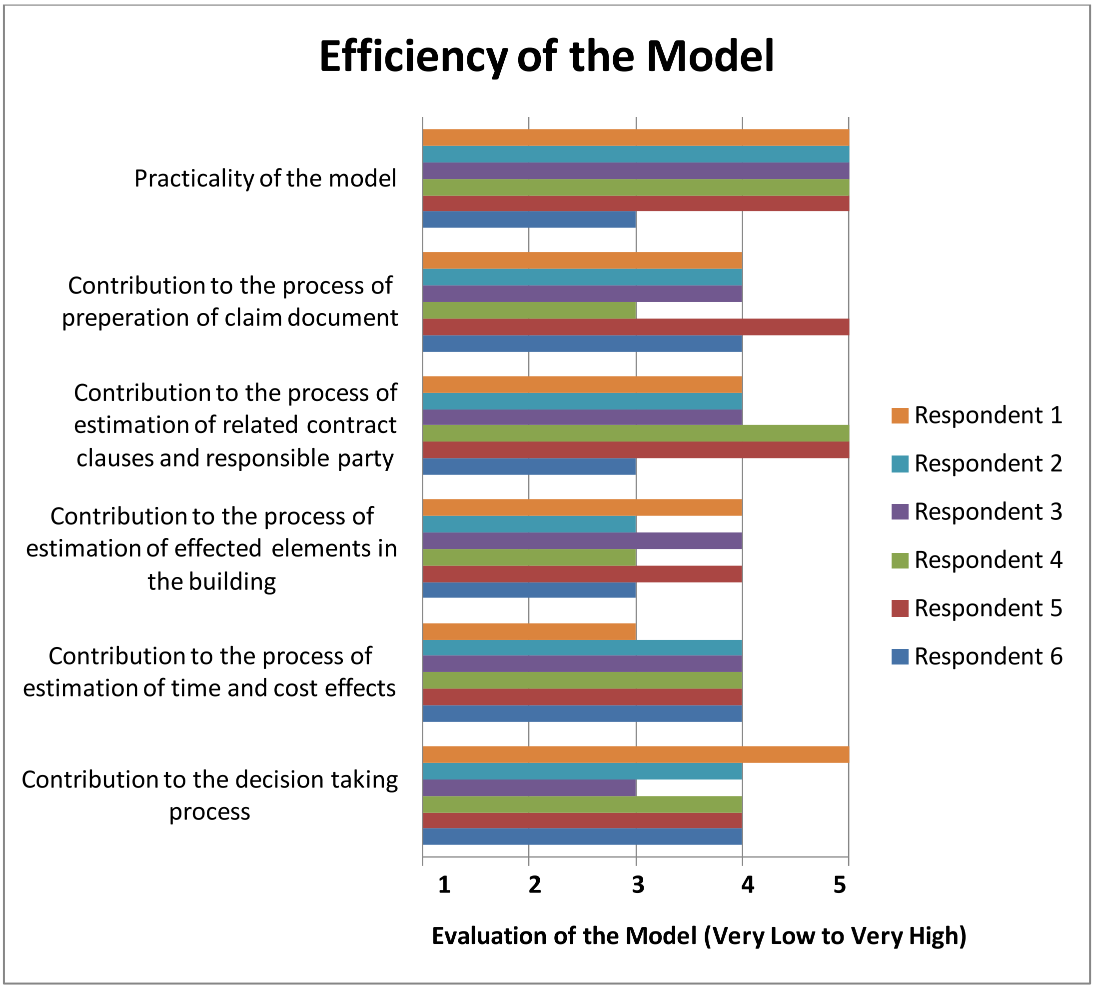

Figure 4.14 Results of the Model with respect to the Efficiency Section

In the efficiency section, the performance of the model in accelerating the process of management of a project change was evaluated. According to the results of the survey, the model slightly accelerates the general decision making process in the management of project changes. In the same manner, the process of finding time and cost impacts of a project change relatively decreases with the help of the model. However, the model does not contribute to the process of finding effects of the change on the other elements in the building. The model excessively accelerates the process of finding related contract clause and the responsible party of the occasion.

The process of preparation of a claim document related with the project change slightly decreases with the help of the model. Finally, the model was evaluated as practical by the respondents.

- **Satisfaction**

In the last section, satisfaction of the respondents about the model was tested. First of all, the participants indicated that they prefer to use the model in their construction project. Furthermore, learnability of the model was evaluated as easy. Satisfaction about the interface of the model was evaluated as neutral. All of the respondents agreed upon the adaptability of the model to the other housing projects except than their project. Also, there is a consensus on high opportunity in the development of the model for other project types different from housing. As the final decision, all of the participants indicated that their general satisfaction about the model is acceptable.

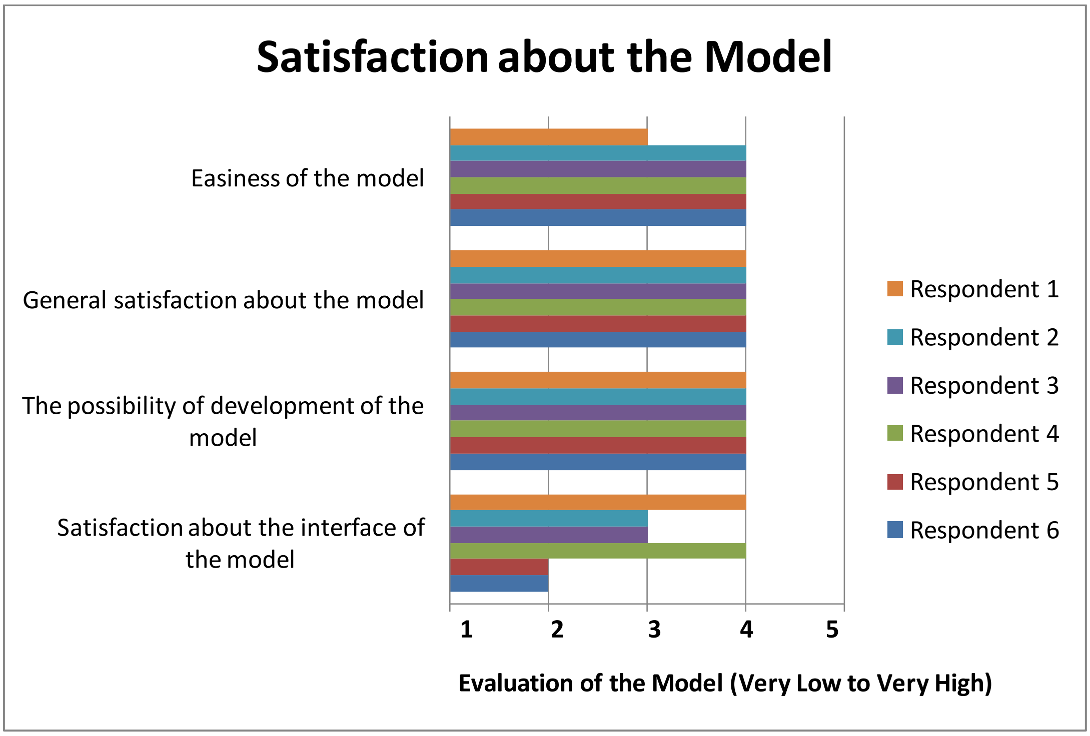

Figure 4.15 Results of the Model with respect to the Satisfaction Section

4.7.4 Analysis of the Results of the Survey

In this section, analysis of the results of the survey are presented. According to the results of the survey, there are positive evaluations about the model together with several negative and neutral considerations. These results are analyzed with respect to the chapters of the survey; effectiveness, efficiency and satisfaction.

- **Effectiveness**

In the first phase of the survey, the respondents were asked to choose a method as the output of the model. In this selection, the aim is to determine the way of use of the results of the model. These methods are presenting the most similar case and presenting five top ranked cases in the retrieved cases list to the user as the final result of the CBR model. All of the participants agreed upon the second method which corresponds to taking account of five top ranked cases as the output of the model. The participants indicated several reasons which were mentioned in the previous section. In order to summarize them, there is a general consideration which can be explained as not trusting on the most similar case retrieved by the model as the final solution. The reason of this can be explained with the subjective nature of the database. Cases in the database were taken from six different housing projects. Impacts of these cases on the duration, on the budget and on the other changes are related with the particular nature of each housing project. It can be said that effects of the project changes are special to one project. In a similar manner, satisfaction of the respondents about the model in finding time and cost effects of a project change and impacts of the change on the other elements in the building was relatively low. It can be concluded that participants cannot be sure about the results of the model related with the effects of the change when solely looking at the values of the most similar case. They are in the need of checking all of the possible results by taking account of five top ranked cases in the retrieved cases list.

Same problem cannot be implied for finding contract clauses related with the change situation. Satisfaction of the users about the model in finding the results related with contractual issues is very significant. Therefore, variations in the results related with the contractual information in the retrieved cases do not fluctuate as in the results related with the effects of the project change. It can be expressed that, if the model is limited to presenting contractual information about the project change, in other words finding effects of the change is excluded from the aim of the model, first method can be also selected by the participants as the output of the model.

Likewise the performance of the model in finding the related contractual information, the respondents are also very pleased with the performance of the model in its contribution to the preparation of claim documents. It can be explained with the subjective nature of the project changes. Differences in the effects of the change does not cause any variation in the contractual results of the project change. The reason of this, contractual results of the project changes generally depends on the causes of the change rather than its effects.

The database of the model was evaluated by the participants as a bit insufficient. The main reason of this attitude can be low similarity measurement ratings of the retrieval results. The respondents were generally unable to confront with cases whose similarity measurement ratings are higher than 90%.

- **Efficiency**

In the second section of the survey, the contribution of the model to the process of management of project changes was evaluated by the respondents. As a general opinion, model can slightly accelerate decision making process about the project changes. The contribution of the model to the process of finding time and cost effects was evaluated same as in the effectiveness section. It was indicated by the participants that there isn't any contribution of the model to the process of finding effects of the change on the other project elements in the building. To summarize, decisions about the contribution of the model to the process of management of project changes are not similar with the decisions about the performance of the model in the accuracy of the results. The participants think that independent from the correctness of the output, model can accelerate the process of finding time and cost effects of the project change. The reason of this, estimation of time and cost effects requires a significant amount of time and the model can diminish this period. However, prediction of the impacts of a project change on the other project elements in the building was not regarded as an important process by the participants. It can be admitted that the users can easily find impacts of the project changes on the other project elements in the building without any need of the CBR model. Therefore, contribution of the model to this process was evaluated by the respondents as not important.

The respondents also stated that the model significantly accelerates the process of finding contractual information related with the project change. The process of preparation of a claim document related with the project change can relatively decrease with the help of the CBR model. It can be concluded that the decision making process related with contractual issues was interpreted as time consuming by the participants. Contribution of the model to this processes was evaluated as significant as in the effectiveness section. Regarding these feedbacks, the most significant impact of the model can be stated as its contribution to the management of contractual issues related with the project changes.

Finally, the respondents indicated that model is practical for the users. It can be concluded that the respondents are in a consensus about the positive contribution of the CBR model to the process of management of project changes.

- **Satisfaction**

In the last section, satisfaction of the users about the CBR model was evaluated. It can be stated that the participants had a positive attitude towards the model in the first two sections and the results of the survey were positive. Similar with this attitude, the users prefer to use the CBR model in their current construction project. All of the respondents stated that their general satisfaction about the model is acceptable. These answers can be also regarded as the verification of the survey. If these answers were negative, it can be indicated that the results of the survey cannot be evaluated as consistent.

There is also a consensus about the easiness in the learning process of the model. However, general opinion of the participants about the interface of the model is neutral. As a result, there can be several developments in order to improve the visual attractiveness of the CBR model. Flexibility of the model was also evaluated as positive. It can be concluded that there is an opportunity in the development of the model for different types of construction projects.

4.7.5 Guide for Using the Model

In this section, the way of using the model is presented to the users step by step. After the analysis of the results of the survey, a guide is proposed for using the model. As mentioned in the results of the survey, participants preferred presentation of the five top ranked cases in the retrieved cases list as the output of the model.

In the first step, the user enters a new project change into the model by defining the related attributes. These are type of the change, location of the change, related project element, reason(s) of the change and source party. The model starts retrieving similar cases from the case-base and the results are listed according to their similarity measurement values. First of all, the user should find the cases whose similarity measurement ratings are equal to or higher than 70% from the retrieved cases list. If there exist at least five cases whose similarity measurement values are equal or above than 70%, the process continues with the next step. If not, the process fails and the model cannot be used for the related project change event. Five top ranked cases in the retrieved cases list are shown at the bottom of the screen. The user must analyze all of these five cases by comparing their features of time and cost effects, impacts on the other elements, related contract clauses and the responsible party together with the causes of the cases. At the final stage, the user reaches a decision about possible impacts of the project change which will be helpful in his or her decision making process.

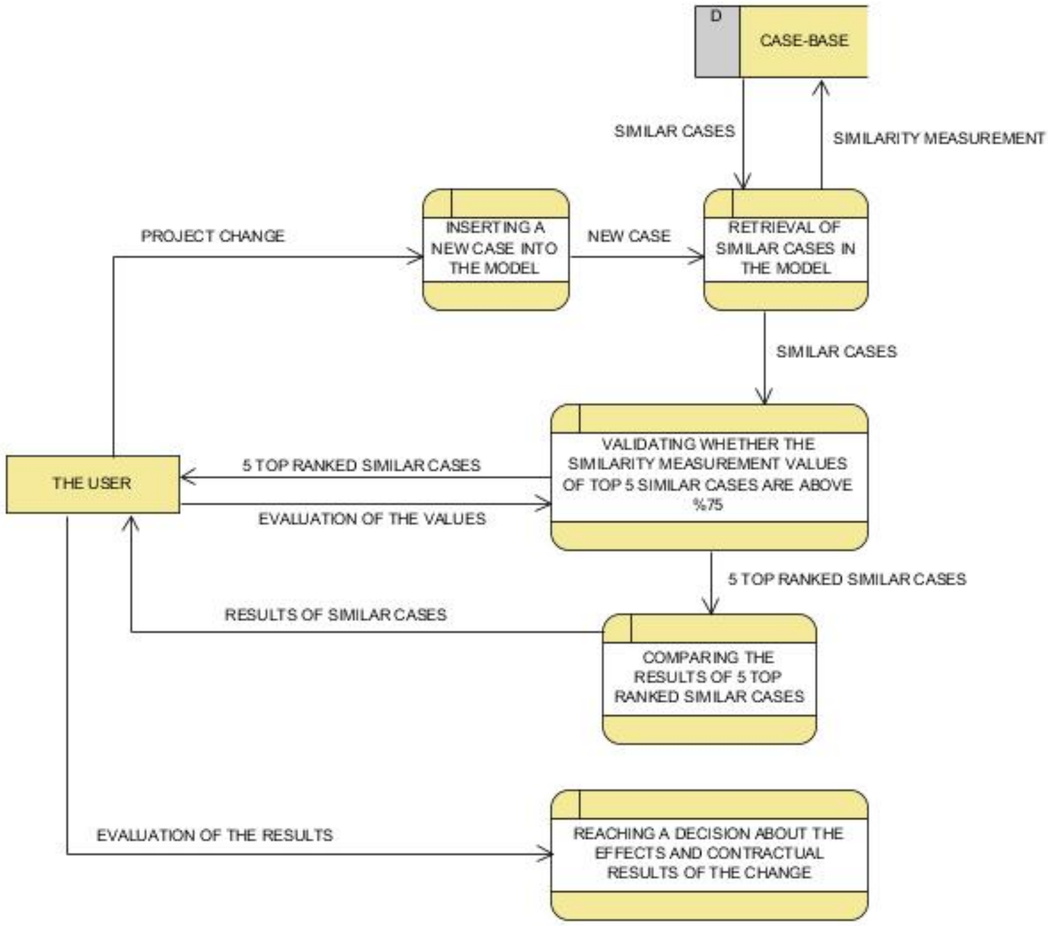

Figure 4.16 Guide for Using the CBR Model

4.8 Comparing the CBR Method with Database Filtering

In this stage, the CBR model is compared with the database filtering by using MS Excel©. The aim is to investigate the differences between database filtering and CBR model. For this investigation, some of the cases in the testing set are entered into the MS Excel© file.

4.8.1 Material

The method of case-based reasoning is different from manual filtering with respect to many issues. It supplies the user several advantages such as global similarity measurement and local similarity measurement in retrieval stage. Therefore, while filtering a case in the database, the results given by the CBR model should be different from the results given by manual filtering in a MS Excel© file. The performance of these methods in searching a case is compared in this stage.

As mentioned previously, at the end of the semi-structured interviews in the first stage, the results are summarized in a list by using MS Excel©. In this file, all of the changes are defined according to the features of the CBR Model. This information is directly transferred to the CBR model in order to generate the case-base. This MS Excel© file corresponds to the database of the research.

The database consists of 227 project change examples which are arranged with respect to their project. There are eleven columns in the file. These are *total number*, *no, type*, *location*, *project element*, *causes of the change*, *source party*, *effects on the office*, *effects on the site*, *effects on the cost* and *effects on the other changes* respectively. First column refers to the sequence of the change within the total changes. The column of *No* indicates the sequence of the change within the changes related with the particular project. Other columns corresponds to the each feature in the CBR as mentioned in the section 4.5.1. All of the changes in the database are arranged in the rows under six groups corresponding to each housing project. The full version of the list is presented in Appendix B. In this stage, it will be used in database filtering.

4.8.2 Filtration

MS Excel© provides the user to filter values in a file with respect to a specific column. For instance, when the user selects a specific value from the column C, the examples which have this specific value in their column C is filtered. The filtration process can be conducted with several columns. In this case, examples which have specific values selected in the filtration stage in the related columns are filtered.

In the filtration stage, several cases in the testing set are used. The aim is to find other cases in the database which are similar to the testing case. Six cases from the testing set are selected randomly. These cases are filtered in the MS Excel© file one by one in order to find similar cases in the database. Filtering is conducted with respect to the importance weights of the features as in the CBR model. As mentioned previously, new cases are entered in to the case-base by defining five features which are *type of the change*, *location of the change*, *project element*, *cause of the change* and *source party*. Thereafter, the CBR model retrieves similar cases according to the global similarity function. In this function, these five features have an importance weights which are depicted in Table 4.9.

