DESIGN PERFORMANCE EVALUATION: A DATA ENVELOPMENT ANALYSIS MODEL

A Thesis Submitted to
the Graduate School of Engineering and Sciences of
İzmir Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in Architecture

by
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July 2015
İZMİR

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ACKNOWLEDGMENTS

I am honored to express my sincere thanks to my supervisor Assist. Prof. Dr. Sevgi Zeynep Doğan for her invaluable knowledge, encouragement, guidance and patience. I am also very thankful to Prof. Dr. Serdar Kale for his support and helpful critics and suggestions throughout the development of this thesis. I would also like to thank other jury members, Assoc. Prof. Dr. Suat GÜNHAN, Assist. Prof. Dr. Yakup EĞERCİOĞLU, Assist. Prof. Dr. Hasan Engin DURAN for their guiding comments, valuable ideas and suggestions. Finally, I am deeply indebted to my family for their endless patience, encouragement and confidence in me.

ABSTRACT

DESIGN PERFORMANCE EVALUATION: A DATA ENVELOPMENT ANALYSIS MODEL

Design performance evaluation has been the center of interest for many social actors since the antique period dating back to Aristoteles and Vitruvius. Numerous performance evaluation models have been developed for assessing design value since then. In this thesis, a Data Envelopment Analysis model is proposed for design performance evaluation in order to support the decision making process of the stakeholders in the built environment. The proposed model is based on the Design Quality Indicator (DQI), Life Cycle Cost Analysis (LCCA) and Data Envelopment Analysis (DEA) methods. DQI is a measure of design quality that measures functionality, build quality and impact assessment of the projects. LCCA is a measure for calculating the life cycle cost (LCC) of the projects. DEA is an efficiency measurement system that depends on the relative performance of the assessed units. In this thesis, a DEA model based on LCCA and DQI is developed for design performance evaluation. LCC values are used as the inputs and DQI values are used as the outputs. Accordingly, the design performance efficiency is conceptualized as the value of design calculated by the ratio of the DQI to the LCC. The developed model is applied to a sample of housing projects in İzmir. Efficient coded design values and relatively inefficient coded design values are determined. Input and output oriented strategies are then developed and discussed for improvement purposes. The proposed model constitutes an effective decision support tool for a thorough evaluation of the design performance of the given projects.

ÖZET

TASARIM BAŞARIM DEĞERLENDİRMESİ: BİR VERİ ZARFLAMA ANALİZ MODELİ

Tasarım başarım değerlendirmesi, Aristoteles ve Vitruvius'a kadar antik çağlardan beri birçok sosyal aktörün ilgi merkezinde olmuştur. Tasarım değerini belirlemek üzere birçok başarım değerlendirme modeli geliştirilmiştir. Bu tezde yapılı çevre paydaşlarının karar verme sürecini desteklemek üzere, tasarım başarım değerlendirilmesi amacıyla bir Veri Zarflama Analizi (VZA) modeli önerilmektedir. Önerilen model tasarım kalite göstergesi (TKG), yaşam döngüsü maliyeti analizi (YDMA) ve veri zarflama analizi (VZA) yöntemlerine dayanmaktadır. TKG, projelerin işlevselliğini, yapım kalitesini ve etki değerini araştıran bir tasarım kalite ölçüsüdür. YDMA, projelerin yaşam döngüsü maliyetini hesaplamak için bir ölçüdür. VZA ise değerlendirilen birimlerin göreceli başarımlarına dayanan bir verimlilik ölçüm sistemidir. Bu tezde, tasarım başarım değerlendirilmesi amacıyla TKG ve YDMA tabanlı VZA modeli geliştirilmiştir. YDM değerleri girdi ve TKG değerleri de çıktı değerleri olarak kullanılmıştır. Buna uygun olarak, tasarım başarım verimliliği de tasarım değeri şeklinde kavramsallaştırılmış ve TKG'nin ve YDM'ye oranı olarak hesaplanmıştır. Geliştirilen model İzmir'deki bir grup konut projesine uygulanmıştır. Verimli kodlanan tasarım başarım değerleri ve göreceli olarak verimsiz kodlanan tasarım başarım değerleri belirlenmiştir. Daha sonra, iyileştirme amaçlı girdi ve çıktı yönelimli stratejiler geliştirilmiş ve tartışılmıştır. Önerilen model, verilen projelerin tasarım başarımının kapsamlı bir şekilde değerlendirilmesi için etkili bir karar destek aracı oluşturmaktadır.

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LIST OF ABBREVIATIONS

BCC	: Banker-Charnes-Cooper
CCR	: Charnes-Cooper-Rhodes
CRS	: Constant Return to Scale
DEA	: Data Envelopment Analysis
DQI	: Design Quality Indicator
IO	: Input Oriented
OO	: Output Oriented
LCC	: Life Cycle Cost
LCCA	: Life Cycle Costing Analysis
VAM	: Value Assessment Methods
VBED	: Value-Based Evaluation of Design
VDPM	: Value-Driven Performance Models
VRS	: Variable Return to Scale

CHAPTER 1

INTRODUCTION

1.1. Problem Statement

Value-based evaluation (VBE) is a concept that has not lost its prevalence and importance from ancient times until the present regarding the built environment. In this ongoing process, the concept of value-based evaluation has undergone significant transformations. These transformations have also enriched the meaning of value for the built environment, which has eventually resulted in an increasing demand for developing value-driven performance models (VDPM). Specifically, in recent years, the literature of the built environment has been abundant with VDPM studies, which assess the design value of buildings. This growing interest in the value-based evaluation of design (VBED) urged the adoption of various performance assessment applications. The initial intent of these applications was to map any value indicator specific to the built environment. Then, the determined value indicators have been used for the development of various VDPM for further assessment and comparison purposes in design, which in turn contributed to the achievement of better performing buildings.

Even though there has been a wide consensus on the value indicators, the data processing methods differed but were mostly still confined to a simple processing level. This limited level of development could be explained by the conservative position of researchers towards the steps to be followed in the processing data. Some researchers argue that using simple methods for the data processing phase is essential for the evaluation. Although the simplicity is a basic principle for any mathematical method, the more simplified the method became, the more information loss occurred during the data processing phase.

Such generalization problems related to value driven performance evaluation models for the built environment constitute the main inputs for setting the objectives of this thesis. Accordingly, the thesis develops an integrated approach for VDPM, which is respectful both of the simplicity principle of mathematical methods and well-suited to a thorough evaluation of design performance. The proposed Data Envelopment Analysis (DEA) model is based on a series of methods: Design Quality Indicator (DQI), Life Cycle Cost Analysis (LCCA) and DEA. An Excel-based questionnaire is developed for defining and measuring the DQI and LCC values for the proposed model. Additionally, a DEA method, based on an Efficiency Measurement System (EMS), is applied to measure design performance efficiency of the eight housing projects. The findings of the model aim to inform the stakeholders of the built environment on how to improve the design quality and the cost performance while simultaneously enhancing the value of design.

1.2. Aim of Study

The main objective of this thesis is to develop a simple and effective design performance model for improving the value of housing projects by assessing both their design quality indicators and life cycle costs. The existing body of knowledge on the concept of best value and value-based evaluation of design is reviewed in the first place. Value and value defining concepts have been examined thoroughly in various disciplines and then specifically in the built environment. The inquiry reveals the relationship between the design value and value driven performance models in the built environment.

Psychology, anthropology, philosophy, manufacturing, customer value management, lean manufacturing, marketing, engineering and economics all focus on the concept of value that could be defined in terms of an evaluation, an assessment or a comparison of the relationship between the quality and the cost properties of the assessed units, which are defined by the concerned individuals (Kluckhohn 1951, Gale and Wood 1994, Slater and Narver 2000, Jahani and El-Gohary 2012, Womack and Jones 1996, Fowler 1990, Zengin and Ada 2010, Dent 1995, Hartman 1967, Rokeach 1973, Schwartz 2012).