The filtering is conducted step by step and five columns in the database are filtered which corresponds to the features mentioned in the previous paragraph. The sequence of the filtration is designed according to the importance weights of these features. The filtration is conducted in columns D,E,F,G and H in the database. Firstly, cases in the database are filtered according to the features which have highest importance weights. These are *project element* and *causes of the change* corresponding to the columns F and G in the database. Third step is filtration according to the *type of change* feature which corresponds to column D, then *location of the change* which corresponds to column E and lastly *source party* which corresponds to column H. However, the results of the filtration is generally insufficient so that the filtration cannot continue after first two columns.

4.8.3 Results of the Filtration

The filtration is conducted for each six cases in the testing set separately. The process of filtration is explained within six headings respectively and the process is stated with several figures. In these figures, the values used in the filtration process and the screenshot of the database after the filtration of first two columns which are related with features of *project element* and *causes of the change* are shown. Cases which are highlighted by the red color is the testing cases, other cases in the list are filtered cases.

- **Filtration of Case-1**

In the first case, the filtration is started with column F and G as mentioned before. According to Figures 4.17 and 4.18, *interior fixed partitions* and *change of plan* are selected as the filtering criteria.

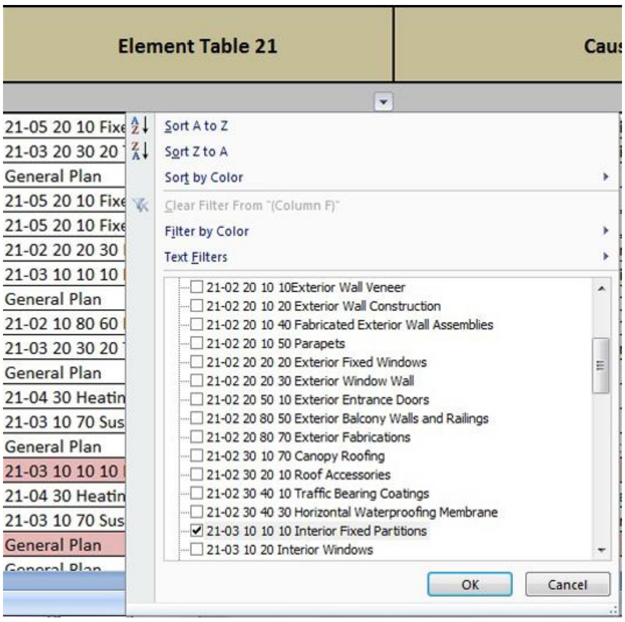

Figure 4.17 Filtration of the Case-1 in Column F

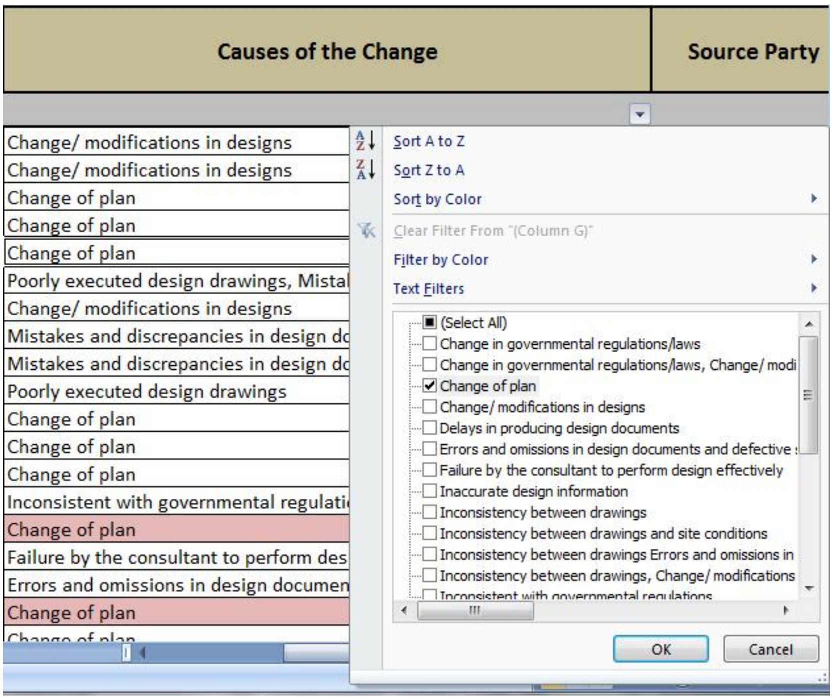

Figure 4.18 Filtration of the Case-1 in Column G

In Figure 4.19, the results of filtration is depicted. It can be seen that only one case can be sorted in the database when the filtration is conducted according to two features. The filtration process can continue with columns D and E. However, in the filtration of last column, there won't be any cases in the sorted cases list because source parties of two cases are different.

Type	Location Table 13	Element Table 21	Causes of the Change	Source Party
Revision	13-65 00 00 Private Residential Spaces	21-03 10 10 10 Interior Fixed Partitions	Change of plan	Contractor
Revision	13-65 00 00 Private Residential Spaces	21-03 10 10 10 Interior Fixed Partitions	Change of plan	Client

Figure 4.19 Results of the Filtration of the Case-1

- **Filtration of Case-2**

In the second case, the filtration is made with the values of *electrical* and *overdesign increasing the overall cost; change/modifications in the design* in the columns F and G respectively.

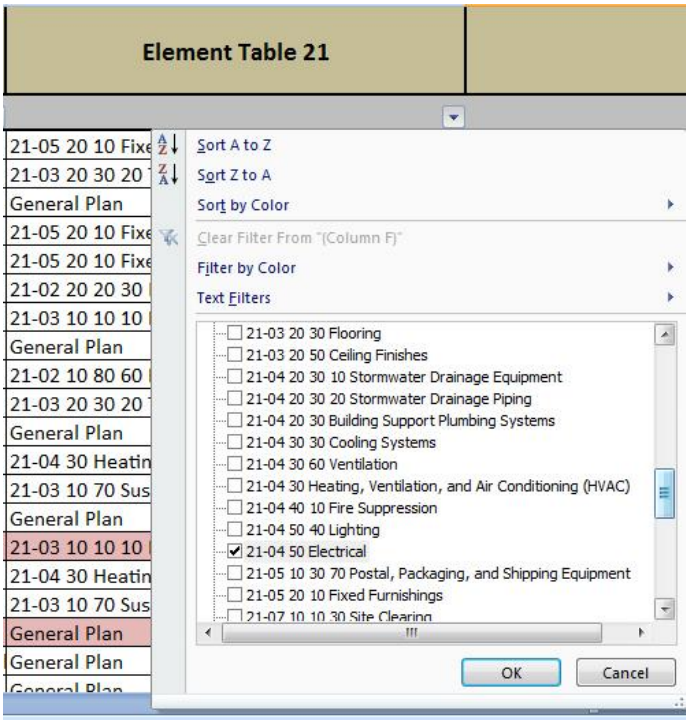

Figure 4.20 Filtration of the Case-2 in Column F

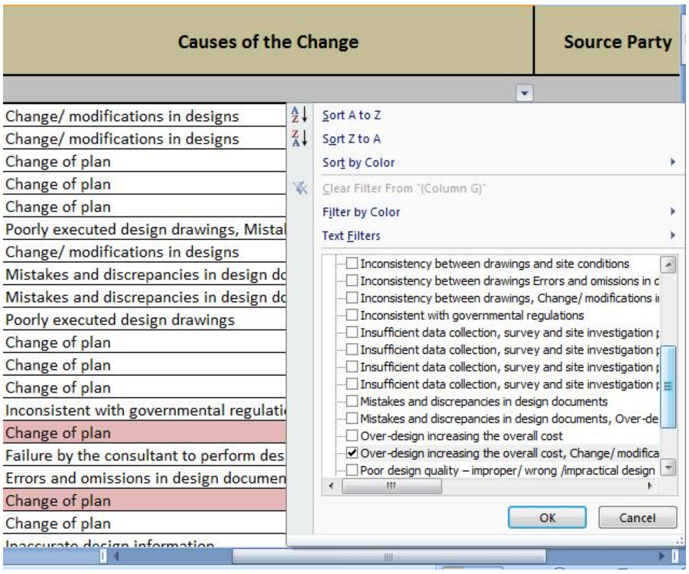

Figure 4.21 Filtration of the Case-2 in Column G

According to Figure 4.22, the result of the filtration is not satisfactory. There aren't any cases sorted in the database when the filtration is conducted according to two features.

Type	Location Table 13	Element Table 21	Causes of the Change	Source Party
Revision	13-65 00 00 Private Residential Spaces	21-04 50 Electrical	Over-design increasing the overall cost, Change/ modifications in designs	Contractor

Figure 4.22 Results of the Filtration of the Case-2

- **Filtration of Case-3**

In the third case, the filtration is made with the values of *interior fixed partitions* and *change/modifications in the design* in the columns F and G respectively.

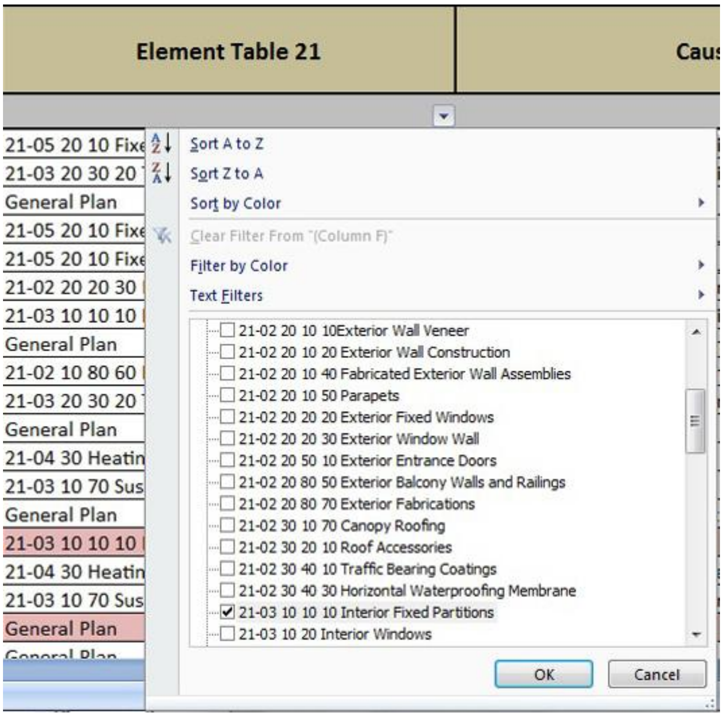

Figure 4.23 Filtration of the Case-3 in Column F

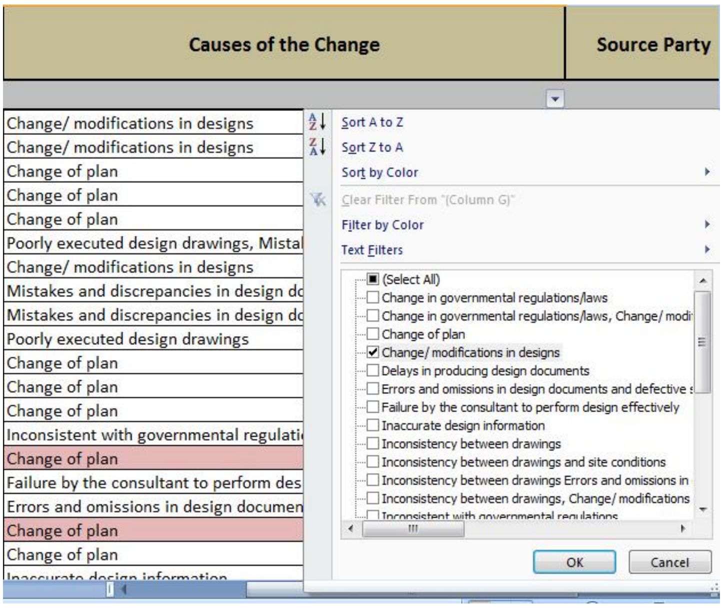

Figure 4.24 Filtration of the Case-3 in Column G

The results of the filtration can be seen in Figure 4.25. According to the results, there are two cases sorted in the database. The filtration can continue with the third feature, namely *type of the change* and it can be seen that the results will be the same. If the filtration continues with the fourth feature, namely *location of the change*, these two cases wouldn't be in the sorted cases list.

Type	Location Table 13	Element Table 21	Causes of the Change	Source Party
Revision	13-25 11 11 Corridor	21-03 10 10 10 Interior Fixed Partitions	Change/ modifications in designs	Contractor
Revision	13-65 23 00 Kitchen	21-03 10 10 10 Interior Fixed Partitions	Change/ modifications in designs	Contractor
Revision	13-65 13 00 Bathroom	21-03 10 10 10 Interior Fixed Partitions	Change/ modifications in designs	Contractor

Figure 4.25 Results of Filtration of the Case-3

- **Filtration of Case-4**

In the fourth case, the filtration is made with the values of *general plan* and *poorly executed design drawings* in the columns F and G respectively.

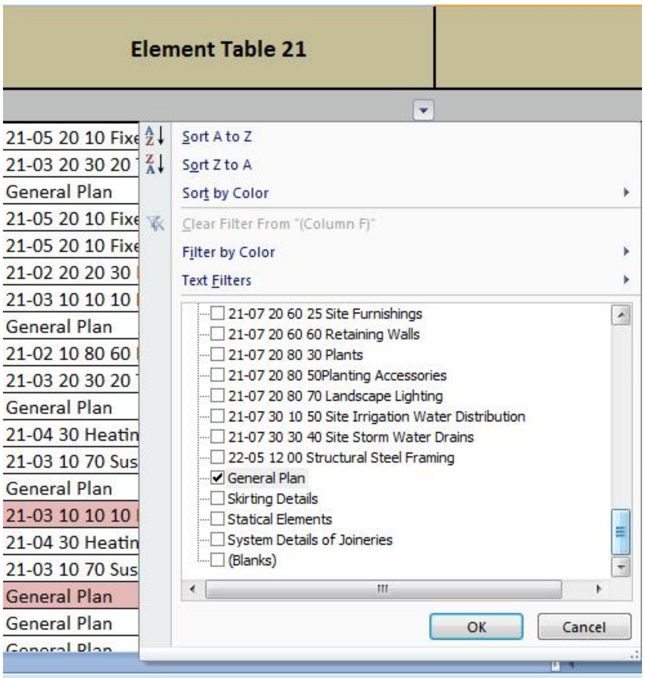

Figure 4.26 Filtration of the Case-4 in Column F

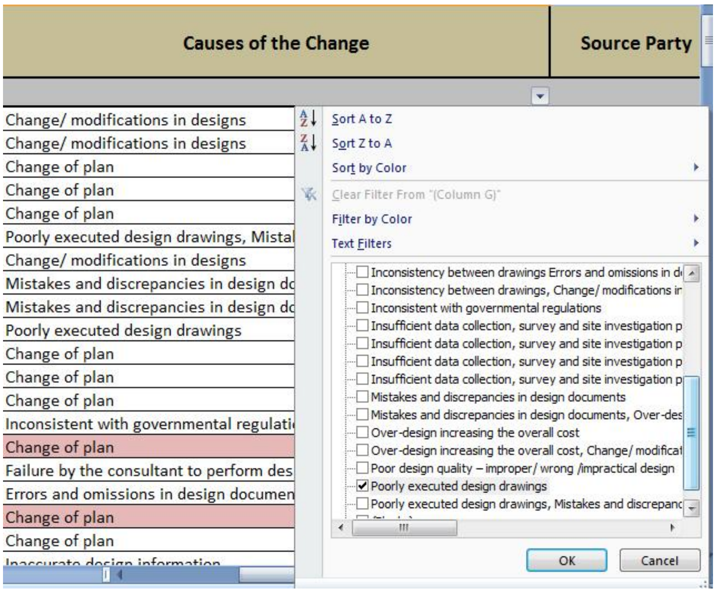

Figure 4.27 Filtration of the Case-4 in Column G

The filtration results of the fourth case is similar with the third one. However, one of the sorted cases will be omitted in the continuing filtration according to the *type of the change*. After the filtration according to the fourth feature there wouldn't be any case in sorted cases list.

Type	Location Table 13	Element Table 21	Causes of the Change	Source Party
Addition	13-61 15 17 Canopy	General Plan	Poorly executed design drawings	Architect
Revision	13-23 19 00 Utility Equipment Room	General Plan	Poorly executed design drawings	Mechanical Consulta
Revision	Facade	General Plan	Poorly executed design drawings	Architect

Figure 4.28 Results of Filtration of the Case-4

- **Filtration of Case-5**

In the fifth case, the filtration is made with the values of *tile flooring* and *overdesign increasing the overall cost* in the columns F and G respectively.

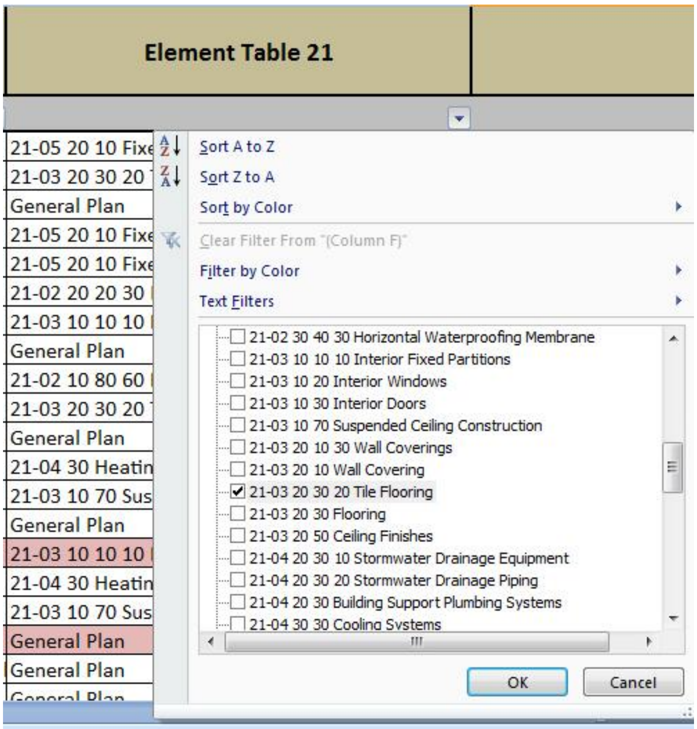

Figure 4.29 Filtration of the Case-5 in Column F

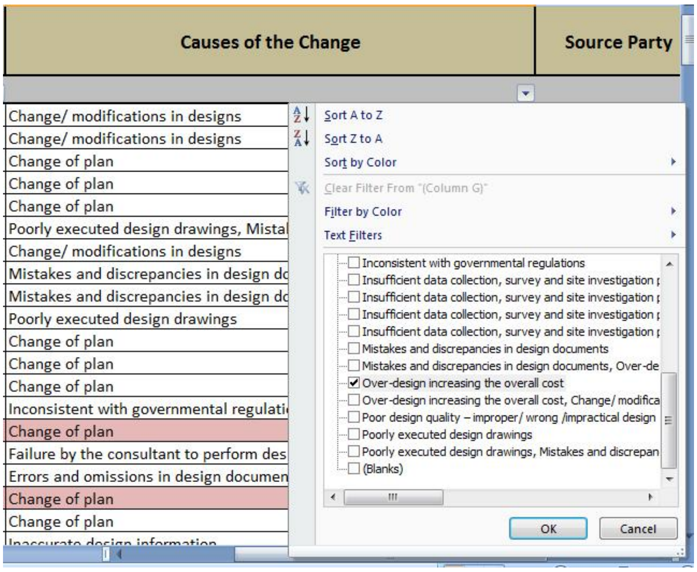

Figure 4.30 Filtration of the Case-5 in Column G

The filtration results of the fifth case are exactly similar with the second one. The filtration process cannot continue with the other columns as can be seen in Figure 4.31. There isn't any cases in the database when the filtration is conducted with two criteria.

Type	Location Table 13	Element Table 21	Causes of the Change	Source Party
Revision	13-25 11 11 Corridor	21-03 20 30 20 Tile Flooring	Over-design increasing the overall cost	Contractor

Figure 4.31 Results of Filtration of the Case-5

- **Filtration of Case-6**

In the last case, the filtration is made with the values of *general plan* and *poorly executed design drawings* in the columns F and G respectively.

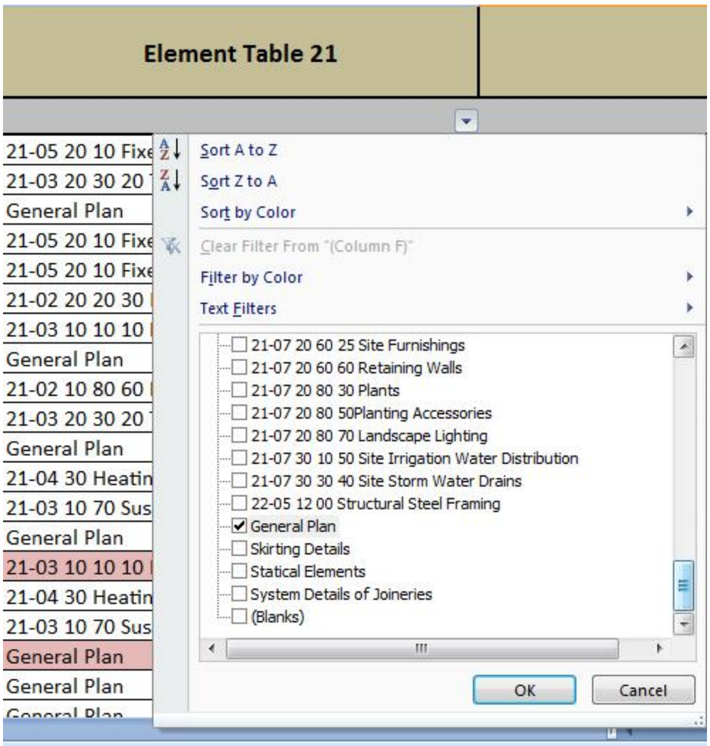

Figure 4.32 Filtration of the Case-6 in Column F

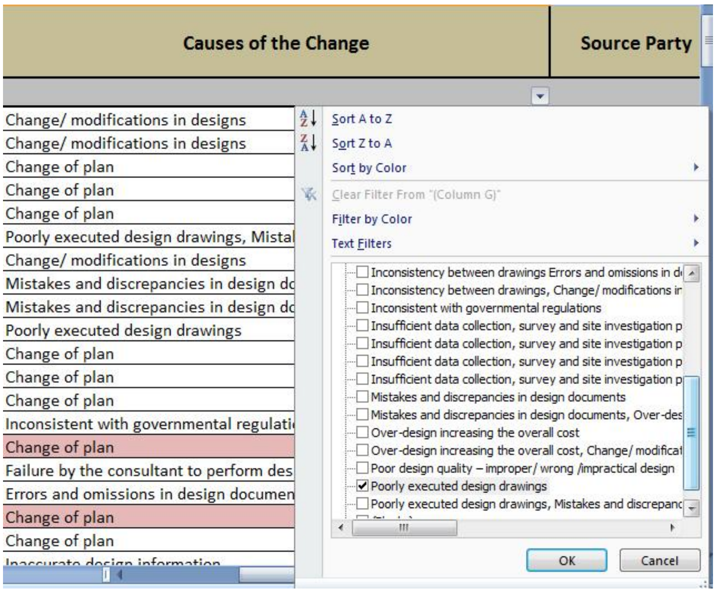

Figure 4.33 Filtration of the Case-6 in Column G

In the Figure 4.34, results of the filtration process is depicted. It can be seen that two cases are sorted when the filtration is conducted with two criteria. However, if the filtration process continues with column D and column E, there won't be any cases in the sorted cases list.

Type	Location Table 13	Element Table 21	Causes of the Change	Source Party
Addition	13-61 15 17 Canopy	General Plan	Poorly executed design drawings	Architect
Revision	13-23 19 00 Utility Equipment Room	General Plan	Poorly executed design drawings	Mechanical Consulta
Revision	Facade	General Plan	Poorly executed design drawings	Architect

Figure 4.34 Results of the Filtration of Case-6

4.8.4 Discussion of the Results

In this chapter, the results of the filtration are analyzed and they are compared with the retrieval results of the CBR Model. It can be seen that, the process of database filtration cannot give any results at the end. To summarize, the database does not contain cases which are exactly similar with the cases in the testing set with respect to five features. Therefore, manual filtration of the database is not useful in this case.

However in the validation stage depicted in section 4.7, same cases in the testing set were entered into the CBR model. All of the six cases which are used in this stage are used in the retrieval stage. The retrieval results are sufficient in the first phase of the testing process in other words all of the results contains at least five cases with the similarity scores at least %70. In the second phase of the testing, the satisfaction of the users about the retrieval results the CBR model is satisfactory.

The reason of the differences between two results is the absence of similarity measurement in the database filtration. Without the need of exact matching of all of the features, the CBR model can give retrieval results to the users which are satisfying for them. However, manual filtration of the database requires exact matching of all of the features in the new case and cases in the database. Therefore, database filtration is not useful in this stage. Moreover, the CBR model retrieves several cases on the other hand, MS Excel© can only select the similar case. It can be concluded that the case-base reasoning is more satisfactory than database filtering in terms of retrieving the similar cases.

CHAPTER 5

CONCLUSION

Project changes correspond to an important problem for construction projects and can occur at any stage of the construction process. They bring about cost overruns and delays in the construction projects. Change orders or claim situations can also appear at the end of this process. Several researches about project changes, change management and claim management were discussed in the literature review section in this thesis. According to these analysis, changes regarding the design process were specified as one of the most problematical type of change in the construction projects. It can also be stated that causes and effects of the changes varies depending on the type of the construction project, location of the project and procurement type of the project.

In this research, the aim is to focus on project changes regarding the design process in the construction projects. Researches about change and claim management generally focused on the relationship between the client and the contractor. However design-oriented changes generally cause conflicts between the designer and the contractor. Therefore, the contract between the designer and the contractor was examined for the solution of the claim situations in this thesis. The material of the research is limited with large-sized housing projects. The reason of this, the role of the designer in these type of projects is very significant (Dluhosch, 2006).

The model can only be used for construction projects procured by design-build method. Different from the design-bid-build method, the contractor has a direct responsibility of contractual situations related with the design process in design-build procurement type (Cushman & Loulakis, 2001). Therefore, solution of the claim situations related with the design related project changes is very significant for the contractors.

5.1 Summary of the Study

The aim of this research is to propose a knowledge based decision support model for the management of changes regarding the design process. The model is going to be used in housing projects which are procured with design-build method. When a project change appears in the construction project, the contractor will make use of the model in the decision making process about the change. The knowledge based decision support model was formed by using case-based reasoning methodology.

In the first phase of the research, a survey semi-structured interviews were conducted with professionals who are responsible for the construction of six different large-sized housing projects. The interview consists of two sections. In the first section, information about the current situation of change management, problems about project change and change management tools was collected. It was verified by the audience that project changes regarding the design process correspond to an important problem in the construction projects. According to the results, the professionals are also in the need of assistance for management of the project changes. Second section of the interview includes several headings such as general information about the change, causes of the change and effects of the change. Information about project changes was given by the participants according to these headings in the interview. In the effects section, the respondents were asked to rate several impacts of the project changes. These are effects on project office and construction site with respect to time, effects on the budget and effects on other changes in the construction project. Finally, 227 project change examples were collected from the semi-structured interviews.

The model was formed according to case-based reasoning method. Cased-based reasoning method is based on the idea of solving an actual problem using previous experiences. Therefore, the process of case-based reasoning excessively suits the experience based nature of construction industry. It was used in several fields such as design, cost estimation, planning, negotiation and dispute solving.

When user inserts a new case into the model, the model finds similar cases from its database and presents the list of similar cases. A case is defined with features in the case-based reasoning approach. Features in the case-based reasoning (CBR) model were formed depending on the information given by the respondents in the interviews. In the CBR model, 11 features were defined for identification of a change event. Answers in the survey were structured and arranged according to these features in the MS Excel© format. At the end, final documentation of these answers was approved by the respondents before transforming them into the CBR model.

Similarity measurement function corresponds to the selection method of the case-based reasoning model. The function was formed with the help of another survey conducted with the same audience. In this research, the respondents determined importance weights of the features in the CBR model. At the end, 227 project change examples were inserted to the database of the model and the CBR model was formed.

In the validation stage, the final product was tested through semi-structured interviews conducted with the same audience. There are 227 cases in the database and 10% of them were selected for the testing process by using simple random sampling. Then, a usability measurement survey was designed according to ISO 9241. In this survey, the respondents evaluated the model with respect to measures of effectiveness, efficiency and satisfaction. At the end of this stage, the results of the survey were analyzed and a guide was proposed for using the model.

5.2 Limitations of the Study

First limitation of the study is related with the scope of the research. CBR model can only be used by the contractors of housing projects which are constructed with design-build procurement type. There are two reasons. Project change examples in the database were collected from housing projects. Furthermore, one type of contract was defined in the model which is AGC 420 contract between designer and contractor.

According to results of the testing survey, the database of the model was evaluated as poor. Both of the cases in the database were collected from housing projects. Six housing projects were used in the formation of the database of the model. Hence, the model is limited with same kind of project changes.

5.3 Conclusion

The decision support model will be used in the management of project changes regarding the design process in the housing projects procured with design-build method. When a project change occurs, the contractor will make use of the CBR model. Information about possible effects and contractual results of the occasion is going to be presented to the user.

The results of the research were depicted with several charts in Chapter 3 and 4. According to the results of the survey conducted in the first phase of the research, it was determined that project changes depending on the design process is a substantial problem for construction projects. As a general opinion, the impact of the project changes on the construction process is significant. The respondents also indicated that they are in need of assistance for coping with this kind of project changes in their current projects. Moreover, it was stated by the respondents that there isn't any method or tool for management of project changes currently used in construction of housing projects in Turkey. Therefore, the argument of the research about the problems related with management of project changes was verified in the first section of the study.

In the second phase of the research, project change examples were collected via semi-structured interviews from six large-sized housing projects located in Turkey. The respondents give information about the project changes with the help of revision records. At the end, 227 project change examples were collected from semi-structured interviews. It can be seen that some type of project changes occur in several projects at the same time. It can be interpreted that these changes can possibly appear in a housing project. The frequency of occurrence of a particular change event, the most important causes which brings about project changes and the most frequent location where a change can emerge can be analyzed with the help of these foundations.

The database of the decision support model was formed with examples of project changes collected during the interviews. The decision support model was developed according to case-based reasoning approach. Testing of the model was also made with the same audience of the research. In this phase, a usability measurement survey was designed and semi-structured interviews were conducted. As a general opinion, the CBR model can find effects and contractual consequences of a project change accurately. The process of management of project changes can diminish by employing the model in construction projects. The general satisfaction of the respondents from the CBR model was significant. However, they also emphasized some weak points in the model such as limited scope of the model, insufficiency related with variety of cases in the database and the interface of the model. These feedbacks give ideas about the future works of CBR model which are depicted in the following section.

In conclusion, this study aims to help contractors in the management of design related project changes in their housing projects. In this study, cased-based reasoning model is proposed for the process of management of project changes regarding the design process. The user is able to find possible effects and contractual outcomes of a change event with the help of the CBR model.

5.4 Future Works

Several future works and improvements of the model are discussed in this section. According to the results of the usability measurement survey, the interface of the model was evaluated as neutral. When comparing with results of the other questions, this result can be interpreted as insufficient. Therefore, addition of an interface to the model corresponds to an important future step in the process of development of the model. In this stage, the model can be transformed to a software by using the Application Protocol Interface (API) supplied by the myCBR tool. Moreover, API can also be used in the development of a web-site related with the CBR model. In this case, a web application can be formed for the model's standalone retrieval engine. A host can be bought which will work as the interface of the CBR model. The user will be able to define the project change and the results of the model will be given in the web application. Therefore, the retrieval process can be performed in an easier way than as in a software. The user won't need to install the software in his or her computer and will be able to access the model in anywhere by connecting to the internet.

Another future work can be the development of a general design management plan with the help of the database of this study. As mentioned before, project change examples related with the design process in the construction of housing projects were collected in the first phase of the research. Depending on this founding, change events can be classified according to their frequency of appearance. By this way, most problematic project elements in the design of the housing projects could be found. A plan for design management can be established with the aim of prevention of these changes from the beginning of the design process. This plan will consist of several guidelines. Ideal design organization process with the aim of minimizing occurrence of a project change can be presented with these guidelines.

Finally, this study can be also used in development of the ideal type of contract between the designer and the contractor to be used in design-build construction projects. The contractor can find out advantages and disadvantages of AGC 420 standard type of contract with the analysis of the results of the model. At the further stages, the contractor can develop another type of contract in order to minimize effects of the changes. In this manner, the contractor can implement a more contractor-favorable contract in the future agreements with designers in the other construction projects.

REFERENCES

Aamodt, A., & Plaza, E. (1994). Case-Based Reasoning: Foundational Issues, Methodological Variations, and System Approaches. *AI Communications*, *7*(1), 39–59.

Abran, A., Khelifi, A., Suryn, W., & Seffah, A. (2003). Usability Meanings and Interpretations in ISO Standards. *Software Quality Journal*, *11*(4), 325–338. doi:10.1023/A:1025869312943

Aibinu, A., & Jagboro, G. (2002). The Effects of Construction Delays on Project Delivery in Nigerian Construction Industry. *International Journal of Project Management*, *20*(8), 593–599.

Al-Jishi, S., & Al-Marzoug, H. (2008). *Change Orders in Construction Projects in Saudi Arabia* [PDF Document]. Dhahran, Saudi Arabia. Retrieved December 21, 2014, from http://faculty.kfupm.edu.sa/CEM/assaf/Students_Reports/Change-Orders-in-Construction_2.pdf

Alnuaimi, A. S., Taha, R. A., Mohsin, M. A., & Al-harthi, A. S. (2010). Causes , Effects , Benefits , and Remedies of Change Orders on Public Construction Projects in Oman. *Journal of Construction Engineering and Management*, *136*(5), 615–623.

Al-Sabah, S. S. J. A., Fereig, S. M., & Hoare, D. J. (2003). A Database Management System to Document and Analyse Construction Claims. *Advances in Engineering Software*, *34*(8), 477–491.

Alwi, S., & Hampson, K. (2003). Identifying the Important Causes of Delays in Bulding Construction Projects. In *Proceedings The 9th East Asia-Pacific Conference on Structural Engineering and Construction*. Bali, Indonesia.

American Institute of Architects. (2007). *A201 - 2007 General Conditions of the Contract for Construction* [PDF Document]. Retrieved January 15, 2014, from http://www.aia.org/groups/aia/documents/pdf/aias076835.pdf

American Institute of Architects. (2009). *The American Institute of Architects Official Guide to the 2007 AIA Contract Documents*. New Jersey, U.S.A.: John Wiley & Sons.

American Institute of Architects. (2014). *Design-Bid-Build Construction Management at Risk Design Build Integrated Project Delivery*. Retrieved January 15, 2014, from http://www.aia.org/groups/ek_public/documents/pdf/aiab046284.pdf

An, S.-H., Kim, G.-H., & Kang, K.-I. (2007). A Case-Based Reasoning Cost Estimating Model Using Experience by Analytic Hierarchy Process. *Building and Environment*, *42*(7), 2573–2579. doi:10.1016/j.buildenv.2006.06.007

Apolot, R., Alinaitwe, H., & Tindiwensi, D. (2013). Investigation into the Causes of Delays and Cost Overruns in Uganda’s Public Sector Construction Projects. *Journal of Construction in Developing Countries*, *18*(2), 33–47.

Arain, F. M. (2008). IT-based Approach for Effective Management of Project Changes: A Change Management System (CMS). *Advanced Engineering Informatics*, *22*(4), 457–472. doi:10.1016/j.aei.2008.05.003

Arain, F. M., & Pheng, L. S. (2005). The Potential Effects of Variation Orders on Institutional Building Projects. *Facilities*, *23*(11/12), 496–510. doi:10.1108/02632770510618462

Arditi, D., & Lee, D.-E. (2003). Assessing the Corporate Service Quality Performance of Design-Build Contractors Using Quality Function Deployment. *Construction Management and Economics*, *21*(2), 175–185. doi:10.1080/0144619032000079716

Ashley, D. B., & Laurie, C. S. (1987). Determinants of construction project success. *Project Management Journal*, *18*(2), 69–79.

Associated General Contractors of America. (2002). *AGC Contract Documents at a Glance* [PDF Document]. Virginia, U.S.A. Retrieved March 20, 2014, from http://www.nibca.net/documents/agc_at_a_glance.pdf

Atkinson, A. V. (1985). *Civil Engineering Contract Administration*. London, England: Hutchinson.

Austin, S., Baldwin, A., Li, B., & Waskett, P. (2000). Application of the Analytical Design Planning Technique to Construction Project Management. *Project Management Journal*, *31*(2), 48–59.

Babak, R. M. (2012). *A Taxonomy for Causes of Changes in Construction*. Unpublished MS thesis, Middle East Technical University, Ankara, Turkey.