The concept of value was firstly mapped as a reference point for a more specific design value. The value of building was firstly investigated by specifying inherent properties of a building (Fasal 1972, Vitruvius 1960), then dwelling on the value of the construction process and finally valuing the design by inquiring into different expectations of the stakeholders (Macmillan 2006a, Gann, Salter, and Whyte 2003, Devine-Wright, Thomson, and Austin 2003, Saxon 2005). Various value assessment methods (i.e., Value Engineering, Value Management and Best Value) and numerous value definitions can be found in the literature to be used to attain a proper design value concept for building projects (Kelly, Male, and Graham 2004, AfsharGhotli and Rezaei 2013, El-Gohary 2010, Scott et al. 2006, Abdelrahman, Zayed, and Elyamany 2008, Zhang 2006). With regard to all these perspectives on the concept of value in the built environment, the value could be explained as the ratio of the outputs, what a stakeholder gives up, and inputs, what a stakeholder gets from processes, products, services, projects etc.

Recent researches focusing on the built environment evaluate both the cost and tangible properties of projects for different life cycle phases of the project. Such evaluations seek the value of design specific to a life-cycle phase (Table 2.6, Table 3.8). However, design value could be described as a quantitative relation of the design quality to the overall cost.

Value based evaluation of design (VBED) aims to assess the design value of buildings by developing value-driven performance models (VDPM) according to some pre-defined indicators, which are based on stakeholder expectations. VDPM are defined as the mathematical models that assess the value by collecting, measuring and analyzing indicators by using simple and practical methods. In recent years, the interest in the concept of value and specifically design value has accelerated studies on VBED (e.g., Preiser 2002, Hartkopf and Loftness 1999, Wong and Jan 2003, Gann, Salter, and Whyte 2003, Pulaski and Horman 2005, Moon, Ha, and Yang 2011, Abdelrahman, Zayed, and Elyamany 2008, Barima 2010, Yu, Wang, and Wang 2012, Kale, İlal, and Ülkeryıldız 2012, Jahani and El-Gohary 2012, Santoyo-Castelazo and Azapagic 2014). Various VDPM have been developed depending on different value indicators (VI) that are collected and measured in different ways.

The proposed VDPM in this thesis aims to (1) interfere with the conservative position of researchers towards the value indicators and evaluation methods for buildings (2) propose a simple mathematical method to assess the design value effectively and (3) improve value by focusing on the expectations of stakeholders. Accordingly, an integrated Data Envelopment Analysis (DEA) model is proposed based on these priorities. The model aims to provide a performance measure based on the relative efficiency of various aspects of design performance. The collected efficiency measurements are used for improving the design quality of housing projects. The proposed model also assists stakeholders to properly evaluate the design value of a selected building. Finally, different strategies are developed and proposed in order to increase the design value of housing projects for promoting stakeholders' expectations.

The proposed DEA performance model is an easy-to-use and helpful decision making tool for the participants of the built environment. The model could be further improved to contribute to various research areas such as design management, quality management and real estate investments.

1.3. Research Methodology

The thesis includes six main phases; (1) an extended literature review on the concept of value (e.g., best value and design value), (2) a detailed literature review of performance models based on value indicators, (3) model development of the value driven performance model (VDPM), (4) VDPM application for housing projects in İzmir, (5) discussion of the results and (6) concluding remarks.

The main objectives of the proposed VDPM are determined by a deductive inquiry based on an extended literature review. The objectives are driven from a thorough analysis of the literature on value concept, value assessment methods, design value, value-based evaluation of design and value-driven performance models. Consequently, in this thesis, the design value of buildings is hypothesized in quantitative terms as the ratio of design quality indicators (DQI) and the life cycle cost (LCC) of buildings. The developed DEA performance model measures design value in a simple and effective way in order to assess design performance of selected buildings and measure their relative efficiency level. The proposed model is developed so that (1) the developers are respectful of the expectations of stakeholders and (2) the model is capable of developing strategies for improving the design value of selected buildings.

The proposed model is based on Design Quality Indicators (DQI), LCCA (Life Cycle Costing Analysis) and Data Envelopment Analysis (DEA) methods. Design Quality Indicator (DQI) is an assessment method that could be considered as a contemporary explanation of "Vitruvian framework" (Gann, Salter, and Whyte 2003).

The main design quality indicators and their sub-indicators are defined as (1) functionality, (1.1) access, (1.2) space, and (1.3) use, (2) build quality, (2.1) performance, (2.2) engineering systems, (2.3) construction and (3) impact (3.1) urban and social integration, (3.2) internal environment, (3.3) form and materials, (3.4) identity and character (Gann, Salter, and Whyte 2003). LCCA is an economic method used for the financial analysis of buildings in the built environment (Gluch and Baumann 2004, Ristimäki et al. 2013). It calculates LCC of buildings which is defined as the sum of initial (capital) cost, operation cost, maintenance and repair cost and demolition cost (Dhillon 2010, Mearig, Coffee, and Morgan 1999). DEA is a simple but effective method for measuring the relative performance efficiency levels of units (e.g., processes, products, services) (Ramanathan 2003). DEA is capable of distinguishing the success level of any unit effectively because of its two main characteristics, which are (1) envelopment surfaces and (2) strategic orientation (McCabe, Tran, and Ramani 2005). These characteristics provide DEA with a wide range of application areas in various fields. In order to test the proposed model, a case study is applied. The selected case study consists of the eight design-built housing projects in İzmir. The questionnaire based on DQI and LCC principles is used to collect the design value indicators and cost values of the housing projects. In data analysis, LCCA is applied to determine the annual LCC of buildings and a seven-point Likert scale is used to determine the DQI. After defining the value indicators quantitatively, Efficiency Measurement System (EMS) is used to analyze the collected indicators for defining relative success levels of selected housing projects and to develop effective strategies for under-performing (e.g., unsuccessful, least rated) projects. Finally, the quantitative results obtained from the model are transformed into qualitative indicators to be used for the development of similar projects.

1.4. Limitation and Assumptions

The model is tested on eight housing projects. According to the rule of thumb of the DEA method, the number of samples is required to be at least twice the sum of the inputs and outputs (Ozbek, de la Garza, and Triantis 2009, Zhu and Cook 2007). In this thesis, the number of samples is adequate for reliable results. Because the DEA method evaluates relative design performance efficiency of the units, increasing the number of samples could affect the determination of the best performing projects and the development strategies for under-performing projects.

The sample type ranges from two to three story luxury housing projects located in İzmir. Different building types could also be evaluated as further research by the developed model.

In this thesis, the samples are assessed solely by the architect who provides only a one-point perspective evaluation. However, a multi-point perspective evaluation, which could be achieved by the contribution of other stakeholders (e.g., sub-contractors, engineers, designers, clients, occupants) could lead to the development of various better strategies by meeting the expectations of a larger portion of the stakeholders. The developed model could also be applied for different life cycle phases of building projects (e.g., pre-design, design, construction, after-sale, bidding) for a more complete performance inquiry. Accordingly, DQI items could also be expanded by considering newly added environmental impact indicators and related cost issues.

1.5. Outline

This thesis consists of six main chapters. The first chapter highlights the problem statement, the aim of the study, the research methodology, and the limitation and assumptions. The second chapter provides a framework for the concept of value in general and specifically in the built environment; and several types of value assessment methods are explained. The third chapter investigates the value-based evaluation of design via value indicators and reviews the value-driven performance models in the built environment literature. In the fourth chapter, a design performance evaluation model is developed by using the Design Quality Indicator (DQI), Life Cycle Cost Analysis (LCCA) and Data Envelopment Analysis (DEA) methods. In the fifth chapter, the developed model is applied and tested on eight housing projects by following three main steps: (1) defining the project features, (2) collecting and measuring the input and outputs of the all projects, and (3) discussing the outcomes. Finally, the sixth chapter involves a brief summary of the general approach of the thesis and its contribution to the literature of the built environment.

CHAPTER 2

A CONCEPTUAL FRAMEWORK FOR THE INQUIRY OF VALUE

This chapter consists of four sections. In the first section, different value definitions in other disciplines and their interaction with the built environment are examined. The second section highlights how value has been defined in the literature of the built environment. In the third section, different types of value assessment methods are explained in the literature of the built environment. Finally, the fourth section investigates how the concept of design value is construed in the built environment. The main objective of this chapter is to understand how design value is defined and assessed in the built environment highlighting the literature review on the concept of value both in other disciplines and in the built environment.

2.1. The Concept of Value

The concept of value is a commonly used term in numerous disciplines such as psychology, anthropology, philosophy, manufacturing, customer value management, lean manufacturing, marketing, engineering and economics (e.g., Kluckhohn 1951, Gale and Wood 1994, Slater and Narver 2000, Jahani and El-Gohary 2012, Womack and Jones 1996, Fowler 1990, Zengin and Ada 2010, Dent 1995, Hartman 1967, Rokeach 1973, Schwartz 2012). Accordingly, several definitions of value and value-related concepts have been described in the literature. For instance, in anthropology, Kluckhohn (1951, 395) refers to the value as “the conception of the desirable, which influences the selection of available modes, means and ends of action”. In customer value management, Gale and Wood (1994, xiv) specify value as “market-perceived product and non-product quality adjusted for the relative price of your product”. Slater and Narver (2000, 120) reveal customer value as “when the benefits to the customer associated with a product or a service exceed the offering’s life-cycle costs to the customer”. In economics, value is introduced as “the worth of a commodity in the market” and in engineering, value refers to “amount or quantity of a measurable phenomenon” (Jahani and El-Gohary 2012, 798). In lean manufacturing, Womack and Jones (1996, 14) indicate the value as “capability provided to customer at the right time at appropriate price as defined in each case by the customer”. In manufacturing, Fowler (1990) indicates value as the ratio of user’s initial impression and satisfaction in use to first cost and follow on costs. In marketing, the value of a product is defined as “maximizing customer satisfaction and minimizing costs” (Zengin and Ada 2010, 5594). Furthermore, in philosophy, Dent (1995) assumes that value is related with three factors: (1) defining types of properties to assess value, (2) how value is assessed (objectively or subjectively), (3) indicating things to define their values. Moreover, in psychology, Rokeach (1973, 5) defines values as “an enduring belief”, Hartman (1967, 39) explains the value as “meaning and richness of properties”, and Schwartz (2012, 3-4) indicates values as “...beliefs...desirable goals...and guide the selection or evaluation of actions, policies, people, and events” (Table 2.1).

According to numerous definitions of value and value-related concepts in the different disciplines, presented in Table 2.1, value is related with the quality, the worth, the capability or properties of objects. Furthermore, they prove that relationship between price and quality, non-price properties, are dependent on values and goals of individuals. Thus, in general, value could be defined from a subjective point of view as an attribution of the judgment and from an objective point of view as the result of an evaluation, an assessment or a comparison of the relationship between “positive and negative consequences, outputs and inputs, beliefs and sacrifices or expenses and benefits”, which consist of quality and cost properties of objects (e.g., products, services, processes), are indicated by values, goals, and the satisfaction of individuals in a specific context (Devine-Wright, Thomson, and Austin 2003, 339).

As a consequence, all mentioned definitions underlie the research on assessing value both theoretically and practically in the built environment because value has also been assessed in a similar manner. For instance, the built environment involves many stakeholders (e.g., designers, architects, engineers, manufacturers, clients, users). Additionally, it realizes products and design solutions for stakeholders and offers commodities. For these reasons, the built environment collaborates with the other disciplines to define the concept of value.

Table 2.1. Value and Values.

Source	Discipline	Definition
Kluckhohn (1951)	anthropology	value is referred as the conception of the desirable which influences the selection of available modes, means and ends of action
Gale and Wood (1994)	customer value management	value is market-perceived product and non-product quality adjusted for the relative price of your product
Slater and Narver (2000)	customer value management	customer value reveals when the benefits to the customer associated with a product or a service exceed the offering's life-cycle costs to the customer
Jahani and El-Gohary (2012)	economics	value is worth of a commodity in the market
Jahani and El-Gohary (2012)	engineering	value is amount or quantity of a measurable phenomenon
Womack and Jones (1996)	lean manufacturing	value is capability provided to customer at the right time at appropriate price as defined in each case by the customer
Fowler (1990)	manufacturing	value is the ratio of user's initial impression and satisfaction in use to first cost and follow on costs"
Zengin and Ada (2010)	marketing	the value of a product is defined as maximizing customer satisfaction and minimizing costs
Dent (1995)	philosophy	value is related with three factors: (1) defining types of properties to assess value, (2) how value is assessed (objectively or subjectively), (3) indicating things to define their values
Hartman (1967)	psychology	value is meaning and richness of properties
Rokeach (1973)	psychology	values are as an enduring belief
Schwartz (2012)	psychology	values are beliefs, desirable goals and guide the selection or evaluation of actions, policies, people, and events

2.2. Mapping Value in the Built Environment

The concept of value is an important research study in the built environment within the fields of construction management and design management. The built environment involves many stakeholders, products and processes within different contexts. In this respect, numerous studies have been done to define and to assess the value from different perspectives since ancient times.

Within the history of the built environment, the concept of value has been affected by different theories, methodologies, methods and phenomena (Table 2.2). Firstly, many studies had been done for specifying properties of buildings. After this, the value of projects has been assessed in the construction process. Finally, in recent years, there has been an increasing demand for the assessment of the design value of buildings.

In ancient times, Aristotle focused on the economic, political, social, aesthetic, ethical, religious, and judicial properties of the buildings to define their value (Fasal 1972). After that, Vitruvius (B.C. 80-70 to B.C. 15) mentioned three indicators: (1) commodity, (2) firmness and (3) delight properties of buildings to indicate their quality (Vitruvius 1960).

Between the 1960s and 1970s, "Architecture and Urban Renewal" neglected the expectations of users on quality-related issues under the movement of "Architectural Determinism" (Macmillan 2006a, Dewulf and van mil 2004). As a reaction, "Architectural Psychology and Sociology" evolved to include the demands of users in the design (Dewulf and van mil 2004). Reflections caused the focus on different methodologies such as "Participatory Planning", "Post Occupancy Evaluation", and "Environmental Psychology" but the lack of communication between design communities and the construction area prevented its practical usage (Dewulf and van Meel 2004).

Between the 1980s and 1990s, the quality of buildings considered the wellness of users under the phenomenon of "Sick Building Syndrome" and "Building Related Illness" (Dewulf and van Meel 2004). Accordingly, quantitative studies increased by including several tangible properties such as air quality, illumination levels and temperature of buildings considering the psychology of the users (Dewulf and van Meel 2004).

Beginning in the 1990s, the focus turned to assessing value by comparing the properties of buildings. In the 1990s, the focus changed from product related issues to construction related issues such as improving performance and assessing tangible properties and the cost of construction processes (Macmillan 2006a). According to Macmillan (2006a, 259), Latham (1994) and Egan (1998) Reports supported this idea and led to many studies on "greater efficiency, the elimination of waste, reduced cost, on-time delivery, improved health and safety, improved collaborative working arrangements, supply chain management, and the exploitation of information and communication technologies". Then, "Key Performance Indicator" (KPI) was developed to improve construction processes (Gann, Salter, and Whyte 2003).

After focusing on comparing properties of construction processes to assess their value, at the end of 1990, there was a reaction to the absence of assessing the design value of products in the built environment. Firstly, the reaction occurred in reply to

Latham and Egan Reports because they did not include product properties in their expressions (Macmillan 2006a). Many organizations in the UK such as The Royal Institute of British Architects (RIBA), The Construction Research and Innovation Strategy Panel (CRISP), The Construction Industry Council (CIC), The Royal Academy of Engineering (RAEng), and the Commission for Architecture and the Built Environment (CABE) have published many papers proposing several models for evaluating all product-related aspects of the built environment (Macmillan 2006a). "Housing Quality Indicator" (HQI) and "Design Quality Indicator" (DQI) have been developed to assess design quality of buildings and "Whole Life Costing" and "1:5:200 ratio" concepts have been highlighted for well-designed buildings (Gann, Salter, and Whyte 2003).

Beginning with the 21st century Egan Report, which has been republished for assessing value including product qualities within the title of "Accelerating Change" by the Strategic Forum for Construction (2002), the new approach of the built environment on the concept of value has been highlighted as; "... realise maximum value for all clients, end users and stakeholders... exploit the economic and social value of good design to improve both the functionality and enjoyment for its end users…" (Macmillan 2006a, Devine-Wright, Thomson, and Austin 2003, 42). In addition to developments on defining concept of value in the built environment, CABE defines six types of value that a building should involve; (1) exchange value, which is considered as commercial value to measure how much the customers want to pay, (2) use value, which focuses on the purpose of products that are valued by their organizations, (3) image value, which deals with the visual impression of the product in order to raise the profile of the organization, (4) social value, which focuses on both communication of a building with its surrounding buildings and the affect of a building to the interaction of people, (5) environmental value, which investigates the measurable qualities of the building regarding environmental and cost related aspects and (6) cultural value, which investigates the contribution of a product to time, the placement in history and connectivity to the past and the future (Macmillan 2006b). Moreover, the different expectations of stakeholders on building projects are defined. For instance, Saxon's model defines six stakeholders, which are the staff, the occupying organization, the consumer, the facility manager, the government and the investor and their value exchange with each other (Saxon 2005).