Bach, K., & Althoff, K. D. (2012). Developing Case-Based Reasoning Applications Using myCBR. In I. Watson & B. D. Agudo (Eds.), *Case-Based Reasoning Research and Development* (Vol. 7466, pp. 17–31).

Bach, K., Sauer, C. S., Althoff, K. D., & Roth-Berghofer, T. (2014). Knowledge Modeling with the Open Source Tool myCBR. In *Knowledge Engineering and Software Engineering* (p. 11).

Bevan, N. (2008). Classifying and Selecting UX and Usability Measures. In E. Law, N. Bevan, G. Christou, M. Springett, & M. Larusdottir (Eds.), *Proceedings of the International Workshop on Meaningful Measures: Valid Useful User Experience Measurement (VUUM)* (pp. 13–18). Reykjavik, Iceland.

Bower, D. (2000). A Systematic Approach to the Evaluation of Indirect Costs of Contract Variations. *Construction Management and Economics*, *18*(3), 263–268. doi:10.1080/014461900370636

Callahan, M. T. (2005). *Construction Change Order Claims* (2nd ed.). New York, U.S.A.: Aspen Publishers, Inc.

Castro, J. B. (2013). *Evolving Liability for Design-Build Contracts: The Perfect Storm of Conftlicting Interests*. Castro & Associates LLC. Retrieved July 10, 2014, from http://www.defectlaw.com/pdf/Understanding Design Build Contracts JBC1.239.pdf

Chan, A. P. C., Ho, D. C. K., & Tam, C. M. (2001). Design and Build Project Success Factors: Multivariate Analysis. *Journal of Construction Engineering and Management*, *127*(2), 93–100. doi:10.1061/(ASCE)0733-9364(2001)127:2(93)

Chan, A. P. C., Scott, D., & Lam, E. W. M. (2002). Framework of Success Criteria for Design/Build Projects. *Journal of Management in Engineering*, *18*(3), 120–128. doi:10.1061/(ASCE)0742-597X(2002)18:3(120)

Chappell, D. (2005). *Building Contract Claims*. (V. Powell-Smith & J. Sims, Eds.) (4th ed.). Oxford, United Kingdom: Blackwell Publishing. Retrieved January 20, 2014, from https://books.google.com.tr/books?id=VTi1-aVslh0C&printsec=frontcover&dq=Building+Contract+Claims&hl=tr&sa=X&redir_esc=y#v=onepage&q=Building Contract Claims&f=false

Chester, M., & Hendrickson, C. (2005). Cost Impacts, Scheduling Impacts, and the Claims Process During Construction. *Journal of Construction Engineering and Management*, *131*(1), 102–107.

Choy, K. L., & Lee, W. B. (2002). A Generic Tool for the Selection and Management of Supplier Relationships in an Outsourced Manufacturing Environment: the Application of Case-Based Reasoning. *Logistics Information Management*, *15*(4), 235–253. doi:10.1108/09576050210436093

Chua, D. K. H., Li, D. Z., & Chan, W. T. (2001). Case-Based Reasoning Approach in Bid Decision Making. *Journal of Construction Engineering and Management*, *127*(1), 35–45. doi:10.1061/(ASCE)0733-9364(2001)127:1(35)

Clifford, N., French, S., & Valentine, G. (2010). *Key Methods in Geography* (2nd ed.). London, United Kingdom: SAGE Publications Ltd. Retrieved December 8, 2013, from http://www.google.com.tr/books?hl=tr&lr=&id=bAXmXbF1pkMC&pgis=1

Cox, R. (1997). Managing Change Orders and Claims. *Journal of Management in Engineering*, *13*(1), 24–29.

Cushman, R. F., & Loulakis, M. C. (2001). *Design-build Contracting Handbook* (2nd ed.). New York, U.S.A.: Aspen Publishers Online. Retrieved July 10, 2014 from https://books.google.com/books?id=wIge579lte4C&pgis=1

Deakin, P. (1999). Client’s local experience on design and build projects. In *Proceedings on design and build procurement system* (pp. 11–15). Hong-Kong, China.

Deniz, A. (2012). *Opportunities and Barriers of Architect Led Design-Build Projects*. Unpublished MS thesis, Middle East Technical University, Ankara, Turkey.

Design Build vs. Design Bid Build. (2010). *AnCor Inc.* Retrieved September 15, 2014, from http://thedesignbuildblog.wordpress.com/2010/08/02/design-build-vs-design-bid-build/

Design-Build Institute of America. (2015). Books & Contracts. Retrieved March 29, 2015, from http://www.dbia.org/resource-center/Pages/Contracts.aspx

Design-Build Institute Of America (DBIA) Releases Revised Contract Documents. (n.d.). Retrieved April 13, 2015, from http://www.consupt.com/news/news-archive/226-design-build-institute-of-america-dbia-releases-revised-contract-documents-.html

Diekmann, J., & Nelson, M. (1985). Construction Claims: Frequency and Severity. *Journal of Construction Engineering and Management*, *I*(1), 74–81.

Dikmen, I., Birgonul, M. T., & Gur, A. K. (2007). A Case-Based Decision Support Tool for Bid Mark-Up Estimation of International Construction Projects. *Automation in Construction*, *17*(1), 30–44. doi:10.1016/j.autcon.2007.02.009

Dluhosch, E. (2006). The Role of the Architect in Housing Design: Old and new. *ITU A|Z, 3*(1/2), 5–23.

Erdem, A. (2015). Yapı İzin İstatistikleri, Ocak-Mart, 2015. Retrieved March 12, 2015, from http://www.tuik.gov.tr/PreHaberBultenleri.do?id=18613

Finke, M. R. (1998). A Better Way to Estimate and Mitigate Disruption. *Journal of Construction Engineering and Management*, *124*(6), 490–497. doi:10.1061/(ASCE)0733-9364(1998)124:6(490)

Flemming, U., & Woodbury, R. (1995). Software Environment to Support Early Phases in Building Design (SEED): Overview. *Journal of Architectural Engineering*, *1*(4), 147–152. doi:10.1061/(ASCE)1076-0431(1995)1:4(147)

Friedlander, M. C. (2005). *The New AIA Design-Build Documents*. Chicago, U.S.A.: Schiff Hardin LLP. Retrieved February 2, 2014, from http://www.schiffhardin.com/binary/new_aia_march2005.pdf

Grindsted, A. (2005). Interactive Resources Used in Semi-Structured Research Interviewing. *Journal of Pragmatics, 37*(7), 1015–1035. doi:10.1016/j.pragma.2005.02.011

Gür, A. K. (2005). *Case-Based Decision Support System for Bid Markup Estimation of International Construction Projects at the Tender Stage*. Unpublished MS thesis. Middle East Technical University, Ankara, Turkey.

Hale, R., Shrestha, P., Jr., G., & Migliaccio, C. (2009). Empirical Comparison of Design/Build and Design/Bid/Build Project Delivery Methods. *Journal of Construction Engineering and Management*, *135*(7), 579–587.

Hanna, A. S., Lotfallah, W. B., & Lee, M.-J. (2002). Statistical-Fuzzy Approach to Quantify Cumulative Impact of Change Orders. *Journal of Computing in Civil Engineering*, *16*(4), 252–258. doi:10.1061/(ASCE)0887-3801(2002)16:4(252)

Hanna, A. S., Russell, J. S., Gotzion, T. W., & Nordheim, E. V. (1999). Impact of Change Orders on Labor Efficiency for Mechanical Construction. *Journal of Construction Engineering and Management*, *125*(3), 176–184. doi:10.1061/(ASCE)0733-9364(1999)125:3(176)

Hanna, A. S., Taylor, C. S., & Sullivan, K. T. (2005). Impact of Extended Overtime on Construction Labor Productivity. *Journal of Construction Engineering and Management*, *131*(6), 734–739. doi:10.1061/(ASCE)0733-9364(2005)131:6(734)

Haseeb, M., Xinhai-Lu, Bibi, A., Rabbani, W., & Dyian, M. (2011). Causes and Effects of Delays in Large Construction Projects of Pakistan. *Kuwait Chapter of Arabian Journal of Business and Management Review*, *1*(4), 18–42.

Hassanein, A. a. G., & Nemr, W. El. (2008). Claims Management in the Egyptian Industrial Construction Sector: A Contractor's Perspective. *Engineering, Construction and Architectural Management*, *15*(3), 246–259. doi:10.1108/09699980810867406

Hsieh, T., Lu, S., & Wu, C. (2004). Statistical Analysis of Causes for Change Orders in Metropolitan Public Works. *International Journal of Project Management*, *22*(8), 679–686.

Hughes, G. A., & Barber, J. (1992). *Building and Civil Engineering Claims in Perspective* (1st ed.). Harlow, United Kingdom: Longman Scientific and Technical.

Hwang, B.-G., & Low, L. K. (2012). Construction Project Change Management in Singapore: Status, Importance and Impact. *International Journal of Project Management*, *30*(7), 817–826. doi:10.1016/j.ijproman.2011.11.001

Ibbs, C., Kwak, Y., Ng, T., & Odabasi, A. (2003). Project Delivery Systems and Project Change: Quantitative Analysis. *Journal of Construction Engineering and Management*, *129*(4), 382–387. doi:10.1061/(ASCE)0733-9364(2003)129:4(382)

Ibbs, C., Wong, C., & Kwak, Y. (2001). Project Change Management System. *Journal of Management in Engineering*, *29*(3), 159–165.

Ibbs, W. (2005). Impact of Change's Timing on Labor Productivity. *Journal of Construction Engineering and Management*, *131*(11), 1219–1223. doi:10.1061/(ASCE)0733-9364(2005)131:11(1219)

Ijaola, I. A., & Iyagba, R. O. (2012). A Comparative Study of Causes of Change Orders in Public Construction Project in Nigeria and Oman. *Journal of Emerging Trends in Economics and Management Sciences*, *3*(5), 495 – 501.

Joo, S., Lin, S., & Lu, K. (2011). A Usability Evaluation Model for Academic Library Websites: Efficiency, Effectiveness and Learnability. *Journal of Library and Information Studies*, *9*(2), 11–26.

Karancı, H. (2010). *A Comparative Study of Regression Aanalysis, Neutral Networks and Case-Based Reasoning for Early Range Cost Estimation of Mass Housing Projects*. Unpublished MS thesis. Middle East Technical University, Ankara, Turkey.

Karim, A., & Adeli, H. (1999). CONSCOM: An OO Construction Scheduling and Change Management System. *Journal of Construction Engineering and Management*, *125*(5), 368–376.

Kartam, S. (1999). Generic Methodology for Analyzing Delay Claims. *Journal of Construction Engineering and Management*, *125*(6), 409–419. doi:10.1061/(ASCE)0733-9364(1999)125:6(409)

Kim, G.-H., An, S.-H., & Kang, K.-I. (2004). Comparison of Construction Cost Estimating Models Based on Regression Analysis, Neural Networks, and Case-Based Reasoning. *Building and Environment*, *39*(10), 1235–1242. doi:10.1016/j.buildenv.2004.02.013

Konchar, M., & Sanvido, V. (1998). Comparison of U.S. Project Delivery Systems. *Journal of Construction Engineering and Management*, *124*(6), 435–444. doi:10.1061/(ASCE)0733-9364(1998)124:6(435)

Kululanga, G., & Kuotcha, W. (2001). Construction Contractors' Claim Process Framework. *Journal of Construction Engineering and Management*, *127*(4), 309–314.

Kumaraswamy, M. M. (1997). Conflicts, Claims and Disputes in Construction. *Engineering Construction and Architectural Management*, *4*(2), 95–111. doi:10.1046/j.1365-232X.1997.00087.x

Kumaraswamy, M. M., & Chan, D. W. M. (1998). Contributors to Construction Delays. *Construction Management and Economics*, *16*(1), 17–29. doi:10.1080/014461998372556

Lam, E. W., Chan, A. P., & Chan, D. W. (2008). Determinants of Successful Design-Build Projects. *Journal of Construction Engineering and Management*, *134*(5), 333–341. doi:10.1061/(ASCE)0733-9364(2008)134:5(333)

Lee, M.-J., Choi, M.-S., & Kim, Y.-S. (2010). Attitudes of Engineers Related to Prevention of Change Order Claims. *Journal of Asian Architecture and Building Engineering*, *9*(1), 87–94. doi:10.3130/jaabe.9.87

Levin, P. (1998). *Construction Contract, Claims, Changes and Dispute Resolution* (1st ed., Vol. 56). Reston, U.S.A.: American Society of Civil Engineers.

Li, H. (1996). Case-Based Reasoning for Intelligent Support of Construction Negotiation. *Information & Management*, *30*(5), 231–238. doi:10.1016/S0378-7206(96)01058-0

Mazlum, S. K. (2015). *Lean Design Management - An Evaluation of Waste Items for Architectural Design Process*. Unpublished MS thesis, Middle East Techinal University, Ankara, Turkey.

Mo, J. K., & Ng, L. Y. (1997). Design and build procurement method in Hong Kong. In *Proceedings of CIB W92 Procurement Systems Symposium* (pp. 453–462). Hong Kong, China.

Moghaddam, A. G. (2012). Change Management and Change Process Model for the Iranian Construction Industry. *International Journal of Management and Business Research*, *2*(2), 85–94.

Mohammad, N., Che Ani, A. I., Rakmat, R. A. O. K., & Yusof, M. A. (2010). Investigation on the Causes of Variation Orders in the Construction of Building Project - a Study in the State of Selangor, Malaysia. *Journal of Building Performance*, *1*(1), 73–82.

Mohsini, R. A., & Davidson, C. H. (1992). Determinants of performance in the traditional building process. *Construction Management and Economics*, *10*(4), 343–359. doi:10.1080/01446199200000030

Molly, K. (2007). Six Steps for Successful Change Order Management. *Cost Engineering*, *49*(4), 12–20.

Motawa, I. A., Anumba, C. J., Lee, S., & Pena-Mora, F. (2007). An Integrated System for Change Management in Construction. *Automation in Construction*, *16*(3), 368–377. doi:10.1016/j.autcon.2006.07.005

MyCBR. (2012). Retrieved May 15, 2014, from http://www.mycbr-project.net/

Ndihokubwayo, R., & Haupt, T. (2009). Variation Orders on Construction Projects: Value-adding or Waste? *International Journal of Construction Project Management*, *ISSN: 1944-1436*, *1*(2).

Nielsen, J. (1994). *Usability Engineering*. Mountain View, U.S.A.: Academic Press, Inc. Retrieved September 21, 2014, from http://www.google.com.tr/books?hl=tr&lr=&id=DBOowF7LqIQC&pgis=1

Odeh, A. M., & Battaineh, H. T. (2002). Causes of Construction Delay: Traditional Contracts. *International Journal of Project Management*, *20*(1), 67–73.

OmniClass Introduction and User's Guide. (2006). Retrieved July 15, 2014, from http://www.omniclass.org/tables/OmniClass_Main_Intro_2006-03-28.pdf

Özorhon, B. (2004). *Organizational Memory in Construction Companies: A Case-Based Reasoning Model as an Organizational Learning Tool*. Unpublished MS thesis. Middle East Technical University, Ankara, Turkey.

Palaneeswaran, E., & Kumaraswamy, M. M. (2000). Contractor Selection for Design/Build Projects. *Journal of Construction Engineering and Management*, *126*(5), 331–339. doi:10.1061/(ASCE)0733-9364(2000)126:5(331)

Pantic, M. (n.d.). *Introduction to Machine Learning & Case-Based Reasoning*. Lecture presented at Course 395: Machine Learning in Computing Department, Imperial College London, London.

Park, M., & Pena-Mora, F. (2003). Dynamic Change Management for Construction: Introducing the Change Cycle into Model-Based Project Management. *System Dynamics Review*, *19*(3), 213–242. doi:10.1002/sdr.273

Pearce, M., Goel, A. K., Kolodner, I. L., Zimring, C., Sentosa, L., & Billington, R. (1992). Case-Based Design Support: A Case Study in Architectural Design. *IEEE Expert*, *7*(5), 14–20. doi:10.1109/64.163668

Perera, S., & Watson, I. (1998). Collaborative Case-Based Estimating and Design. *Advances in Engineering Software*, *29*(10), 801–808. doi:10.1016/S0965-9978(97)00064-1

Pinto, J. K., & Slevin, D. P. (1988). Critical success factors across the project life cycle. *Project Management Journal*, *19*(3), 67–75.

Quinlan, J. R. (1986). Induction of Decision Trees. *Machine Learning*, *1*(1), 81–106. doi:10.1023/A:1022643204877

Roth, M. (1995). *An Empirical Analysis of United States Navy Design/ build Contracts*. Unpublished MS thesis, University of Texas, Austin, USA.

Roth-Berghofer, T., García, J. A. R., Sauer, C. S., Bach, K., Althoff, K.-D., Agudo, B.-D., & Calero, P. A. G. (2012). Building Case-based Reasoning Applications with myCBR and COLIBRI Studio. In M. Petridis, T. Roth-Berghofer, & N. Wiratunga (Eds.), *Proceedings of the 17th UK Workshop on Case-Based Reasoning* (pp. 71–82). Cambridge, United Kingdom.

Semple, C., Hartman, F., & Jergeas, G. (1994). Construction Claims and Disputes: Causes and Cost/Time Overruns. *International Journal of Construction Project Management*, *120*(4), 785–795.

Shackel, B. (1991). *Human Factors for Informatics Usability*. New York, U.S.A.: Cambridge University Press. Retrieved December 10, 2014, from https://books.google.com.tr/books?id=KSHrPgLlMJIC&redir_esc=y

Smyth, B., & Cunningham, P. (1998). *Advances in Case-Based Reasoning: 4th European Workshop, EWCBR'98, Dublin, Ireland, September 23-25, 1998, Proceedings*. Berlin, Heidelberg: Springer Science & Business Media. Retrieved July 10, 2014, from https://books.google.com.tr/books?id=NTeuPhCzBJgC&dq=ID3+case-based&hl=tr&sitesec=reviews

Songer, A. D., & Molenaar, K. R. (1996). Selecting Design-Build: Public and Private Sector Owner Attitudes. *Journal of Management in Engineering*, *12*(6), 47–53. doi:10.1061/(ASCE)0742-597X(1996)12:6(47)

Songer, A. D., & Molenaar, K. R. (1997). Project Characteristics for Successful Public-Sector Design-Build. *Journal of Construction Engineering and Management*, *123*(1), 34–40.

Stare, A. (2011). Reducing Negative Impact of Project Changes with Risk and Change Management. *Zagreb International Review of Economics and Business*, *14*(2), 71–85.