Table 2.2. Value Perspectives.

Periods	Value Perspectives
Properties of Buildings	
B.C. 384-322	• Aristotle had focused on economical, political, social, aesthetic, ethical, religious, and judicial properties of the building.
B.C. 80, 70-15	• Vitruvius had mentioned about three properties: commodity, firmness and delight properties of buildings
Between the 1960s and 1970s	• Emphasis on User's Demands • Architectural Determinism Theory; ignoring expectations of user • Architectural Psychology and Sociology Theory; as a reaction to Architectural Determinism, highlighting necessity of involving the user's demand • Participatory Planning, Post Occupancy Evaluation, Environmental Psychology Methods; evolving after Architectural Psychology and Sociology Theory • Lack of communication between stakeholders preventing usage of proposed methods
Between the 1980s and 1990s	• Sick Building Syndrome and Building Related Illness Phenomenon; emphasizing on wellness of users • Quantitative studies; focusing on several tangible properties of buildings
Assessment of Value in Construction Processes	
In the 1990s	• Researches on; improving performance by considering properties of process and cost • Key Performance Indicator (KPI) improving construction processes • Latham and Egan Reports
Assessment of Design Value of Buildings	
End of the 1990s	• Reaction on not including product properties, only focusing process • Publications, models, methods proposed by organizations for assessing design value • Housing Quality Indicator (HQI) and Design Quality Indicator (DQI) indicating quality of different types of buildings • Whole Life Costing and 1:5:200 ratio concept are introduced
In the 21st century	• Emphasis on design value for all stakeholders considering whole life cycle of the products • Egan Report have been republished according to reactions in the end of 1990s • Types of value are developed for buildings • Saxon Model defining stakeholder expectations on buildings

However, in modern times, studies on the concept of value have been developed in the disciplines of construction and design management. Numerous studies make different value definitions in the current literature (Table 2.3). For instance, Barima (2010, 200) argues that "...the influence of goals and standards as terms which (if fulfilled) can best explain the meaning of value in construction projects". Gann, Salter, and Whyte (2003, 319) consider it as "the benefits that accrue to users through ideas developed in the design process and then acted on through production". CRISP

Commission 04/13 (2005,11) indicates that "value is a focus on outcomes (what you get) that are often termed benefits, in addition to a broader view of inputs (what you give) than costs". Saxon (2005, 7) explains that "value is the balance between what you get and what you give. Positive value exists for any player when they get more in their own terms than they must give up...". CABE (2001, 1) considers both objective and subjective views and defines value as "a measure of worth of something to its owner or any person who derives benefit from it, this being the amount at which it can be exchanged". Burt (1978) assumes that "maximum value is obtained from a required level of quality at least cost, the highest level of quality for a given cost, or from an optimum compromise between the two". Thomson et al. (2003, 339) explain that "value does not exist it is own right, but is an assessment of an object; this assessment occurs in a context and is framed by characteristics of that context and value assessment can be subjective when framed against an individual's values, or objective when the relationship between benefit and expense is compared". Dell'Isola (1997) defines value as "the ratio of function and quality to cost".

How value is defined is important in order to assess the value of buildings in the built environment. Definitions of the concept of value in the built environment and in other disciplines are relevant. For instance, in the built environment, the value is also considered as the result of an assessment of the properties of projects according to the values and expectations of stakeholders. After considering the below definitions (Table 2.3), generally, the value could be defined as the result of an assessment that is the ratio of outputs, what stakeholders get from projects, processes, products, services, etc. and inputs, or what stakeholders give up to get them. The outputs consist of the tangible and intangible quality properties of the projects. The inputs consist of the costs of projects. Considering this definition, it is important to investigate different approaches of value assessment methods that are developed for defining the value of projects in the built environment.

Table 2.3. Definitions of Value.

Source	**Definitions**
Barima (2010)	...the influence of goals and standards as terms which (if fulfilled) can best explain the meaning of value in construction projects
Gann, Salter, and Whyte (2003)	Value is meant the benefits that accrue to users through ideas developed in the design process and then acted on through production
CRISP Commission 04/13 (2005)	Value is a focus on outcomes (what you get) that are often termed benefits, in addition to a broader view of inputs (what you give) than costs
Saxon (2005)	Value is the balance between what you get and what you give. Positive value exists for any player when they get more in their own terms than they must give up
CABE (2001)	Value is a measure of worth of something to its owner or any person who derives benefit from it, this being the amount at which it can be exchanged (both objective and subjective view in construction)
Burt (1978)	Maximum value is obtained from a required level of quality at least cost, the highest level of quality for a given cost, or from an optimum compromise between the two
Thomson et al. (2003)	Value does not exist, it is own right, but is an assessment of an object. This assessment occurs in a context and is framed by characteristics of that context. Value assessment can be subjective when framed against an individual's values or objective when the relationship between benefit and expense is compared
Dell'Isola (1997)	Value is the ratio of function and quality to cost

2.3. Types of Value Assessment Methods

Numerous value assessment methods (VAM) have been established according to developments on the concept of value in the built environment. Some of the prominent VAM in the literature of the built environment are Value Analysis/Engineering, Value Management (VM), and Best Value (BV). Each VAM has been defined according to its approach to the concept of value (Table 2.4Table 2.4). Firstly, Value Engineering (VE) is explained by different researchers. For instance, Kelly, Male, and Graham (2004, 12) indicate VE as "an organized approach to the identification and elimination of unnecessary cost". AfsharGhotli and Rezaei (2013, 84) suggest that VE is "a hard system method in terms of cost reduction, which is carried out during the design phase (where hard information in terms of technical solutions, drawings, specifications, etc. already exists)". According to El-Gohary (2010, 1), VE is "to accomplish the essential functions at the lowest total cost, consistent with the required levels of performance and quality". Secondly, Value Management is described by Kelly, Male, and Graham (2004, ix) as "the name given to a process in which the functional benefits of a project are made explicit and appraised consistent with a value system determined by the client, customer or other stakeholders". Best Value is also explained by different researchers. For instance, Scott et al. (2006, 73) define BV as "a procurement process where price and other key factors are considered in the evaluation and selection process to minimize impacts and enhance the long-term performance and value of construction". Abdelrahman, Zayed, and Elyamany (2008, 179) say that BV "aims at enhancing the long-term performance through selecting the contractor with the offer most advantageous to the owner where price and other selection factors are considered". Zhang (2006, 108) indicates BV as "it aims to maximize the outcome of a business transaction. It emphasizes efficiency, value for money, and performance standards".

Although there are numerous definitions of different value assessment methods (VAM), the scope of how value is assessed is similar. Generally, in the built environment, the developed VAM assess the value of projects by evaluating costs and other properties of the building projects. Besides, it is also essential to investigate methodological frameworks of VAM for understanding why numerous value definitions have been evolved and to get a more generalized definition of the value of the built environment.

Table 2.4. Value Assessment Methods (VAM).

Source	VAM	Definitions
Kelly, Male, and Graham (2004)	Value Analysis/ Engineering	VE is an organized approach to the identification and elimination of unnecessary cost
AfsharGhotli and Rezaei (2013)	Value Analysis/ Engineering	VE is suggested as a hard system method in terms of cost reduction which is carried out during the design phase (where hard information in terms of technical solutions, drawings, specifications, etc. already exist)
El-Gohary (2010)	Value Analysis/ Engineering	VE is to accomplish the essential functions at the lowest total cost, consistent with the required levels of performance and quality
Kelly, Male, and Graham (2004)	Value Management	VM is the name given to a process in which the functional benefits of a project are made explicit and appraised consistent with a value system determined by the client, customer or other stakeholders
Scott et al. (2006)	Best Value	BV is a procurement process where price and other key factors are considered in the evaluation and selection process to enhance the long-term performance and value of construction
Abdelrahman, Zayed, and Elyamany (2008)	Best Value	BV aims at enhancing the long-term performance through selecting the contractor with the offer most advantageous to the owner where price and other selection factors are considered
Zhang (2006)	Best Value	BV approach aims to maximize the outcome of a business transaction. It emphasizes efficiency, value for money, and performance standards

In general, a value assessment method could be defined according to three main factors: (1) units of analysis, (2) assessors and (3) objectives of the value assessment. Firstly, the factor of units of analysis determines limitations of VAM and defines the types of units according to their properties. Moreover, it also determines the context to focus on during the assessment. Secondly, the factor of assessors indicates who assesses the value considering their specific expectations, values, goals etc. Finally, the value assessment objectives underline the aim of value assessment methods to indicate the value of units. In the literature of the built environment, numerous combinations of the three factors have been highlighted to define different types of VAM.

Firstly, units of analysis are defined according to three sub-factors; (1) types of unit, (2) types of properties of the units that constitute indicators of the assessment and (3) contexts. In terms of the first sub-factor, different units are defined to assess their value. Types of units in the literature of the built environment are projects, products, processes, systems, technical solutions, drawings, specifications, constructions, facilities, equipment, supplies etc. (Table 2.5, Table 2.6). Furthermore, in value assessments, types of units are compared according to different properties of units. For instance, in the literature of the built environment, different properties of units are defined and compared, which are function with cost (Kelly, Male, and Graham 2004), hard information with cost (AfsharGhotli and Rezaei 2013), price with other key factors (Scott et al. 2006), operational and maintenance properties with cost (Fowler 1990), cost, time, qualification and performance, quality, design alternates (Abdelrahman, Zayed, and Elyamany 2008), cost with performance, quality and safety (Dell'Isola 1998), things that each stakeholder gets and what each stakeholder gives up (CRISP Commission 04/13 2005), aesthetics, quality and economics (Macmillan 2006a), functionality, appearance, longevity, robustness, ergonomics, adaptability (Gann, Salter, and Whyte 2003), time, image, aesthetics/appearance, operation, maintenance, managerial safety, and environmental aspects (Gransberg and Ellicott 1997).

In terms of the third sub-factor of the unit of analysis, different contexts are selected for assessing the value of units (Table 2.6). Some contexts that are chosen to assess the value of projects such as procurement (Scott et al. 2006), selection and evaluation (Akintoye et al. 2003), the design phase (AfsharGhotli and Rezaei 2013), the planning and design (Levitt 2007), all areas of construction; design, health and safety, productivity (Devine-Wright, Thomson, and Austin 2003) project delivery and whole life cycle phases of building projects (Zhang and El-Gohary 2014, Lu, Cui, and Le 2012).

Table 2.5. Types of Units and Properties.

Source	Type of Unit	Type of Properties
Kelly, Male, and Graham (2004)	projects products processes systems	function cost
AfsharGhotli and Rezaei (2013)	technical solutions drawings specifications	hard information cost
Scott et al. (2006)	construction	price other key factors
Fowler (1990)	facility	operational properties maintenance properties cost
Abdelrahman, Zayed, and Elyamany (2008)	project	cost time qualification and performance quality design alternates
Dell'Isola (1998)	system equipment facility service supply	cost performance quality safety
Gann, Salter, and Whyte (2003)	product	functionality appearance longevity robustness ergonomics adaptability
Macmillan (2006a)	product service	aesthetics quality economics
CRISP Commission 04/13 (2005), Saxon (2005)	project	what each stakeholder gets what each stakeholder give up
Gransberg and Ellicott (1997)	process	time image aesthetics/appearance operation maintenance managerial safety environmental aspects

Table 2.6. Contexts.

Source	Contexts
Scott et al. (2006), Akintoye et al. (2003)	procurement selection evaluation
AfsharGhotli and Rezaei (2013)	design phase
Levitt (2007)	building project planning and design
Zhang and El-Gohary (2014)	project delivery whole life cycle phases of building projects
Lu, Cui, and Le (2012)	planning design construction operations and maintenance reconstruction deconstruction
Devine-Wright, Thomson, and Austin (2003)	all areas of construction; design health and safety productivity

With respect to the second factor, assessors evaluate the value of units according to their different expectations, values and goals. They also indicate the objectives of value assessment. In general, in the built environment, the assessors of value assessment could be stakeholders such as architects, engineers, contractors, sub-contractors, clients, users, organizations etc.

With respect to the third factor, objectives define the aim of value assessment methods. Numerous objectives in the built environment are defined as “providing the necessary functions at the lowest cost” (Kelly, Male, and Graham 2004, 12), “maximizing economic, environmental, and societal value of the built environment” (Levitt 2007, 619), “enhancing long term performance” (Abdelrahman, Zayed, and Elyamany 2008, 179), “going beyond least cost to encompass a combination of customer satisfaction, productivity, safety, value for money” (Devine-Wright, Thomson, and Austin 2003, 42), “for long term cost and performance decisions” (CRISP Commission 04/13 2005, 11), “emphasizing efficiency, value for money and exact quantitative performance standards” (Akintoye et al. 2003, 463) (Table 2.7).

Table 2.7. Objectives of VAM.

Source	**Objectives**
Kelly, Male, and Graham (2004)	providing the necessary functions at the lowest cost
Levitt (2007)	maximizing economic, environmental, and societal value of the built environment
Abdelrahman, Zayed, and Elyamany (2008)	enhancing long term performance
Devine-Wright, Thomson, and Austin (2003)	going beyond least cost to encompass a combination of customer satisfaction, productivity, safety, value for money
CRISP Commission 04/13 (2005)	for long term cost and performance decisions"
Akintoye et al. (2003)	emphasizing efficiency, value for money and exact quantitative performance standards

As a result, after investigating factors to define approaches of VAM in the built environment, it is possible to make a more generalized value definition. Thus, in the built environment, the concept of value could be defined as a result of an assessment that is a quantitative relation of quality properties of units, what stakeholders expect to get from units, cost properties of units, and what stakeholders give up, in a specific context. Until now, defining the concept of value has been investigated by many researchers in the different contexts of the built environment. However, there is an increased demand for valuing the design of buildings in recent studies.

2.4. Valuing Design

Since the 1990s, the value has been assessed implicitly by defining the relationship between cost and other tangible properties of the processes of construction, whereas quality of products, which is non-cost tangible and intangible properties, have been considered later or have not been considered during decisions on how to build (Devine-Wright, Thomson, and Austin 2003, Gambatese and Dunston 2003, Gann, Salter, and Whyte 2003). In general, different models and methods that have been developed in the literature of the built environment (e.g., Life Cycle Cost Analysis (LCCA), Value Engineering (VE) and Value Management (VM)) to assess the value in an objective way such as the ratio of cost and other tangible properties of buildings, processes, services, etc. It is the fact that the architecture and construction cannot be considered separately from economics, which also constitute an essential property (cost property) of the building to assess its value (Loe 2000, Saxon 2005). However, the emphasis on the construction processes only and the approach of "value for money" in the construction industry weakens the value of design by creating unappealing buildings by restricting the value to two dimensions, which are process improvement and cost minimization (Devine-Wright, Thomson, and Austin 2003, Spencer and Winch 2002, Gann, Salter, and Whyte 2003). Consequently, two dimensional value definitions ignore the expectations and values of stakeholders to indicate the quality of buildings (Devine-Wright, Thomson, and Austin 2003) whereas the built environment is a multi-dimensional context, which intersects many stakeholders and products in different contexts (Winch, Courtney, and Allen 2010). Thus, from a more extended point of view, the values of stakeholders and quality of buildings add new dimensions to the concept of value and enable researchers to understand the concept of design value (Gann, Salter, and Whyte 2003, Devine-Wright, Thomson, and Austin 2003).

As a result, it is also essential for valuing the design of buildings to consider the values of each stakeholder, comparing tangible and intangible properties with cost property of buildings in both objective and subjective manners (Barima 2010, CRISP Commission 04/13 2005, El-Gohary 2010, Devine-Wright, Thomson, and Austin 2003). In this respect, the design value is not a concept separate from the concept of value in terms of its meaning. Accordingly, the design value could be defined as the result of a value-based evaluation of design, which indicates a quantitative relation of the design quality (non-cost properties) of buildings that stakeholders expect to get from buildings and cost property of buildings that stakeholders give up in a specific context. In the literature of the built environment, numerous value-driven performance models have been implemented to define this quantitative relationship for assessing value and design value. Different approaches to value-based evaluations of design have also been developed for valuing design of buildings in the literature of the built environment.