Sun, M., & Meng, X. (2009). Taxonomy for Change Causes and Effects in Construction Projects. *International Journal of Project Management*, *27*(6), 560–572.

Tah, J. H., Carr, V., & Howes, R. (1999). Information Modelling for Case-Based Construction Planning of Highway Bridge Projects. *Advances in Engineering Software*, *30*(7), 495–509. doi:10.1016/S0965-9978(98)00128-8

Taylor, M. (2000). *Avoiding Claims in Building Design: Risk Management in Practice*. London, United Kingdom: Blackwell Science Ltd.

Thomas, H. R., & Napolitan, C. L. (1995). Quantitative Effects of Construction Changes on Labor Productivity. *Journal of Construction Engineering and Management*, *121*(3), 290–296. doi:10.1061/(ASCE)0733-9364(1995)121:3(290)

Tokdemir, O. B., & Arditi, D. (1999). Using Case-Based Reasoning to Predict the Outcome of Construction Litigation. *Computer-Aided Civil and Infrastructure Engineering*, *14*(6), 385–393. doi:10.1111/0885-9507.00157

Tüfekçi, G. (2009, August 20). 250 bin lüks konut elde kaldı. *Hürriyet*. Retrieved March 15, 2015, from http://www.hurriyet.com.tr/250-bin-luks-konut-elde-kaldi-12350999

Uhlik, F. T., & Eller, M. D. (1999). Alternative Delivery Approaches for Military Medical Construction Projects. *Journal of Architectural Engineering*, *5*(4), 149–155.

Vidogah, W., & Ndekugri, I. (1997). Improving Management of Claims: Contractors' Perspective. *Journal of Management in Engineering*, *13*(5), 37–44. doi:10.1061/(ASCE)0742-597X(1997)13:5(37)

Vidogah, W., & Ndekugri, I. (1998). A Review of the Role of Information Technology in Construction Claims Management. *Computers in Industry, 35*(1), 77–85.

Winkler, G., & Chiumento, G. C. (2009). *Construction Administration for Architects* (1st ed.). New York, U.S.A.: The McGraw-Hill Companies Inc.

Yau, N.-J., & Yang, J.-B. (1998a). Applying Case-Based Reasoning Technique to Retaining Wall Selection. *Automation in Construction*, *7*(4), 271–283. doi:10.1016/S0926-5805(97)00072-1

Yau, N.-J., & Yang, J.-B. (1998b). Case-Based Reasoning in Construction Management. *Computer-Aided Civil and Infrastructure Engineering*, *13*(2), 143–150. doi:10.1111/0885-9507.00094

Yıldız, B. (2010). *Impact of Culture on Claims Management in International Construction Joint Ventures*. Unpublished MS thesis. Istanbul Technical University, Istanbul, Turkey.

Yitmen, I., & Soujeri, E. (2010). An Artificial Neural Network Model for Estimating the Influence of Change Orders on Project Performance and Dispute Resolution Development of the Back-Propagation ANN Model. In *Proceedings of the International Conference on Computing in Civil and Building Engineering* (Vol. 1). Nottingham, United Kingdom.

Zaneldin, E. K. (2006). Construction Claims in United Arab Emirates: Types, Causes, and Frequency. *International Journal of Project Management*, *24*(5), 453–459. doi:10.1016/j.ijproman.2006.02.006

Zhao, Z. Y., Lei, Q., Zuo, J., & Zillante, G. (2010). Prediction System for Change Management in Construction Project, *136*(6), 659–669.

APPENDIX A

SAMPLE OF THE SURVEY FOR THE COLLECTION OF PROJECT CHANGE EXAMPLES FROM SIX DIFFERENT HOUSING PROJECTS VIA SEMI-STRUCTURED INTERVIEWS

A - General Information About the Status of Change Management

1. What is the impact of project changes to the construction process in terms of loss of time and cost?

None ( ) Low ( ) Medium ( ) High ( ) Very High ( )

2. What is your decision about the need of establishing a plan for management of project changes for the success of the construction projects?

I totally disagree ( )

I disagree ( )

I've no idea ( )

I agree ( )

I totally agree ( )

3. Have you ever heard any model or tool for management of project changes?

Yes ( ) No ( )

4. How frequently do you need assistance for management of project changes in your construction projects?

Never ( ) Rarely ( ) Neutral ( ) Usually ( ) Frequently ( )

5. Have you ever used any model or tool for management of project changes?

Yes ( ) No ( )

6. What is your expectation from the model before you experience it?

Very Low ( ) Low ( ) Neutral ( ) High ( ) Very High ( )

B - Information About the Project Changes

Table A.1 Sample of the Form Used in the Interviews

Type of Change	Causes of Change	Effects of Change	Effects on other changes

APPENDIX B

THE RESULTS OF THE SURVEY FOR THE COLLECTION OF PROJECT CHANGE EXAMPLES FROM SIX DIFFERENT HOUSING PROJECTS VIA SEMI-STRUCTURED INTERVIEWS

In this section, results of the semi-structured interviews conducted for the collection of project change examples are depicted. The interviews were conducted with six professionals responsible for six different housing projects. Firstly, the results of the survey about the status of change management in the construction projects are depicted. Then, examples of the project changes are listed according to the features of the CBR model.

A - General Information About the Status of Change Management

Table B.1 Results of the First Section of the Interviews

	Project 1	**Project 2**	**Project 3**	**Project 4**	**Project 5**	**Project 6**
Impact of project changes to the construction process in terms of loss of time and cost	Medium	Medium	Very High	Low	High	High
Need of establishing a plan for management of project changes for the success of the construction projects	I agree	I agree	I agree	I agree	I totally agree	I totally agree
Have you ever heard any model or tool for management of project changes?	Yes	No	No	No	No	Yes
Need assistance for management of project changes	Neutral	Neutral	Usually	Rarely	Usually	Usually
Have you ever used any model or tool for management of project changes?	No	No	No	No	No	No
Expectation from the model before you experience it	High	Neutral	High	Neutral	Very High	High

B - Information About the Project Changes

Table B.2 List of Project Changes collected from Project 1, Part 1

Total Number	No	Type	Location Table 13	Element Table 21
Project 1				
1	1	Revision	13-65 23 00 Kitchen	21-05 20 10 Fixed Furnishings
2	2	Revision	13-65 13 00 Bathroom	21-03 20 30 20 Tile Flooring
3	3	Revision	13-65 00 00 Private Residential Spaces	General Plan
4	4	Revision	13-65 13 00 Bathroom	21-05 20 10 Fixed Furnishings
5	5	Revision	13-63 13 15 Coat Check	21-05 20 10 Fixed Furnishings
6	6	Addition	Facade	21-02 20 20 30 Exterior Window Wall
7	7	Revision	13-25 11 11 Corridor	21-03 10 10 10 Interior Fixed Partitions
8	8	Addition	13-23 19 00 Utility Equipment Room	
9	9	Revision	13-25 17 00 External Circulation Spaces	21-02 10 80 60 Fire Escapes
10	10	Revision	13-25 11 11 Corridor	21-03 20 30 20 Tile Flooring
11	11	Revision	13-33 17 11 Fitness Center	General Plan
12	12	Revision	13-33 17 11 Fitness Center	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)
13	13	Revision	13-33 17 11 Fitness Center	21-03 10 70 Suspended Ceiling Construction
14	14	Revision	13-23 11 13 Stairway	General Plan
15	15	Revision	13-65 00 00 Private Residential Spaces	21-03 10 10 10 Interior Fixed Partitions
16	16	Revision	13-65 00 00 Private Residential Spaces	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)
17	17	Addition	13-65 00 00 Private Residential Spaces	21-03 10 70 Suspended Ceiling Construction
18	18	Revision	13-21 13 00 Interior Parking Spaces	General Plan
19	19	Revision	13-61 17 00 Spaces for Protection from Violence	General Plan
20	20	Revision	13-25 13 13 Entry Lobby	General Plan
21	21	Revision	13-25 13 13 Entry Lobby	21-05 10 30 70 Postal, Packaging, and Shipping Equipment
22	22	Addition	13-61 15 17 Canopy	
23	23	Revision	13-33 17 11 Fitness Center	21-04 50 40 Lighting
24	24	Revision	13-65 00 00 Private Residential Spaces	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)
25	25	Revision	13-65 00 00 Private Residential Spaces	21-04 50 40 Lighting
26	26	Revision	13-33 15 00 Non-Athletic Recreation Spaces	General Plan
27	27	Revision	13-23 19 00 Utility Equipment Room	21-04 50 Electrical
28	28	Revision	13-21 13 00 Interior Parking Spaces	21-04 50 Electrical
29	29	Revision	13-25 11 11 Corridor	21-04 50 40 Lighting
30	30	Revision	13-33 15 00 Non-Athletic Recreation Spaces	21-07 20 80 70 Landscape Lighting
31	31	Revision	13-65 00 00 Private Residential Spaces	Statical Elements
32	32	Revision	13-33 17 11 Fitness Center	Statical Elements
33	33	Revision	13-61 17 00 Spaces for Protection from Violence	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)
34	34	Revision	13-61 17 00 Spaces for Protection from Violence	21-04 50 Electrical
35	35	Revision	13-21 13 00 Interior Parking Spaces	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)
36	36	Revision	13-23 19 00 Utility Equipment Room	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)

Table B.3 List of Project Changes collected from Project 1, Part 2

Total Number	No	Causes of the Change	Source Party	Effects On the Office	Effects on the Site	Effects on the Cost	Effects on Other Changes
Project 1							
1	1	Change/ modifications in designs	Contractor	Low	Low	No	7
2	2	Change/ modifications in designs	Contractor	Low	Low	No	
3	3	Change of plan	Contractor	Low	No	Negative	4,5, 25, 15, 24, 31
4	4	Change of plan	Contractor	Low	No	Negative	
5	5	Change of plan	Contractor	Low	No	Negative	
6	6	Poorly executed design drawings, Mistakes and discrepancies in design documents	Architect	Low	No	Negative	
7	7	Change/ modifications in designs	Contractor	Low	No	No	
8	8	Mistakes and discrepancies in design documents	Architect	Medium	Medium	Negative	9, 27, 36
9	9	Mistakes and discrepancies in design documents, Over-design increasing the overall cost	Contractor, Architect	Medium	Low	Positive	
10	10	Poorly executed design drawings	Architect	Low	Low	Negative	
11	11	Change of plan	Contractor	Low	Low	No	12, 23, 32
12	12	Change of plan	Contractor	Low	Low	No	14, 23
13	13	Change of plan	Contractor	Low	Low	No	23
14	14	Citation of inadequate specification	Architect	Low	Low	No	
15	15	Change of plan	Contractor	Low	No	No	
16	16	Failure by the consultant to perform design effectively	Mechanical Consultant	Low	No	No	17
17	17	Errors and omissions in design documents and defective specifications	Architect	Low	No	Negative	25, 29
18	18	Change of plan	Contractor	Low	No	No	19, 35
19	19	Change of plan	Contractor	Low	No	No	33, 34
20	20	Inaccurate design information	Architect	Low	Low	Negative	
21	21	Inaccurate design information	Architect	Low	No	No	
22	22	Poorly executed design drawings	Architect	Low	Low	Negative	
23	23	Poorly executed design drawings	Architect	Low	Low	Negative	
24	24	Change of plan	Contractor	No	No	No	
25	25	Change of plan	Contractor	Low	No	No	
26	26	Change of plan	Contractor	High	Low	Negative	30
27	27	Change/ modifications in designs	Contractor	Low	Low	Negative	
28	28	Change/ modifications in designs	Contractor	Low	Low	Negative	
29	29	Errors and omissions in design documents and defective specifications	Architect	Low	Low	Negative	
30	30	Change of plan	Contractor	Medium	Low	Negative	
31	31	Change of plan	Contractor	Low	No	No	
32	32	Change of plan	Contractor	Low	No	No	
33	33	Change of plan	Contractor	Low	Low	No	
34	34	Change of plan	Contractor	Low	Low	Negative	
35	35	Change of plan	Contractor	Low	Low	No	
36	36	Change of plan	Contractor	Low	Low	No	

Table B.4 List of Project Changes collected from Project 2, Part 1

Total Number	No	Type	Location Table 13	Element Table 21
Project 2				
37	1	Revision	Facade	21-02 20 10 10 Exterior Wall Veneer
38	2	Revision	13-69 11 00 Roof	General Plan
39	3	Deletion	13-33 15 00 Non-Athletic Recreation Spaces	21-07 20 80 30 Plants
40	4	Revision	13-21 11 13 Exterior Parking Access Control Point	General Plan
41	5	Revision	13-33 15 00 Non-Athletic Recreation Spaces	21-07 20 60 60 Retaining Walls
42	6	Revision	13-33 17 11 Fitness Center	General Plan
43	7	Revision	13-65 00 00 Private Residential Spaces	21-02 10 80 10 Stair Construction
44	8	Revision	13-65 00 00 Private Residential Spaces	General Plan
45	9	Revision	13-21 11 00 Exterior Parking Spaces	21-07 20 60 20 Fences and Gates
46	10	Revision	13-21 11 00 Exterior Parking Spaces	Statical Elements
47	11	Revision	13-69 11 00 Roof	21-02 10 20 10 Roof Structural Frame
48	12	Revision	13-65 23 00 Kitchen	21-05 20 10 Fixed Furnishings
49	13	Revision	13-65 00 00 Private Residential Spaces	21-03 10 10 10 Interior Fixed Partitions
50	14	Revision	13-65 00 00 Private Residential Spaces	21-04 50 Electrical
51	15	Revision	13-65 00 00 Private Residential Spaces	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)
52	16	Revision	13-69 11 00 Roof	21-03 10 10 10 Interior Fixed Partitions
53	17	Revision	13-33 15 00 Non-Athletic Recreation Spaces	General Plan
54	18	Deletion	13-33 15 00 Non-Athletic Recreation Spaces	21-07 20 60 10 Exterior Fountains
55	19	Revision	13-33 15 00 Non-Athletic Recreation Spaces	21-07 20 80 70 Landscape Lighting
56	20	Revision	13-33 15 00 Non-Athletic Recreation Spaces	21-07 30 10 50 Site Irrigation Water Distribution
57	21	Revision	13-69 11 00 Roof	21-04 50 Electrical
58	22	Revision	13-69 11 00 Roof	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)
59	23	Revision	13-65 00 00 Private Residential Spaces	21-03 20 30 20 Tile Flooring
60	24	Revision	13-69 11 00 Roof	21-02 30 40 30 Horizontal Waterproofing Membrane
61	25	Addition	13-33 15 00 Non-Athletic Recreation Spaces	21-07 20 80 30 Plants

Table B.5 List of Project Changes collected from Project 2, Part 2

Total Number	No	Causes of the Change	Source Party	Effects On the Office	Effects on the Site	Effects on the Cost	Effects on Other Changes
Project 2							
37	1	Over-design increasing the overall cost	Contractor	Medium	No	Positive	
38	2	Change in governmental regulations/laws	Governmental Authorities	Medium	High	Negative	11, 24
39	3	Over-design increasing the overall cost	Contractor	No	Medium	Positive	25
40	4	Insufficient data collection, survey and site investigation prior to design	Contractor	Medium	Medium	Negative	10, 9
41	5	Over-design increasing the overall cost	Contractor	Medium	No	Positive	
42	6	Change of plan	Contractor	Medium	Medium	Negative	
43	7	Over-design increasing the overall cost	Contractor	Medium	Low	Positive	8
44	8	Over-design increasing the overall cost	Contractor	Medium	Low	Positive	
45	9	Insufficient data collection, survey and site investigation prior to design	Contractor	Medium	Medium	Negative	
46	10	Insufficient data collection, survey and site investigation prior to design	Contractor	Low	Low	Negative	
47	11	Change in governmental regulations/laws	Governmental Authorities	Medium	High	Negative	
48	12	Over-design increasing the overall cost, Change/ modifications in designs	Contractor	Medium	Medium	No	13, 23
49	13	Over-design increasing the overall cost, Change/ modifications in designs	Contractor	Low	No	No	14, 15
50	14	Over-design increasing the overall cost, Change/ modifications in designs	Contractor	No	Low	Negative	
51	15	Over-design increasing the overall cost, Change/ modifications in designs	Contractor	No	Low	No	
52	16	Inconsistent with governmental regulations	Governmental Authorities	Medium	No	Positive	21.22
53	17	Insufficient data collection, survey and site investigation prior to design	Contractor	High	Low	Positive	19, 20
54	18	Over-design increasing the overall cost	Contractor	Medium	Low	Positive	19, 20
55	19	Insufficient data collection, survey and site investigation prior to design, Over-design increasing the overall cost	Contractor	Medium	Medium	Positive	
56	20	Insufficient data collection, survey and site investigation prior to design, Over-design increasing the overall cost	Contractor	Medium	No	Negative	
57	21	Inconsistent with governmental regulations	Governmental Authorities	Medium	Low	No	
58	22	Inconsistent with governmental regulations	Governmental Authorities	Medium	Low	No	
59	23	Over-design increasing the overall cost, Change/ modifications in designs	Contractor	Low	No	No	
60	24	Change in governmental regulations/laws	Governmental Authorities	No	Medium	Negative	
61	25	Change of plan	Client	No	Medium	Negative	

Table B.6 List of Project Changes collected from Project 3, Part 1

Total Number	No	Type	Location Table 13	Element Table 21
Project 3				
62	1	Revision	13-65 00 00 Private Residential Spaces	General Plan
63	2	Revision	13-23 11 13 Stairway	21-02 10 80 60 Fire Escapes
64	3	Revision	13-21 13 00 Interior Parking Spaces	21-01 20 10 Walls for Subgrade Enclosures
65	4	Addition	13-63 13 11 Storage Room	General Plan
66	5	Revision	13-65 23 00 Kitchen	21-03 10 10 10 Interior Fixed Partitions
67	6	Revision	13-21 13 00 Interior Parking Spaces	General Plan
68	7	Revision	Facade	System Details of Joineries
69	8	Revision	13-65 00 00 Private Residential Spaces	21-03 20 30 20 Tile Flooring
70	9	Addition	Whole Building	21-04 30 30 Cooling Systems
71	10	Revision	13-25 13 13 Entry Lobby	General Plan
72	11	Revision	13-25 13 13 Entry Lobby	21-05 10 30 70 Postal, Packaging, and Shipping Equipment
73	12	Revision	13-65 13 00 Bathroom	21-05 20 10 Fixed Furnishings
74	13	Addition	13-65 00 00 Private Residential Spaces	21-03 10 70 Suspended Ceiling Construction
75	14	Addition	13-65 00 00 Private Residential Spaces	21-04 40 10 Fire Suppression
76	15	Addition	13-69 21 00 Balcony	21-02 30 10 70 Canopy Roofing
77	16	Revision	13-25 13 13 Entry Lobby	21-02 20 20 30 Exterior Window Wall
78	17	Revision	13-33 17 11 Fitness Center	21-05 20 10 Fixed Furnishings
79	18	Revision	13-33 13 11 Outdoor Swimming Pool	General Plan
80	19	Revision	13-33 17 11 Fitness Center	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)
81	20	Revision	13-33 15 00 Non-Athletic Recreation Spaces	21-07 20 60 60 Retaining Walls
82	21	Addition	13-23 19 00 Utility Equipment Room	General Plan
83	22	Deletion	13-33 15 00 Non-Athletic Recreation Spaces	21-07 20 80 30 Plants
84	23	Revision	13-21 11 11 Exterior Parking Circulation	General Plan
85	24	Revision	13-33 17 11 Fitness Center	21-03 20 10 Wall Covering
86	25	Addition	13-23 11 19 Chimney	General Plan
87	26	Revision	13-65 00 00 Private Residential Spaces	21-04 50 Electrical
88	27	Revision	13-65 00 00 Private Residential Spaces	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)
89	28	Revision	13-25 13 13 Entry Lobby	21-04 50 Electrical
90	29	Revision	13-65 00 00 Private Residential Spaces	21-04 50 40 Lighting
91	30	Revision	13-21 13 00 Interior Parking Spaces	21-04 50 Electrical
92	31	Revision	13-21 13 00 Interior Parking Spaces	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)
93	32	Revision	13-65 00 00 Private Residential Spaces	Statical Elements
94	33	Revision	13-21 13 00 Interior Parking Spaces	Statical Elements
95	34	Revision	Facade	General Plan
96	35	Revision	13-65 00 00 Private Residential Spaces	Statical Elements
97	36	Revision	13-33 17 11 Fitness Center	21-03 10 70 Suspended Ceiling Construction

Table B.7 List of Project Changes collected from Project 3, Part 2

Total Number	No	Causes of the Change	Source Party	Effects On the Office	Effects on the Site	Effects on the Cost	Effects on Other Changes
Project 3							
62	1	Change in governmental regulations/laws	Governmental Authorities	High	Medium	Negative	26,27,32
63	2	Change in governmental regulations/laws	Governmental Authorities	Medium	Medium	Negative	26,27,32
64	3	Insufficient data collection, survey and site investigation prior to design	Contractor	High	Medium	Negative	30,31,33
65	4	Change of plan	Contractor	Medium	No	Negative	
66	5	Change/ modifications in designs	Contractor	Low	No	No	
67	6	Change of plan	Contractor	Low	No	Negative	33
68	7	Poor design quality – improper/ wrong /impractical design	Architect	Medium	No	Negative	
69	8	Change/ modifications in designs	Contractor	No	Low	Negative	
70	9	Change/ modifications in designs	Contractor	Medium	Medium	Negative	13,34
71	10	Change of plan	Contractor	High	Medium	Negative	28
72	11	Change in governmental regulations/laws	Governmental Authorities	High	Medium	Negative	
73	12	Change of plan	Client	Medium	Medium	Negative	27
74	13	Change in governmental regulations/laws, Change/ modifications in designs	Contractor, Governmental Issues	Medium	Medium	Negative	29
75	14	Change in governmental regulations/laws	Governmental Authorities	Low	Medium	Negative	27
76	15	Change/ modifications in designs	Contractor	Low	Medium	Negative	
77	16	Over-design increasing the overall cost	Contractor	Low	Low	Negative	
78	17	Over-design increasing the overall cost	Contractor	Low	Low	Positive	
79	18	Errors and omissions in design documents and defective specifications	Architect	Low	Low	Negative	36
80	19	Mistakes and discrepancies in design documents	Mechanical Consultant	Medium	Medium	Negative	
81	20	Inconsistency between drawings and site conditions, Over-design increasing the overall cost	Contractor	High	High	Negative	
82	21	Delays in producing design documents	Mechanical Consultant	Medium	Medium	Negative	
83	22	Inconsistency between drawings	Landscape Consultant	Low	High	Positive	
84	23	Change of plan	Contractor	Medium	High	Negative	
85	24	Change/ modifications in designs	Contractor	No	High	Negative	
86	25	Delays in producing design documents	Mechanical Consultant	Medium	Medium	Negative	
87	26	Change in governmental regulations/laws, Change/ modifications in designs	Contractor, Governmental Issues	Medium	No	No	
88	27	Change in governmental regulations/laws, Change/ modifications in designs	Contractor, Governmental Issues	Medium	Medium	Negative	
89	28	Change of plan	Contractor	Low	Low	Negative	
90	29	Change in governmental regulations/laws, Change/ modifications in designs	Contractor, Governmental Issues	Low	Low	Negative	
91	30	Insufficient data collection, survey and site investigation prior to design	Contractor	Low	No	No	
92	31	Insufficient data collection, survey and site investigation prior to design	Contractor	Low	No	No	
93	32	Change in governmental regulations/laws	Governmental Authorities	Medium	Medium	Negative	
94	33	Insufficient data collection, survey and site investigation prior to design, Change of plan	Contractor	Medium	Medium	Negative	
95	34	Inconsistency between drawings, Change/ modifications in designs	Architect, Contractor	Low	Low	Negative	
96	35	Change in governmental regulations/laws	Governmental Authorities	Medium	Medium	Negative	
97	36	Mistakes and discrepancies in design documents	Mechanical Consultant	Low	Low	Negative	

Table B.8 List of Project Changes collected from Project 4, Part 1

Total Number	No	Type	Location Table 13	Element Table 21
Project 4				
98	1	Revision	13-69 21 00 Balcony	21-02 20 80 70 Exterior Fabrications
99	2	Revision	13-65 00 00 Private Residential Spaces	Skirting Details
100	3	Revision	13-65 00 00 Private Residential Spaces	21-03 20 30 20 Tile Flooring
101	4	Revision	13-65 00 00 Private Residential Spaces	21-03 10 30 Interior Doors
102	5	Revision	13-65 23 00 Kitchen	21-05 20 10 Fixed Furnishings
103	6	Revision	13-65 00 00 Private Residential Spaces	21-03 10 10 10 Interior Fixed Partitions
104	7	Revision	Facade	System Details of Joineries
105	8	Revision	13-69 21 00 Balcony	21-04 20 30 Building Support Plumbing Systems
106	9	Revision	13-25 15 00 Connector	21-02 20 20 30 Exterior Window Wall
107	10	Revision	13-33 15 00 Non-Athletic Recreation Spaces	21-07 20 60 20Fences and Gates
108	11	Revision	13-33 15 00 Non-Athletic Recreation Spaces	21-07 20 80 50Planting Accessories
109	12	Revision	13-69 21 00 Balcony	21-02 20 10 10Exterior Wall Veneer
110	13	Revision	13-69 21 00 Balcony	21-02 20 80 50 Exterior Balcony Walls and Railings
111	14	Revision	13-23 11 19 Chimney	General Plan
112	15	Revision	13-25 15 00 Connector	22-05 12 00 Structural Steel Framing
113	16	Revision	13-23 11 13 Stairway	21-02 10 80 50 Stair Railings
114	17	Revision	13-33 15 00 Non-Athletic Recreation Spaces	22-22 14 26 16 Facility Area Drains
115	18	Addition	13-25 15 00 Connector	21-02 10 80 50 Stair Railings
116	19	Deletion	13-25 15 00 Connector	22-05 12 00 Structural Steel Framing
117	20	Deletion	13-25 15 00 Connector	21-02 20 50 10 Exterior Entrance Doors
118	21	Revision	13-25 15 00 Connector	21-02 20 20 30 Exterior Window Wall
119	22	Revision	13-25 15 00 Connector	21-01 10 20 40 Foundation Anchors
120	23	Revision	13-69 13 00 Roof Terrace	21-02 30 40 10 Traffic Bearing Coatings
121	24	Revision	13-33 15 00 Non-Athletic Recreation Spaces	21-07 20 60 25 Site Furnishings
122	25	Addition	13-25 15 00 Connector	21-02 10 80 10 Stair Construction
123	26	Addition	13-25 15 00 Connector	21-02 30 40 30 Horizontal Waterproofing Membrane
124	27	Revision	13-23 11 17 Ramp	21-07 20 10 10 Roadway Pavement
125	28	Addition	13-25 15 00 Connector	21-02 20 10 40 Fabricated Exterior Wall Assemblies
126	29	Revision	13-13 11 00 Light Well	General Plan
127	30	Revision	Facade	21-02 20 20 30 Exterior Window Wall
128	31	Addition	13-23 17 00 Restroom	General Plan
129	32	Revision	13-25 11 11 Corridor	21-04 50 40 Lighting
130	33	Revision	13-33 15 00 Non-Athletic Recreation Spaces	21-07 20 60 60 Retaining Walls
131	34	Revision	13-69 13 00 Roof Terrace	21-02 30 40 30 Horizontal Waterproofing Membrane
132	35	Revision	13-33 15 00 Non-Athletic Recreation Spaces	21-07 20 30 10 Pedestrian Pavement
133	36	Revision	13-21 11 15 Exterior Parking Spaces	21-07 20 10 10 Roadway Pavement
134	37	Revision	13-65 00 00 Private Residential Spaces	21-02 10 80 50 Stair Railings
135	38	Addition	13-33 15 00 Non-Athletic Recreation Spaces	21-07 10 10 30 Site Clearing
136	39	Revision	13-25 13 13 Entry Lobby	21-05 10 30 70 Postal, Packaging, and Shipping Equipment
137	40	Revision	13-23 19 00 Utility Equipment Room	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)
138	41	Revision	13-23 19 00 Utility Equipment Room	General Plan
139	42	Revision	13-69 21 00 Balcony	21-02 30 40 10 Traffic Bearing Coatings
140	43	Deletion	13-33 15 00 Non-Athletic Recreation Spaces	21-07 20 80 30 Plants
141	44	Revision	13-65 13 00 Bathroom	21-05 20 10 Fixed Furnishings
142	45	Revision	13-25 15 00 Connector	22-05 12 00 Structural Steel Framing

Table B.9 List of Project Changes collected from Project 4, Part 2

Total Number	No	Causes of the Change	Source Party	Effects On the Office	Effects on the Site	Effects on the Cost	Effects on Other Changes
Project 4							
98	1	Over-design increasing the overall cost	Contractor	low	high	positive	
99	2	Poor design quality – improper/ wrong /impractical design	Architect	high	high	negative	
100	3	Poor design quality – improper/ wrong /impractical design	Architect	low	medium	no	2
101	4	Over-design increasing the overall cost	Contractor	low	low	negative	
102	5	Poor design quality – improper/ wrong /impractical design	Architect	medium	medium	no	
103	6	Over-design increasing the overall cost	Contractor	high	no	no	44
104	7	Poor design quality – improper/ wrong /impractical design	Architect	low	no	no	
105	8	Errors and omissions in design documents and defective specifications	Architect	high	high	negative	
106	9	Errors and omissions in design documents and defective specifications	Architect	medium	high	no	18
107	10	Poorly executed design drawings	Landscape Consultant	low	low	no	
108	11	Change/ modifications in designs	Contractor	low	low	negative	
109	12	Over-design increasing the overall cost	Contractor	low	low	positive	
110	13	Change/ modifications in designs	Contractor	medium	medium	no	
111	14	Change/ modifications in designs	Contractor	low	no	no	
112	15	Errors and omissions in design documents and defective specifications	Architect	high	high	positive	
113	16	Errors and omissions in design documents and defective specifications	Architect	high	high	no	
114	17	Inconsistency between drawings	Landscape Consultant	medium	high	negative	
115	18	Errors and omissions in design documents and defective specifications	Architect	medium	medium	negative	
116	19	Over-design increasing the overall cost	Contractor	high	high	positive	20
117	20	Over-design increasing the overall cost	Contractor	low	no	no	
118	21	Poorly executed design drawings	Statical Consultant	low	no	no	22
119	22	Poorly executed design drawings	Statical Consultant	low	no	negative	
120	23	Errors and omissions in design documents and defective specifications	Architect	medium	medium	negative	
121	24	Change/ modifications in designs	Contractor	low	low	no	
122	25	Change/ modifications in designs	Contractor	medium	high	negative	
123	26	Change/ modifications in designs	Contractor	no	low	negative	
124	27	Poor design quality – improper/ wrong /impractical design	Architect	medium	low	positive	
125	28	Poorly executed design drawings	Architect	medium	medium	negative	
126	29	Insufficient data collection, survey and site investigation prior to design	Contractor	medium	low	no	
127	30	Poor design quality – improper/ wrong /impractical design	Architect	medium	low	positive	
128	31	Inconsistent with governmental regulations	Contractor	medium	medium	negative	32
129	32	Inconsistent with governmental regulations	Contractor	low	low	no	
130	33	Inconsistency between drawings and site conditions	Contractor	low	low	positive	
131	34	Change/ modifications in designs	Contractor	no	no	positive	
132	35	Change/ modifications in designs	Contractor	medium	low	positive	
133	36	Change/ modifications in designs	Contractor	medium	medium	positive	
134	37	Change/ modifications in designs	Contractor	low	low	positive	
135	38	Insufficient data collection, survey and site investigation prior to design	Contractor	low	low	positive	
136	39	Change/ modifications in designs	Contractor	low	no	no	
137	40	Poorly executed design drawings	Mechanical Consultant	low	low	no	
138	41	Poorly executed design drawings	Mechanical Consultant	low	low	no	
139	42	Poor design quality – improper/ wrong /impractical design	Architect	low	no	negative	
140	43	Change/ modifications in designs	Contractor	medium	low	positive	
141	44	Change/ modifications in designs	Contractor	medium	no	no	
142	45	Inconsistency between drawings	Statical Consultant	low	low	positive	

Table B.10 List of Project Changes collected from Project 5, Part 1

Total Number	No	Type	Location Table 13	Element Table 21
			Project 5	
143	1	Revision	13-65 23 00 Kitchen	21-03 20 30 20 Tile Flooring
144	2	Revision	13-65 23 00 Kitchen	21-03 20 10 30 Wall Coverings
145	3	Revision	13-13 13 00 Air Shaft	General Plan
146	4	Revision	13-65 00 00 Private Residential Spaces	21-03 10 70 Suspended Ceiling Construction
147	5	Revision	Facade	System Details of Joineries
148	6	Revision	13-25 11 11 Corridor	21-03 20 30 20 Tile Flooring
149	7	Revision	Facade	21-02 20 20 30 Exterior Window Wall
150	8	Revision	Facade	21-02 20 10 10 Exterior Wall Veneer
151	9	Deletion	13-65 00 00 Private Residential Spaces	21-02 10 10 30 Balcony Floor Construction
152	10	Revision	13-25 11 11 Corridor	21-03 20 10 30 Wall Coverings
153	11	Revision	13-33 15 00 Non-Athletic Recreation Spaces	21-07 20 60 60 Retaining Walls
154	12	Revision	13-25 13 13 Entry Lobby	General Plan
155	13	Revision	13-65 00 00 Private Residential Spaces	21-03 10 10 10 Interior Fixed Partitions
156	14	Revision	Facade	General Plan
157	15	Revision	13-65 23 00 Kitchen	21-05 20 10 Fixed Furnishings
158	16	Revision	13-69 11 00 Roof	21-02 30 20 10 Roof Accessories
159	17	Revision	13-69 21 00 Balcony	21-04 20 30 20 Stormwater Drainage Piping
160	18	Revision	13-65 00 00 Private Residential Spaces	General Plan
161	19	Revision	13-65 00 00 Private Residential Spaces	21-03 10 20 Interior Windows
162	20	Revision	13-65 13 00 Bathroom	21-05 20 10 Fixed Furnishings
163	21	Revision	13-65 00 00 Private Residential Spaces	21-02 20 50 10 Exterior Entrance Doors
164	22	Revision	13-25 13 13 Entry Lobby	21-05 20 10 Fixed Furnishings
165	23	Revision	13-69 21 00 Balcony	21-03 20 30 20 Tile Flooring
166	24	Deletion	13-23 11 11 17 Elevator Machine Room	General Plan
167	25	Revision	13-65 00 00 Private Residential Spaces	21-02 20 20 20 Exterior Fixed Windows
168	26	Revision	13-13 13 00 Air Shaft	21-04 30 60 Ventilation
169	27	Addition	13-23 11 19 Chimney	21-02 20 10 50 Parapets
170	28	Revision	13-65 00 00 Private Residential Spaces	21-04 40 10 Fire Suppression
171	29	Revision	13-65 00 00 Private Residential Spaces	21-02 20 10 20 Exterior Wall Construction
172	30	Revision	13-65 13 00 Bathroom	21-05 20 10 Fixed Furnishings
173	31	Revision	13-65 13 00 Bathroom	General Plan
174	32	Revision	13-65 00 00 Private Residential Spaces	21-05 20 10 Fixed Furnishings
175	33	Revision	13-65 13 00 Bathroom	21-05 20 10 Fixed Furnishings
176	34	Revision	13-65 00 00 Private Residential Spaces	21-04 50 40 Lighting
177	35	Revision	13-61 17 00 Spaces for Protection from Violence	21-03 10 10 10 Interior Fixed Partitions
178	36	Deletion	13-69 21 00 Balcony	21-02 10 10 20 Floor Decks, Slabs, and Toppings
179	37	Revision	13-25 13 13 Entry Lobby	21-03 20 30 Flooring
180	38	Addition	13-23 11 13 Stairway	21-02 10 80 50 Stair Railings
181	39	Revision	13-65 13 00 Bathroom	21-03 20 30 20 Tile Flooring
182	40	Revision	13-65 00 00 Private Residential Spaces	21-04 50 Electrical
183	41	Revision	13-65 00 00 Private Residential Spaces	Statical Elements
184	42	Revision	13-25 13 13 Entry Lobby	21-03 20 10 30 Wall Coverings
185	43	Revision	13-25 13 13 Entry Lobby	21-04 50 40 Lighting
186	44	Revision	13-65 00 00 Private Residential Spaces	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)
187	45	Revision	13-69 21 00 Balcony	21-04 20 30 10 Stormwater Drainage Equipment
188	46	Revision	13-23 19 00 Utility Equipment Room	Statical Elements
189	47	Revision	13-23 19 00 Utility Equipment Room	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)
190	48	Revision	13-69 11 00 Roof	Statical Elements
191	49	Revision	13-65 13 00 Bathroom	21-03 10 10 10 Interior Fixed Partitions
192	50	Revision	13-65 13 00 Bathroom	21-03 20 10 30 Wall Coverings
193	51	Revision	13-61 17 00 Spaces for Protection from Violence	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)
194	52	Revision	13-69 21 00 Balcony	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)