CHAPTER 3

THE VALUE-BASED EVALUATION OF DESIGN

Developing studies on valuing design in the literature of the built environment also increase the level of interest in the value-based evaluation of design (VBED). VBED is an important research area in both theoretical and practical studies to assess and define the design value of buildings in the built environment. Generally, VBED aims to measure the design value of buildings according to pre-defined indicators to assess their success with respect to the expectations of stakeholders by developing value-driven performance models (VDPM) (Yavuz, Doğan, and Kale 2014). VDPM are developed for value based evaluation (VBE) because performance evaluation models quantify efficiency and effectiveness of projects according to performances of projects by highlighting the important issues considering the different expectations of the stakeholders (Waggoner, Neely, and P. Kennerley 1999, Neely 1999).

In recent years, the interest in the concept of value has increased the number of VBED studies in the built environment (e.g., Preiser 2002, Hartkopf and Loftness 1999, Wong and Jan 2003, Gann, Salter, and Whyte 2003, Pulaski and Horman 2005, Moon, Ha, and Yang 2011, Abdelrahman, Zayed, and Elyamany 2008, Barima 2010, Yu, Wang, and Wang 2012, Kale, İlal, and Ülkeryıldız 2012, Jahani and El-Gohary 2012, Santoyo-Castelazo and Azapagic 2014 etc.). Additionally, the interest results in an agreement on the value indicators that consist of the tangible and intangible properties of buildings. Moreover, it leads to a search for comparable results that help to achieve efficient architectural design products (Kale, İlal, and Ülkeryıldız 2012). However, this agreement is not achieved on the measurement of value indicators. Generally, studies of value-based evaluation (VBE) focus on the objective measurements of construction processes considering tangible properties of processes (time, cost, and waste etc.) rather than measuring the quality of buildings within both objective and subjective measurements (Gann, Salter, and Whyte 2003). As a result, it ends up with value-lost buildings for their stakeholders (Gann, Salter, and Whyte 2003). This situation causes information lost, which results with less stakeholder satisfaction, low quality products and unrestrained economical decisions. Different VBE approaches occur because different value indicators are measured by different value-driven performance models (VDPM) in different contexts to assess the value of buildings. Accordingly, numerous VDPM are developed to evaluate the design value of buildings in the literature of the built environment.

In conclusion, this chapter aims to define approaches of VBED in the literature of the built environment and consists of two main sections. In the first section, types of VBED are classified according to their types of value indicators, which are (1) iconic indicators, (2) cost indicators, (3) environmental impact indicators and (4) hybrid indicators. In the second section, different developed VDPM are investigated according to their approaches on (1) the collection and measuring of value indicators, (2) the analysis of value indicators.

3.1. The Value Indicators

In the literature of the built environment, value driven performance models evaluate the value of buildings according to pre-defined value indicators. Generally, the value indicators consist of the properties of buildings. These properties are classified as tangible, measurable and physical, and intangible. However VDPM define different types of value indicators with respect to different properties. In the literature of the built environment, four types of value indicators are defined and measured in VDPM. These indicators are (1) iconic, (2) cost, (3) environmental impact, (4) hybrid value indicators.

Firstly, iconic indicators are defined according to sociological and psychological attributes of stakeholders to evaluate design quality of buildings. Particularly, the symbolic and aesthetical properties of architectural designs are evaluated within a subjective and nonanalytic approach (Sklair 2010). Generally, the indicators that define the success level of buildings could be classified as receiving an award on a national or international scale, having affirmative comments in electronic and printed media etc. (Yavuz, Doğan, and Kale 2014).

Secondly, because buildings go through costly processes, the cost of buildings directly affects the design value. Accordingly, cost indicators are defined according to different types of costs that occur in different life cycle phases. For example, Life Cycle Cost Analysis (LCCA) is a method used in economics and is preferred to evaluate the performance of buildings considering their non-repeated initial costs and repeated costs such as operating, maintenance and repair costs (Fuller and Petersen 1996). Moreover, in the literature of the built environment, several researchers focus on different cost indicators in their VDPM (Table 3.1). For instance, Gluch and Baumann (2004) study LLCA and propose ten Life Cycle Cost (LCC) oriented environmental accounting tools indicating several life cycle costs. However, they collected them under three main sources of data to analyze LCC of a building; (1) investment costs, (2) operating and maintenance data and (3) building specific data (Gluch and Baumann 2004). Secondly, Ristimäki et al. (2013) study life cycle green cost of buildings in their hybrid model by studying both LCCA and carbon emissions in a Life Cycle Assessment model. The indicators that are defined in their studies are (1) investment cost data, (2) local energy costs, (3) maintenance costs, (4) other life cycle costs and (5) economic parameters.

Table 3.1. Cost Indicators.

Source	**Cost Indicators**
Gluch and Baumann (2004)	investment costs
	operating and maintenance data building specific data
Ristimäki et al. (2013)	investment cost data
	local energy costs
	maintenance costs
	other life cycle costs
	economic parameters

The preceding studies that are indicated in the Table 3.1 show that a building has different types of cost indicators to measure its cost performance. Considering all cost indicators is important to get realistic results from the VBED.

Thirdly, environmental impact indicators generally focus on tangible properties of buildings to evaluate their energy efficiency and sustainability within an objective measurement. In the literature of the built environment, there are numerous VDPM focusing on environmental impact indicators in different national scales such as; Leadership in Energy and Environmental Design (LEED) - the U.S.A, Building Research Establishment Environmental Assessment Method (BREAM) - The United Kingdom, Comprehensive Assessment System for Building Environmental Efficiency

(CASBEE) - Japan, Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) - Germany, ÇEDBİK - Turkey etc. For instance, LEED focuses on six indicators, which are (1) sustainable sites, (2) water efficiency, (3) energy and atmosphere, (4) materials and resources, (5) indoor air quality, (6) innovation and design. BREAM proposes nine indicators for assessment of any type of building such as; (1) management, (2) health and well-being, (3) energy, (4) transportation, (5) water, (6) material, (7) waste, (8) pollution and (9) land use and ecology. CASBEE deals with (1) indoor environment, (2) service quality, (3) outdoor environment on site, (4) energy, (5) resources and materials and (6) off-site environment (Beydilli 2010). DGNB highlights five indicators consisting of (1) technical quality, (2) process quality, (3) environmental quality, (4) sociocultural and functional quality, (5) economic quality (DGNB 2013). Besides national models, Santoyo and Azapagic (2014) mention 17 sustainable indicators consisting of ten environmental, three economic and four social sustainability indicators in their hybrid Life Cycle Assessment (LCA) model (Table 3.2).

As indicated in Table 3.2, environmental impact indicators focus on physical and measurable properties of buildings to assess their design value. However, environmental impact indicators could be extended to include different indicators that consist of intangible properties of buildings.

Table 3.2. Environmental Impact Indicators.

VDPM	Environmental Impact Indicators
LEED	sustainable sites
	water efficiency
	energy and atmosphere
	materials and resources
	indoor air quality
	innovation and design
BREAM	management
	health and well-being
	energy
	transportation
	water
	material
	waste
	pollution
	land use and ecology
CASBEE	indoor environment
	service quality
	outdoor environment on site
	energy
	resources and materials
	off-site environment
DGNB	technical quality
	process quality
	environmental quality
	sociocultural and functional quality
	economic quality
Santoyo and Azapagic (2014)	environmental sustainability
	economic sustainability
	social sustainability

Fourthly, hybrid value indicators focus on intangible properties as well as cost and other tangible properties of buildings for assessing their value. Accordingly, they could be classified under three sub-categories. The first sub-category of hybrid value indicators focuses on quality, which includes both tangible and intangible properties except for the cost of buildings. The second sub-category of hybrid value indicators focuses on the cost and other tangible properties of buildings. Finally, the third sub-category of hybrid value indicators focuses on both the quality and the cost of buildings.

In the literature of the built environment, VDPM that focus on the first sub-category of hybrid value indicators (quality properties) include Post Occupancy Evaluation (POE) (Preiser 2002), Design Quality Indicator (DQI) (Gann, Salter, and Whyte 2003), Housing Performance Evaluation (Kim et al. 2005) and Total Building Performance (Hartkopf and Loftness 1999, Wong and Jan 2003, Oyedele et al. 2012). For instance, Preiser (2002) evaluates the design performance on ten indicators, which are (1) comfort conditions, (2) functionality, (3) spatial quality, (4) health conditions, (5) security requirements, (6) safety conditions, (7) social impacts, (8) psychological effects, (9) cultural influences, (10) aesthetic qualities. Gann, Salter, and Whyte (2003) evaluate the design performance of a building on three main aspects; (1) functionality, (2) built quality, (3) impact. Kim et al. (2005) focus on three main indicators; (1) house environment, (2) function and (3) comfort. Hartkopf and Loftness (1999), Wong and Jan (2003) and Oyedele et al. (2012) evaluate the design performance of the building focusing on six indicators, which are (1) acoustic, (2) spatial, (3) thermal, (4) visual/lighting, (5) indoor air quality, (6) building integrity (Table 3.3) However there are numerous VDPM to evaluate quality indicators of buildings without considering cost property of buildings. It is not enough to evaluate the value-driven performance of a building objectively to assess its value.

Table 3.3. Quality Properties.

Source	VDPM	Value Indicators based on Quality Properties
Preiser (2002)	Post Occupancy Evaluation (POE)	comfort conditions functionality spatial quality health conditions security requirements safety conditions social impacts psychological effects cultural influences aesthetic qualities
Gann, Salter, and Whyte (2003)	Design Quality Indicator	functionality built quality impact
Kim et al. (2005)	Housing Performance Evaluation	house environment function comfort
Hartkopf and Loftness (1999) Wong and Jan (2003) Oyedele et al. (2012)	Total Building Performance	acoustic spatial thermal visual/lighting indoor air quality building integrity

VDPM that focus on the second sub-category of hybrid value indicators, which consist of the cost and other tangible properties of buildings include Bishop Model (Bishop 1978), Sustainable Value Engineering (Pulaski and Horman 2005), Green Building Assessment Tool (Ali and Al Nsairat 2009), Value Engineering (VE) (Cariaga, El-Diraby, and Osman 2007, Marzouk 2011, Moon, Ha, and Yang 2011), Life Cycle Management (Ristimäki et al. 2013), and Life Cycle Assessment Analysis (LCAA)

(Santoyo-Castelazo and Azapagic, 2014). Bishop (1978) introduces three indicators for the design performance evaluation, which are (1) functionality, (2) form and (3) economy. Pulaski and Horman (2005) evaluate the design performance on eight indicators: (1) cost, (2) quality, (3) schedule process, (4) efficiency, (5) health and safety, (6) maintainability, (7) resource use, (8) LEED credibility. Ali and Al Nsairat (2009) define seven indicators for the design performance evaluation: (1) site, (2) energy efficiency, (3) water efficiency, (4) material, (5) indoor environment quality, (6) waste and pollution, (7) cost and economic. Marzouk (2011) and Moon, Ha, and Yang (2011) consider three main indicators for performance evaluation: (1) functionality, (2) quality, (3) cost. Ristimäki et al. (2013) focus on (1) life cycle costs and (2) carbon emissions to calculate the green cost of buildings. Santoyo-Castelazo and Azapagic (2014) introduce three main indicators for design performance evaluation: (1) energy, (2) sustainability, (3) cost with several sub-environmental indicators under the whole life cycle of building such as global warming (GWP), abiotic depletion (ADP), acidification (AP), eutrophication (EP), freshwater aquatic ecotoxicity (FAETP), human toxicity (HTP), marine aquatic ecotoxicity (MAETP), ozone depletion (ODP), photochemical ozone creation (POCP) or summer smog and terrestrial ecotoxicity (TETP) (Table 3.4).

Table 3.4 indicates the studies that highlight tangible properties of buildings whereas it does not include intangible properties, which are defined by socio-psychological attributes and values of stakeholders (Dewulf and van Meel 2004). However, a building should also be considered with its intangible properties. In the literature of the built environment, there are studies that focus on both tangible and intangible properties of buildings.

Table 3.4. Cost and Other Tangible Properties.

Source	VDPM	Value Indicators based on Cost and Tangible Properties
Bishop (1978)	Bishop Model	functionality form economy
Pulaski and Horman (2005)	Sustainable Value Engineering	cost quality schedule process efficiency health and safety maintainability resource use LEED credibility
Ali and Al Nsairat (2009)	Green Building Assessment Tool	site energy efficiency water efficiency material indoor environment quality waste and pollution cost and economic
Marzouk (2011)	Value Engineering	functionality quality cost
Moon, Ha, and Yang (2011)	Value Engineering	economic efficiency safety durability functionality work efficiency
Ristimäki et al. (2013)	Life Cycle Management	energy design options life cycle costs
Santoyo-Castelazo and Azapagic (2014)	Life Cycle Assessment	energy sustainability cost

VDPM, which focus on the third sub-category of hybrid value indicators based on both cost and quality properties of buildings are Value Engineering (Cariaga, El-Diraby, and Osman 2007), Best Value Methodology (Abdelrahman, Zayed, and Elyamany 2008, Yu, Wang, and Wang 2012), Balance Scorecard Methodology (Wong, Lam, and Chan 2009), and Entropy Based Model (Kale, İlal, and Ülkeryıldız 2012). Cariaga, El-Diraby, and Osman (2007) propose seven indicators, which are (1) provide smartness, (2) attract new students, (3) offer aesthetics, (4) conserve energy, (5) maintain flexibility, (6) provide comfortable space, and (7) cost of five building components. Abdelrahman, Zayed, and Elyamany (2008) study (1) cost, (2) time, (3) qualification and performance, (4) quality and (5) design alternates, Yu, Wang, and Wang (2012) focus on two main indicators: (1) cost, (2) quality. Wong, Lam, and Chan (2009) evaluate four indicators for design performance evaluation: (1) aesthetics, (2) functionality, (3) buildability, (4) economics. Kale, İlal, and Ülkeryıldız (2012) focus on four main indicators: (1) functionality, (2) build quality, (3) impact and (4) life cycle costs for evaluating design performance (Table 3.5).

Table 3.5 indicates that although different properties of buildings are selected the purpose of all VDPM is the same; the assessment of the value of buildings by pre-defined value indicators.

In conclusion, according to the literature review on types of value indicators, it could be said that VDPM, which focus on the third sub-category of hybrid value indicators, aim to evaluate the value-driven performance of buildings in a more proper way because they could evaluate different aspects of buildings including both their tangible and intangible properties. However, how value indicators are collected, measured and analyzed also affects the results of VDPM.

Table 3.5. Cost and Quality Properties.

Source	VDPM	Value Indicators based on Both of Cost and Quality
Cariaga, El-Diraby, and Osman (2007)	Value Engineering	provide smartness attract new students offer aesthetics conserve energy maintain flexibility provide comfortable space cost
Wong, Lam, and Chan (2009)	Balance Scorecard Methodology	aesthetics functionality buildabilitty economics
Abdelrahman, Zayed, and Elyamany (2008)	Best Value Methodology	cost time qualification and performance quality design alternates
Yu, Wang, and Wang (2012)	Best Value Methodology	quality price
Kale, İlal, and Ülkeryıldız (2012)	Entropy Based Model	functionality build quality impact life cycle costs

3.2. The Value-Driven Performance Models

In the literature of the built environment, different value-driven performance models (VDPM) are developed with respect to two main factors: (1) the collection and the measurement of value indicators, (2) the analysis of value indicators. However, these factors are defined according to the value-based evaluation objectives of models and their methods in a specific context.