Table B.11 List of Project Changes collected from Project 5, Part 2

Total Number	No	Causes of the Change	Source Party	Effects On the Office	Effects on the Site	Effects on the Cost	Effects on Other Changes
		Project 5					
143	1	Change/ modifications in designs	Contractor	medium	low	positive	
144	2	Change/ modifications in designs	Contractor	low	low	positive	
145	3	Poor design quality – improper/ wrong /impractical design	Mechanical Consultant	low	medium	negative	39
146	4	Inconsistent with governmental regulations	Architect	high	high	negative	40
147	5	Poor design quality – improper/ wrong /impractical design	Architect	low	medium	negative	38
148	6	Over-design increasing the overall cost	Contractor	medium	low	positive	
149	7	Errors and omissions in design documents and defective specifications	Architect	low	medium	negative	
150	8	Change/ modifications in designs	Contractor	no	low	positive	
151	9	Insufficient data collection, survey and site investigation prior to design, Over-design increasing the overall cost	Architect	medium	low	positive	41
152	10	Change/ modifications in designs	Governmental Authorities	medium	low	negative	
153	11	Change/ modifications in designs	Contractor	low	medium	negative	
154	12	Poor design quality – improper/ wrong /impractical design	Architect	medium	high	negative	42,43
155	13	Change of plan	Client	low	medium	negative	
156	14	Poor design quality – improper/ wrong /impractical design	Architect	low	medium	negative	
157	15	Change/ modifications in designs	Contractor	low	medium	positive	
158	16	Change/ modifications in designs	Contractor, Architect	low	low	no	
159	17	Errors and omissions in design documents and defective specifications, Change/ modifications in designs	Contractor, Architect	medium	medium	negative	45
160	18	Change of plan	Client	medium	medium	negative	
161	19	Change/ modifications in designs	Contractor	low	high	no	
162	20	Change/ modifications in designs	Contractor	medium	high	negative	39
163	21	Poorly executed design drawings	Architect	high	medium	negative	
164	22	Poorly executed design drawings	Architect	high	high	negative	
165	23	Change/ modifications in designs	Contractor	low	low	no	45
166	24	Change/ modifications in designs	Contractor	medium	medium	negative	46.47
167	25	Change/ modifications in designs	Contractor	medium	high	negative	
168	26	Change/ modifications in designs	Contractor	low	low	no	
169	27	Change/ modifications in designs	Contractor	low	low	negative	48
170	28	Change/ modifications in designs	Contractor	low	medium	no	
171	29	Poorly executed design drawings	Architect	low	medium	negative	
172	30	Errors and omissions in design documents and defective specifications	Architect	medium	medium	negative	
173	31	Inconsistency between drawings	Interior Architect	high	high	negative	
174	32	Change of plan	Client	no	medium	negative	
175	33	Change/ modifications in designs	Contractor	medium	medium	positive	49,5
176	34	Change/ modifications in designs	Architect	low	medium	negative	
177	35	Inconsistent with governmental regulations	Architect	medium	medium	negative	51
178	36	Over-design increasing the overall cost	Contractor	low	no	positive	52
179	37	Over-design increasing the overall cost	Contractor	low	medium	positive	
180	38	Poor design quality – improper/ wrong /impractical design	Architect	low	no	positive	
181	39	Poor design quality – improper/ wrong /impractical design	Mechanical Consultant	medium	medium	no	
182	40	Poorly executed design drawings	Architect	no	medium	negative	
183	41	Insufficient data collection, survey and site investigation prior to design, Over-design increasing the overall cost	Architect	medium	high	negative	
184	42	Poor design quality – improper/ wrong /impractical design	Architect	low	medium	negative	
185	43	Poor design quality – improper/ wrong /impractical design	Architect	low	medium	negative	
186	44	Change/ modifications in designs	Contractor	no	medium	no	
187	45	Errors and omissions in design documents and defective specifications, Change/ modifications in designs	Contractor, Architect	low	low	no	
188	46	Change/ modifications in designs	Contractor	no	medium	negative	
189	47	Change/ modifications in designs	Contractor	no	medium	no	
190	48	Change/ modifications in designs	Contractor	no	medium	no	
191	49	Change/ modifications in designs	Contractor	low	medium	negative	
192	50	Change/ modifications in designs	Contractor	low	low	negative	
193	51	Inconsistent with governmental regulations	Architect	no	medium	negative	
194	52	Over-design increasing the overall cost	Contractor	low	no	positive	

Table B.12 List of Project Changes collected from Project 6, Part 1

Total Number	No	Type	Location Table 13	Element Table 21
Project 6				
195	1	Revision	13-33 17 11 Fitness Center	21-02 10 80 10 Stair Construction
196	2	Revision	13-65 00 00 Private Residential Spaces	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)
197	3	Revision	Facade	21-02 20 10 10 Exterior Wall Veneer
198	4	Revision	13-65 13 00 Bathroom	21-05 20 10 Fixed Furnishings
199	5	Revision	Facade	System Details of Joineries
200	6	Revision	13-61 15 17 Canopy	Statical Elements
201	7	Revision	13-25 11 11 Corridor	21-03 20 10 30 Wall Coverings
202	8	Revision	13-65 00 00 Private Residential Spaces	21-03 20 30 20 Tile Flooring
203	9	Revision	13-13 13 00 Air Shaft	General Plan
204	10	Revision	13-65 00 00 Private Residential Spaces	Skirting Details
205	11	Revision	13-65 13 00 Bathroom	21-03 10 10 10 Interior Fixed Partitions
206	12	Revision	13-69 13 00 Roof Terrace	21-02 30 40 10 Traffic Bearing Coatings
207	13	Revision	13-65 13 00 Bathroom	21-05 20 10 Fixed Furnishings
208	14	Revision	13-65 13 00 Bathroom	21-03 20 30 20 Tile Flooring
209	15	Revision	Facade	General Plan
210	16	Revision	13-65 00 00 Private Residential Spaces	21-02 10 10 30 Balcony Floor Construction
211	17	Revision	13-65 23 00 Kitchen	21-04 50 Electrical
212	18	Revision	13-65 23 00 Kitchen	21-05 20 10 Fixed Furnishings
213	19	Revision	Facade	21-02 20 20 30 Exterior Window Wall
214	20	Revision	13-25 23 00 Refuge Spaces	21-04 40 10 Fire Suppression
215	21	Addition	13-21 11 15 Exterior Parking Spaces	General Plan
216	22	Addition	13-23 19 00 Utility Equipment Room	General Plan
217	23	Addition	13-65 00 00 Private Residential Spaces	21-04 40 10 Fire Suppression
218	24	Addition	13-21 11 13 Exterior Parking Access Control Point	General Plan
219	25	Revision	13-65 00 00 Private Residential Spaces	21-03 20 50 Ceiling Finishes
220	26	Revision	13-23 11 11 11 Elevator Shaft	Statical Elements
221	27	Revision	13-65 13 00 Bathroom	General Plan
222	28	Revision	13-33 15 00 Non-Athletic Recreation Spaces	General Plan
223	29	Revision	13-23 11 11 11 Elevator Shaft	General Plan
224	30	Revision	13-33 17 11 Fitness Center	Statical Elements
225	31	Revision	13-65 23 00 Kitchen	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)
226	32	Revision	13-25 23 00 Refuge Spaces	21-04 30 Heating, Ventilation, and Air Conditioning (HVAC)
227	33	Revision	13-65 00 00 Private Residential Spaces	Statical Elements

Table B.13 List of Project Changes collected from Project 6, Part 2

Total Number	No	Causes of the Change	Source Party	Effects On the Office	Effects on the Site	Effects on the Cost	Effects on Other Changes
Project 6							
195	1	Poor design quality – improper/ wrong /impractical design	Architect	high	high	negative	30
196	2	Inconsistency between drawings	Mechanical Consultant	high	medium	no	
197	3	Change/ modifications in designs	Contractor	medium	medium	positive	15
198	4	Inconsistency between drawings	Mechanical Consultant	high	high	negative	27
199	5	Change/ modifications in designs	Contractor	medium	medium	no	
200	6	Over-design increasing the overall cost	Contractor	medium	medium	positive	
201	7	Change in governmental regulations/laws	Governmental Authorities	high	high	negative	
202	8	Change/ modifications in designs	Contractor	high	medium	no	
203	9	Change of plan	Mechanical Consultant	high	high	negative	27
204	10	Change/ modifications in designs	Contractor	high	low	positive	
205	11	Errors and omissions in design documents and defective specifications	Mechanical Consultant	medium	high	negative	27
206	12	Over-design increasing the overall cost	Contractor	no	medium	positive	
207	13	Errors and omissions in design documents and defective specifications	Architect	high	high	negative	
208	14	Change/ modifications in designs	Contractor	high	no	positive	
209	15	Poorly executed design drawings	Architect	high	high	negative	
210	16	Inconsistency between drawings	Architect	no	low	no	
211	17	Change/ modifications in designs	Contractor	high	high	negative	18, 31
212	18	Change/ modifications in designs	Contractor	high	high	negative	31
213	19	Inconsistency between drawings	Architect	no	high	negative	
214	20	Errors and omissions in design documents and defective specifications	Mechanical Consultant	no	high	negative	32
215	21	Insufficient data collection, survey and site investigation prior to design, Over-design increasing the overall cost	Contractor	no	low	positive	28
216	22	Errors and omissions in design documents and defective specifications	Landscape Consultant	high	high	negative	28
217	23	Inconsistent with governmental regulations	Mechanical Consultant	high	no	no	2, 33
218	24	Errors and omissions in design documents and defective specifications	Landscape Consultant	medium	medium	negative	28
219	25	Over-design increasing the overall cost	Contractor	high	no	positive	
220	26	Errors and omissions in design documents and defective specifications	Mechanical Consultant	medium	high	negative	29
221	27	Inconsistency between drawings, Change of plan, Errors and omissions in design documents and defective specifications	Mechanical Consultant	high	medium	negative	
222	28	Insufficient data collection, survey and site investigation prior to design, Over-design increasing the overall cost, Errors and omissions in design documents and defective specifications	Mechanical Consultant, Contractor	no	medium	negative	
223	29	Errors and omissions in design documents and defective specifications	Mechanical Consultant	medium	high	negative	
224	30	Poor design quality – improper/ wrong /impractical design	Architect	medium	medium	negative	
225	31	Change/ modifications in designs	Contractor	low	medium	negative	
226	32	Errors and omissions in design documents and defective specifications	Mechanical Consultant	low	low	negative	
227	33	Inconsistent with governmental regulations	Mechanical Consultant	medium	medium	negative	

APPENDIX C

SAMPLE OF THE SURVEY FOR THE DEFINITION OF THE SIMILARITY MEASUREMENT FUNCTION

In this section, sample of the survey for definition of the similarity measurement function is depicted. This survey was used in the semi-structured interviews conducted with six respondents both of which are responsible for various large-sized housing projects located in Turkey. The survey was conducted in Turkish.

Proje Değişikliği Anketi

Bir proje değişikliğinde aşağıdaki faktörleri etki/önem derecesine göre değerlendiriniz.

NOT: Değerlendirme yaparken derece verdiğiniz faktör haricindekileri sabit tutup, ilgili faktörün değişken olması durumunda proje değişikliğinin sonucunun/etkisinin ne kadar değişebileceğine göre karşılaştırma yapıp değer verebilirsiniz.

ÖRNEK: Giriş Holü Asma Tavan Revizyonu, sebep: çizimdeki hatalar, hatalı olan taraf: müellif mimar

- Bu değişiklik **Giriş Holü Taşıyıcı Eleman Revizyonu** olsa idi etkisi ne kadar değişirdi?
- Bu değişiklik **Mekanik oda Asma Tavan Revizyonu** olsa idi etkisi ne kadar değişirdi?
- Bu değişiklik **Giriş Holü Asma Tavan İptali** olsa idi etkisi ne kadar değişirdi?
- Bu değişikliğin sebebi **belediye yönetmelik değişiklikleri** olsa idi etkisi ne kadar değişirdi?
- Bu değişikliğe sebep olan kişi **yüklenici** olsa idi etkisi ne kadar değişirdi?

Bu şekilde bir karşılaştırma yaparak aşağıdaki faktörleri 1-10 arası rakamlar ile derecelendiriniz. (1- hiç etkilemez, 10- çok etkiler)

	Proje Değişikliği Tanımı	**Örnek**	**Değerlendirme / 10**
Değişiklik Hakkında Genel Bilgiler	**Değişen Proje Elemanı**	**Asma Tavan, Tefriş, Peyzaj Bitkilendirme, Garaj kapısı, Statik/taşıyıcı elemanlar**	
	Değişiklik yeri	**Tip Daire, Giriş Holü, Mekanik Oda, Sosyal Tesis** (Sosyal Tesis Asma Tavan, Mekanik oda Asma Tavan)	
	Değişiklik Tipi	**Revizyon, iptal, ekleme** (Asma tavan revizyonu, Asma tavan iptali)	
Değişiklik Sebepleri	**Değişikliğe sebep olan faktörler**	Çizimlerdeki hatalar ve eksikler, Belediye Yönetmelik Değişiklikleri, Müşteri talebi, Arazi koşulları, Maliyet azaltma	
	Değişikliğe sebep olan taraf	Müellif Mimar, Yüklenici, Mekanik Danışmanı, Peyzaj Mimarı, İşveren/müşteri, Statik Danışmanı	

Ad Soyad

Figure C.1 Survey for the Definition of the Similarity Measurement Function

APPENDIX D

RESULTS OF THE SURVEY FOR THE DEFINITION OF THE SIMILARITY MEASUREMENT FUNCTION

In this section, the results of the survey for definition of the similarity measurement function are depicted with respect to each respondent.

Table D.1 Results of the Survey with respect to Respondent 1

	Proje Değişkliği Tanımı	**Örnek**	**Değerlendirme / 10**
Değişiklik Hakkında Genel Bilgiler	**Değişen Proje Elemanı**	**Asma Tavan, Tefriş, Peyzaj Bitkilendirme, Garaj kapısı**	**8**
	Değişiklik yeri	**Tip Daire, Giriş Holü, Mekanik Oda, Sosyal Tesis** (Sosyal Tesis Asma Tavan, Mekanik oda Asma Tavan)	**7**
	Değişiklik Tipi	**Revizyon, iptal, ekleme** (Asma tavan revizyonu, Asma tavan iptali)	**5**
Değişiklik Sebepleri	**Değişikliğe sebep olan faktörler**	Çizimlerdeki hatalar ve eksikler, Belediye Yönetmelik Değişiklikleri, Müşteri talebi, Arazi koşulları, Maliyet azaltma	**8**
	Değişikliğe sebep olan taraf	Müellif Mimar, Yüklenici, Mekanik Danışmanı, Peyzaj Mimarı, İşveren/müşteri, Statik Danışmanı	**5**

Table D.2 Results of the Survey with respect to Respondent 2

	Proje Değişkliği Tanımı	**Örnek**	**Değerlendirme / 10**
Değişiklik Hakkında Genel Bilgiler	**Değişen Proje Elemanı**	**Asma Tavan, Tefriş, Peyzaj Bitkilendirme, Garaj kapısı**	**9**
	Değişiklik yeri	**Tip Daire, Giriş Holü, Mekanik Oda, Sosyal Tesis** (Sosyal Tesis Asma Tavan, Mekanik oda Asma Tavan)	**7**
	Değişiklik Tipi	**Revizyon, iptal, ekleme** (Asma tavan revizyonu, Asma tavan iptali)	**6**
Değişiklik Sebepleri	**Değişikliğe sebep olan faktörler**	Çizimlerdeki hatalar ve eksikler, Belediye Yönetmelik Değişiklikleri, Müşteri talebi, Arazi koşulları, Maliyet azaltma	**9**
	Değişikliğe sebep olan taraf	Müellif Mimar, Yüklenici, Mekanik Danışmanı, Peyzaj Mimarı, İşveren/müşteri, Statik Danışmanı	**5**

Table D.3 Results of the Survey with respect to Respondent 3

	Proje Değişkliği Tanımı	**Örnek**	**Değerlendirme / 10**
Değişiklik Hakkında Genel Bilgiler	**Değişen Proje Elemanı**	**Asma Tavan, Tefriş, Peyzaj Bitkilendirme, Garaj kapısı**	**9**
	Değişiklik yeri	**Tip Daire, Giriş Holü, Mekanik Oda, Sosyal Tesis** (Sosyal Tesis Asma Tavan, Mekanik oda Asma Tavan)	**6**
	Değişiklik Tipi	**Revizyon, iptal, ekleme** (Asma tavan revizyonu, Asma tavan iptali)	**8**
Değişiklik Sebepleri	**Değişikliğe sebep olan faktörler**	Çizimlerdeki hatalar ve eksikler, Belediye Yönetmelik Değişiklikleri, Müşteri talebi, Arazi koşulları, Maliyet azaltma	**9**
	Değişikliğe sebep olan taraf	Müellif Mimar, Yüklenici, Mekanik Danışmanı, Peyzaj Mimarı, İşveren/müşteri, Statik Danışmanı	**5**

Table D.4 Results of the Survey with respect to Respondent 4

	Proje Değişkliği Tanımı	**Örnek**	**Değerlendirme / 10**
Değişiklik Hakkında Genel Bilgiler	**Değişen Proje Elemanı**	**Asma Tavan, Tefriş, Peyzaj Bitkilendirme, Garaj kapısı**	**8**
	Değişiklik yeri	**Tip Daire, Giriş Holü, Mekanik Oda, Sosyal Tesis** (Sosyal Tesis Asma Tavan, Mekanik oda Asma Tavan)	**4**
	Değişiklik Tipi	**Revizyon, iptal, ekleme** (Asma tavan revizyonu, Asma tavan iptali)	**7**
Değişiklik Sebepleri	**Değişikliğe sebep olan faktörler**	Çizimlerdeki hatalar ve eksikler, Belediye Yönetmelik Değişiklikleri, Müşteri talebi, Arazi koşulları, Maliyet azaltma	**8**
	Değişikliğe sebep olan taraf	Müellif Mimar, Yüklenici, Mekanik Danışmanı, Peyzaj Mimarı, İşveren/müşteri, Statik Danışmanı	**7**

Table D.5 Results of the Survey with respect to Respondent 5

	Proje Değişkliği Tanımı	**Örnek**	**Değerlendirme / 10**
Değişiklik Hakkında Genel Bilgiler	**Değişen Proje Elemanı**	**Asma Tavan, Tefriş, Peyzaj Bitkilendirme, Garaj kapısı**	**9**
	Değişiklik yeri	**Tip Daire, Giriş Holü, Mekanik Oda, Sosyal Tesis** (Sosyal Tesis Asma Tavan, Mekanik oda Asma Tavan)	**7**
	Değişiklik Tipi	**Revizyon, iptal, ekleme** (Asma tavan revizyonu, Asma tavan iptali)	**6**
Değişiklik Sebepleri	**Değişikliğe sebep olan faktörler**	Çizimlerdeki hatalar ve eksikler, Belediye Yönetmelik Değişiklikleri, Müşteri talebi, Arazi koşulları, Maliyet azaltma	**10**
	Değişikliğe sebep olan taraf	Müellif Mimar, Yüklenici, Mekanik Danışmanı, Peyzaj Mimarı, İşveren/müşteri, Statik Danışmanı	**5**

Table D.6 Results of the Survey with respect to Respondent 6

	Proje Değişkliği Tanımı	Örnek	Değerlendirme / 10
Değişiklik Hakkında Genel Bilgiler	**Değişen Proje Elemanı**	**Asma Tavan, Tefriş, Peyzaj Bitkilendirme, Garaj kapısı**	**10**
	Değişiklik yeri	**Tip Daire, Giriş Holü, Mekanik Oda, Sosyal Tesis** (Sosyal Tesis Asma Tavan, Mekanik oda Asma Tavan)	**3**
	Değişiklik Tipi	**Revizyon, iptal, ekleme** (Asma tavan revizyonu, Asma tavan iptali)	**9**
Değişiklik Sebepleri	**Değişikliğe sebep olan faktörler**	Çizimlerdeki hatalar ve eksikler, Belediye Yönetmelik Değişiklikleri, Müşteri talebi, Arazi koşulları, Maliyet azaltma	**8**
	Değişikliğe sebep olan taraf	Müellif Mimar, Yüklenici, Mekanik Danışmanı, Peyzaj Mimarı, İşveren/müşteri, Statik Danışmanı	**4**

Table D.7 Final Results of the Survey

Değişen Proje Elemanı	**9**
Değişiklik yeri	**6**
Değişiklik Tipi	**7**
Değişikliğe sebep olan faktörler	**9**
Değişikliğe sebep olan taraf	**5**

APPENDIX E

LOCAL SIMILARITY FUNCTIONS IN THE CBR MODEL

In this section, local similarity functions in the CBR model are depicted. As mentioned previously, all of the features in the model have a local similarity function. Similarity functions of the features such as type of change and source party is shown in the Chapter 4. Local similarity functions of location of change, project element and reason of change are depicted here. All of these functions are formulated by using Taxonomy Editor in the MyCBR Tool.

- 1.2. Change Location [0.0]
  - 13-13 00 00 Void Areas [0.5]
    - 13-13 13 00 Air Shaft [1.0]
    - 13-13 11 00 Light Well [1.0]
  - 13-80 Facade [1.0]
  - 13-61 00 00 Protective Spaces [0.5]
    - 13-61 17 00 Spaces for Protection from Violence [0.5]
      - 13-61 15 00 Spaces for Protection from the Elements [1.0]
      - 13-61 15 17 Canopy [1.0]
      - 13-61 15 13 Entry Porch [1.0]
  - 13-33 00 00 Recreation Spaces [0.5]
    - 13-33 17 00 Wellness Spaces [0.5]
      - 13-33 17 11 Fitness Center [1.0]
    - 13-33 15 00 Non-Athletic Recreation Spaces [1.0]
    - 13-33 13 00 Swimming Pools [0.5]
      - 13-33 13 13 Indoor Swimming Pool [1.0]
      - 13-33 13 11 Outdoor Swimming Pool [1.0]
    - 13-33 11 00 Athletic Recreation Spaces [1.0]
  - 13-69 00 00 Building Associated Spaces [0.5]
    - 13-69 21 00 Balcony [1.0]
    - 13-69 11 00 Roof [1.0]
    - 13-69 13 00 Roof Terrace [1.0]
    - 13-69 23 00 Deck [1.0]
  - 13-65 00 00 Private Residential Spaces [0.5]
    - 13-65 13 00 Bathroom [1.0]
    - 13-65 23 00 Kitchen [1.0]
  - 13-90 General [1.0]
  - 13-21 00 00 Parking Spaces [0.5]
    - 13-21 11 00 Exterior Parking Spaces [0.5]
      - 13-21 11 13 Exterior Parking Access Control Point [1.0]
      - 13-21 11 11 Exterior Parking Circulation [1.0]
    - 13-21 13 00 Interior Parking Spaces [0.5]
      - 13-21 13 13 Interior Parking Access Control Point [1.0]
  - 13-63 00 00 Storage Spaces [0.5]
    - 13-63 13 00 Non-Warehouse Storage Spaces [1.0]
    - 13-63 13 11 Storage Room [1.0]
    - 13-63 13 15 Coat Check [1.0]
  - 13-23 00 00 Facility Service Spaces [0.5]
    - 13-23 19 00 Utility Equipment Room [1.0]
    - 13-23 17 00 Restroom [1.0]
    - 13-23 11 00 Vertical Penetration [0.5]
      - 13-23 11 11 17 Elevator Machine Room [1.0]
      - 13-23 11 19 Chimney [1.0]
      - 13-23 11 11 11 Elevator Shaft [1.0]
      - 13-23 11 13 Stairway [1.0]
      - 13-23 11 11 Mechanical Circulation [1.0]
      - 13-23 11 17 Ramp [1.0]
  - 13-25 00 00 Circulation Spaces [0.5]
    - 13-25 13 00 Transitional Circulation Spaces [0.5]
      - 13-25 13 13 Entry Lobby [1.0]
    - 13-25 23 00 Refuge Spaces [1.0]
    - 13-25 17 00 External Circulation Spaces [1.0]
    - 13-25 11 00 Primary Circulation Spaces [0.5]
      - 13-25 11 11 Corridor [1.0]
    - 13-25 15 00 Connector [1.0]

Figure E.1 Local Similarity Function of Location of Change

- 1.3. Project Element [0.0]
  - 21-08 General Plan [1.0]
  - 21-07 10 Site Preparation [0.5]
    - 21-07 10 10 Site Clearing [1.0]
    - 21-07 10 20 Site Elements Demolition [1.0]
  - 21-10 Structural Steel Framing [1.0]
  - 21-07 20 Site Improvements [0.5]
    - 21-07 20 80 Landscaping [0.5]
      - 21-02 20 80 70 Exterior Fabrications [1.0]
      - 21-07 20 80 70 Landscape Lighting [1.0]
      - 21-07 20 80 50 Planting Accessories [1.0]
      - 21-07 20 80 30 Plants [1.0]
    - 21-07 20 10 Roadways [0.5]
      - 21-07 20 10 10 Roadway Pavement [1.0]
    - 21-07 20 30 Pedestrian Plazas and Walkways [0.5]
      - 21-07 20 30 10 Pedestrian Pavement [1.0]
    - 21-07 20 60 Site Development [0.5]
      - 21-07 20 60 10 Exterior Fountains [1.0]
      - 21-07 20 60 25 Site Furnishings [1.0]
      - 21-07 20 60 20 Fences and Gates [1.0]
      - 21-07 20 60 60 Retaining Walls [1.0]
  - 21-02 20 Exterior Vertical Enclosures [0.5]
    - 21-02 20 10 Exterior Walls [0.5]
      - 21-02 20 10 20 Exterior Wall Construction [1.0]
      - 21-02 20 10 40 Fabricated Exterior Wall Assemblies [1.0]
      - 21-02 20 10 10 Exterior Wall Veneer [1.0]
      - 21-02 20 10 50 Parapets [1.0]
    - 21-02 20 80 Exterior Wall Appurtenances [0.5]
      - 21-02 20 80 50 Exterior Balcony Walls and Railings [1.0]
    - 21-02 20 20 Exterior Windows [0.5]
      - 21-02 20 20 40 System Details of Joineries [1.0]
      - 21-02 20 20 30 Exterior Window Wall [1.0]
      - 21-02 20 20 20 Exterior Fixed Windows [1.0]
    - 21-02 20 50 Exterior Doors and Grilles [0.5]
      - 21-02 20 50 10 Exterior Entrance Doors [1.0]
  - 21-04 20 Plumbing [0.5]
    - 21-04 20 30 Building Support Plumbing Systems [0.5]
      - 21-04 20 30 10 Stormwater Drainage Equipment [1.0]
      - 21-04 20 30 20 Stormwater Drainage Piping [1.0]
  - 21-05 20 Furnishings [0.5]
    - 21-05 20 10 Fixed Furnishings [1.0]
    - 21-05 10 30 70 Postal, Packaging, and Shipping Equipment [1.0]
  - 21-03 10 Interior Construction [0.5]
    - 21-03 10 20 Interior Windows [1.0]
    - 21-03 10 10 Interior Partitions [0.5]
      - 21-03 10 10 10 Interior Fixed Partitions [1.0]
    - 21-03 10 70 Suspended Ceiling Construction [1.0]
    - 21-03 10 30 Interior Doors [1.0]
  - 21-02 10 Superstructure [0.5]
    - 21-02 10 20 Roof Construction [0.5]
      - 21-02 10 20 20 Roof Decks, Slabs, and Sheathing [1.0]
      - 21-02 10 20 10 Roof Structural Frame [1.0]
    - 21-02 10 80 Stairs [0.5]
      - 21-02 10 80 60 Fire Escapes [1.0]
      - 21-02 10 80 50 Stair Railings [1.0]
      - 21-02 10 80 10 Stair Construction [1.0]
    - 21-02 10 10 Floor Construction [0.5]
      - 21-02 10 10 30 Balcony Floor Construction [1.0]
      - 21-02 10 10 20 Floor Decks, Slabs, and Toppings [1.0]
  - 21-04 50 Electrical [0.5]
    - 21-04 50 40 Lighting [1.0]
  - 21-04 30 Heating, Ventilation, and Air Conditioning (HVAC) [0.5]
    - 21-04 30 60 Ventilation [1.0]
    - 21-04 30 30 Cooling Systems [1.0]
    - 21-04 30 20 Heating Systems [1.0]
  - 21-01 10 Foundations [0.5]
    - 21-01 10 20 Special Foundations [0.5]
      - 21-01 10 20 40 Foundation Anchors [1.0]
  - 21-01 20 Subgrade Enclosures [0.5]
    - 21-01 20 10 Walls for Subgrade Enclosures [1.0]
  - 21-04 40 Fire Protection [0.5]
    - 21-04 40 10 Fire Suppression [1.0]

Figure E.2 Local Similarity Function of Project Element

- 2.1. Change Reasons [0.0]
  - 4. Characteristics of Design [0.5]
    - 4.3 Low constructability of design [1.0]
    - 4.2 Complexity of project design [1.0]
    - 4.1 Complex interfaces (urban environment, link to existing infrastructure) [1.0]
  - 5. Problems related with governmental issues [0.5]
    - 5.1 Change in governmental regulations/laws [1.0]
    - 5.2 Disagreements between governmental authorities [0.0]
  - 1. Accuracy of Design Documents [0.5]
    - 1.17 Inconsistency between drawings [0.0]
    - 1.9 Design errors made by designers [1.0]
    - 1.15. Citation of inadequate specification [1.0]
    - 1.3 Unclear and Inadequate Details in Drawings [1.0]
    - 1.12. Mistakes and discrepancies in design documents [1.0]
    - 1.11. Failure by the consultant to perform design effectively [1.0]
    - 1.5 Errors and omissions in design documents and defective specifications [0.5]
    - 1.16 Inconsistent with governmental regulations [0.0]
    - 1.1 Errors and omissions in design [1.0]
    - 1.2 Inadequate Shop Drawing Details [1.0]
    - 1.6 Inaccurate design information [1.0]
    - 1.13. Inconsistency between drawings and site conditions [1.0]
    - 1.4 Incomplete/Defective/Poor design drawings, specifications or documents [1.0]
    - 1.10. Outdated designs and specifications [1.0]
    - 1.7 Inaccurate design documentation [1.0]
    - 1.14. Poor design quality – improper/ wrong /impractical design [1.0]
    - 1.8 Poorly executed design drawings [1.0]
  - 2. Changes in Design and Specifications [0.5]
    - 2.2 Change in design [1.0]
    - 2.7 Change orders by deficiency design [1.0]
    - 2.5 Design changes in respond to site conditions [1.0]
    - 2.4 Change in specifications [1.0]
    - 2.6 Design changes due to poor brief, errors and omissions [1.0]
    - 2.3 Change of plan [1.0]
    - 2.1 Change/ modifications in designs [1.0]
  - 3. Design Process [0.5]
    - 3.19 Over-design increasing the overall cost [1.0]
    - 3.6 No practical use of the earned value management system [1.0]
    - 3.4 Involvement of several designers/ foreign designers [1.0]
    - 3.13 Delays in producing design documents [1.0]
    - 3.2 Insufficient material/ Equipment investigation before design [1.0]
    - 3.3 Difficulties in preparation and approval of shop drawings [1.0]
    - 3.7 Lack of standardization in design [1.0]
    - 3.17 Failure on the part of the owner to review and approve design documents, schedules, and material on time [1.0]
    - 3.5 Disagreements on design specifications [1.0]
    - 3.16 Slow preparation and approval of shop drawings by consultant [1.0]
    - 3.12 Long waiting time for approval of drawings [1.0]
    - 3.9 Delays in design information [1.0]
    - 3.8 Non-use of advanced engineering design software [1.0]
    - 3.15 Late in reviewing and approving design documents by consultant [1.0]
    - 3.14 Slow correction of design errors [1.0]
    - 3.10 Late in revising and approving design documents by owner [1.0]
    - 3.18 Problems related to using of building codes in design of projects [1.0]
    - 3.1 Insufficient data collection, survey and site investigation prior to design [1.0]
    - 3.11 Slow drawing revision and distribution [1.0]

Figure E.3 Local Similarity Function of Reasons of Change

APPENDIX F

SAMPLE OF THE SURVEY FOR MEASUREMENT OF THE USABILITY OF THE CBR MODEL

Effectiveness

In this section, the accuracy of the results given by the model will be tested.

1. Which method do you prefer to use as the result of the model?

Method 1 ( ) Method 2 ( )

2. Why did you choose this method? Explain.

Suppose that a project change occurs in your housing project. You have to estimate the possible effects and results of this change such as time effects on project office or site, effects on cost, other changes that can be occurred as a result of this change, occurrence of some conflicts, determination of responsible parties and related contract sections about this issue.

3. In this process, what will be the contribution of using this model to the accuracy of the estimation of the time and cost effects of the project change when comparing with the same process in your current project?

Very Low ( ) Low ( ) Neutral ( ) High ( ) Very High ( )

4. In this process, what will be the contribution of using this model to the accuracy of the estimation of possible effected elements in the building because of the project change when comparing with the same process in your current project?

Very Low ( ) Low ( ) Neutral ( ) High ( ) Very High ( )

5. In this process, what will be the contribution of using this model to the accuracy of the finding related contract information and responsible party of this issue when comparing with the same process in your current project?

Very Low ( ) Low ( ) Neutral ( ) High ( ) Very High ( )

6. In this process, what will be the contribution of using this model to your relationship between other parties such as architect or client when comparing with the same process in your current project?

Very Negative ( ) Negative ( ) Neutral ( ) Positive ( ) Very Positive ( )

7. Suppose that a conflict occurs between architect and yourself after implementation of this change. You have to prepare a claim document or argument for dispute resolution board. What will be the contribution of using this model to the correctness of this document?

Very Low ( ) Low ( ) Neutral ( ) High ( ) Very High ( )

8. Evaluate the sufficiency of the scope of database in the model for finding the exact case.

Very Poor ( ) Poor ( ) Neutral ( ) Good ( ) Very Good ( )

Efficiency

In this section, effect of the model on acceleration of the process of management of project changes will be tested.

9. Suppose that you are in the position of taking a decision about implementation of this project change. What will be the contribution of using this model to your decision making process about when comparing with the same process in your current project?

Excessively slows down ( )

Slightly slows down ( )

No effect ( )

Slightly accelerates ( )

Excessively accelerates ( )

10. In this process, what will be the contribution of using this model to the process of the estimation of the time and cost effects of the project change when comparing with the same process in your current project?

Excessively slows down ( )

Slightly slows down ( )

No effect ( )

Slightly accelerates ( )

Excessively accelerates ( )

11. In this process, what will be the contribution of using this model to the process of the estimation of possible effected elements in the building when comparing with the same process in your current project?

Excessively slows down ( )

Slightly slows down ( )

No effect ( )

Slightly accelerates ( )

Excessively accelerates ( )

12. In this process, what will be the contribution of using this model to the process of the finding related contract information and responsible party of this issue when comparing with the same process in your current project?

Excessively slows down ( )

Slightly slows down ( )

No effect ( )

Slightly accelerates ( )

Excessively accelerates ( )

13. Suppose that a conflict occurs between architect and yourself after implementation of this change. You have to prepare a claim document or argument for dispute resolution board. What will be the contribution of using this model to the process of settlement of this document?

Excessively slows down ( )

Slightly slows down ( )

No effect ( )

Slightly accelerates ( )

Excessively accelerates ( )

14. How do you evaluate the process of using the model?

Very time consuming ( )

Time consuming ( )

Neutral ( )

Practical ( )

Very practical ( )

Satisfaction

In this section, satisfaction of the model in terms of learnability, easiness, adaptability and presentation will be tested.

15. Do you prefer to use the model in your current construction project?

Yes ( ) No ( )

16. How do you evaluate the easiness of the model?

Very Hard ( ) Hard ( ) Medium ( ) Easy ( ) Very Easy ( )

17. What is your satisfaction about the interface of the model?

Very Poor ( ) Poor ( ) Neutral ( ) Good ( ) Very Good ( )

18. What is the adaptability of the model to different kinds of housing projects other than yours?

Not Adaptable ( )

No idea ( )

Adaptable ( )

19. Evaluate the possibility of development of the model. Can the scope of the model such as database be improved with cases from type of projects other than housing?

Very Low ( ) Low ( ) Neutral ( ) High ( ) Very High ( )

20. As the final decision, what is your general satisfaction about the model after you experience it

Very Poor ( ) Poor ( ) Neutral ( ) Good ( ) Very Good ( )