Firstly, numerous objectives of VDPM and data analysis methods of VDPM are developed to assess the value of building projects by evaluating their performances. The different objectives are defined because of the existence of different expectations and values of stakeholders. Accordingly, each model and each method define their different objectives. For example, in terms of the objectives of VDPM, Preiser (2002, 9) proposes Post Occupancy Evaluation (POE) for "evaluating buildings in a systematic and rigorous manner". Gluch and Baumann (2004, 571) study Life Cycle Costing Analysis model to "make rational and environmentally responsible investment decisions under uncertainty". Kim et al. (2005, 1103) propose Housing Performance Evaluation model for the "evaluation and comparison residential housing alternatives". Pulaski and Horman (2005, 1274) develop Sustainable Value Engineering methodology for "the integration of sustainable objectives into project management practices and measuring the quality and focus of project team decisions"; Design Quality Indicator (DQI) is studied by Gann, Salter, and Whyte (2003, 318) "for examining performance, providing feedback and capturing different perceptions of the value of design" and by Zemke and Pullman (2008, 543) "to measure design". Abdelrahman, Zayed, and Elyamany (2008, 187) propose Best Value methodology "to enhance the long-term performance of projects". Ali and Al Nsairat (2009, 1053) develop a Green Building Assessment Tool "for achieving sustainable development". Lee and Lee (2009, 3269) develop a Building Energy Performance Evaluation model "benchmarking of building energy performance". Wong, Lam, and Chan (2009, 369) develop Balance Scorecard Methodology "to translate design objectives into actionable goals and measures". Cariaga, El-Diraby, and Osman (2007), Marzouk (2011) and Moon, Ha, and Yang (2011) work on Value Engineering methodology for the evaluation of design alternatives considering efficiency. Hartkopf and Loftness (1999), Wong and Jan (2003) and Oyedele et al. (2012) propose Total Building Performance model to evaluate building performance. Kale, İlal, and Ülkeryıldız (2012, 226) propose Entropy Based Model for "evaluating the housing design performance". Ristimäki et al. (2013, 168) propose Life Cycle Management model "to support decision-making on a long-term basis". Finally, Santoyo-Castelazo and Azapagic (2014, 3) propose Life Cycle Assessment "to develop a decision-support framework for an integrated sustainability assessment of energy systems" (Table 3.6).

Furthermore, there are also different objectives of methods, which are developed under VDPM (Table 3.7). For example, Simple Multicriteria Assessment Algorithm is developed for measuring performance of buildings (Gann, Salter, and Whyte 2003). LCC Oriented Environmental Accounting Tools is used for "making environmentally responsible investment decisions” (Gluch and Baumann 2004, 571). Analytical Network Process (ANP) is proposed for evaluating building performance (Wong and Jan 2003, Chen et al. 2006). Analytical Hierarchy Process (AHP) is used for calculating of the weights performance indicators (Kim et al. 2005, Ali and Al Nsairat 2009). Continuous Value Enhancement Process is developed to “improve project performance and increase levels of sustainability” (Pulaski and Horman 2005, 1274). Functional Analysis System Technique (FAST) diagram is used “to define objectives”, Quality Function Deployment is used “to attain objectives” and Data Envelopment Analysis is used “to select design alternatives” (Cariaga, El-Diraby, and Osman 2007, 763). Weighted Average Method and Analytical Hierarchy Process are proposed “to assess best value” (Abdelrahman, Zayed, and Elyamany 2008, 179). Electre III is proposed “to facilitate evaluation of alternatives” (Marzouk 2011, 596). Quality Function Development Design Quality Indicator Tool is used to “understand the overall design aims in an explicit, systematic and structured manner” (Wong, Lam, and Chan 2009, 389). CVE-IIS tool is designed “to improve the value of design functions by improving performance” (Moon, Ha, and Yang 2011, 841). Entropy and Multi-Attribute Decision Making Methods are proposed “to optimize the conflicting housing design objectives” (Kale, İlal, and Ülkeryıldız 2012, 226). Life Cycle Costing and Life Cycle Assessment are used for “economic and environmental design decisions” (Ristimäki et al. 2013, 168). Data Envelopment Analysis (DEA) is used for calculating energy efficiency of buildings (Grösche 2009, Lee and Lee 2009, Lu, Ashuri, and Shahandashti 2014). Finally, Multi-Criteria Decision Analysis is proposed “to assess and identify the most sustainable energy options” (Santoyo-Castelazo and Azapagic 2014, 1).

Table 3.6. Objectives of VDPM.

Source	VDPM	Objectives
Preiser (2002)	Post Occupancy Evaluation(POE)	evaluating buildings in a systematic and rigorous manner
Gluch and Baumann (2004)	Life Cycle Costing Analysis	making rational and environmentally responsible investment decisions under uncertainty
Kim et al. (2005)	Housing Performance Evaluation	evaluation and comparison residential housing alternatives
Pulaski and Horman (2005)	Sustainable Value Engineering	the integration of sustainable objectives into project management practices and measuring the quality and focus of project team decisions
Gann, Salter, and Whyte (2003)	Design Quality Indicator (DQI)	examining performance, providing feedback and capturing different perceptions of the value of design
Zemke and Pullman (2008)	Design Quality Indicator (DQI)	measuring design
Abdelrahman, Zayed, and Elyamany (2008)	Best Value	enhancing the long-term performance of projects
Ali and Al Nsairat (2009)	Green Building Assessment Tool	achieving sustainable development
Lee and Lee (2009)	Building Energy Performance Evaluation Model	benchmarking of building energy performance
Wong, Lam, and Chan (2009)	Balance Scorecard	translating design objectives into actionable goals and measures
Cariaga, El-Diraby, and Osman (2007) Marzouk (2011) Moon, Ha, and Yang (2011)	Value Engineering	supporting the evaluation of multiple design alternatives considering efficiency
Hartkopf and Loftness (1999) Wong and Jan (2003) Oyedele et al. (2012)	Total Building Performance	evaluating total building performance by focusing the problematic areas
Kale, İlal, and Ülkeryıldız (2012)	Entropy Based Model	evaluating the housing design performance
Ristimäki et al. (2013)	Life Cycle Management	supporting decision-making on a long-term basis
Santoyo-Castelazo and Azapagic (2014)	Life Cycle Assessment	developing adecision-support framework for an integrated sustainability assessment of energy systems

Table 3.7. Objectives of Methods.

Source	Methods	Objectives
Gann, Salter, and Whyte (2003)	Simple Multicriteria Assessment Algorithm	measuring performance of buildings
Wong and Jan (2003) Chen et al. (2006)	Analytical Network Process (ANP)	evaluating building performance
Gluch and Baumann (2004)	LCC Oriented Environmental Accounting Tools	making environmentally responsible investment decisions
Kim et al. (2005) Ali and Al Nsairat (2009)	Analytical Hierarchy Process	calculating of the weights of performance indicators
Pulaski and Horman (2005)	Continuous Value Enhancement Process	improving project performance and increasing levels of sustainability
Cariaga, El-Diraby, and Osman (2007)	Functional Analysis System Technique (FAST) diagram Quality Function Deployment Data Envelopment Analysis (DEA)	defining objectives attaining objectives selecting efficient design alternatives
Abdelrahman, Zayed, and Elyamany (2008)	Weighted Average Method Analytical Hierarchy Process	assessing best value
Wong, Lam, and Chan (2009)	Quality Function Development Design Quality Indicator Tool	understanding the overall design aims in an explicit, systematic and structured manner
Marzouk (2011)	ELECTRE III	facilitating evaluation of alternatives
Moon, Ha, and Yang (2011)	CVE-IIS tool	improving the value of design functions by improving performance
Kale, İlal, and Ülkeryıldız (2012)	Entropy and Multi-Attribute Decision Making Methods	optimizing the conflicting housing design objectives
Ristimäki et al. (2013)	Life Cycle Costing Life Cycle Assessment	economic and environmental design decisions
Lee and Lee (2009) Grösche (2009) Lu, Ashuri, and Shahandashti (2014)	Data Envelopment Analysis (DEA)	optimizing the conflicting housing design objectives
Santoyo-Castelazo and Azapagic (2014)	Multicriteria Decision Analysis	assessing and identifying the most sustainable energy options

Additionally, however, the objectives are important for developing VDPM; it is also important where they are implemented. In the literature, VDPM generally focus on the evaluation of four different life cycle phases of building projects, which are (1) finished buildings (Wong and Jan 2003, Hartkopf and Loftness 1999, Kim et al. 2005, Abdelrahman, Zayed, and Elyamany 2008), (2) processes of production such as design and construction (Marzouk 2011, Moon, Ha, and Yang 2011, Cariaga, El-Diraby, and Osman 2007), (3) tendering (Ali and Al Nsairat 2009, Yu, Wang, and Wang 2012) and (4) whole life cycle phases (e.g., Gann, Salter, and Whyte 2003, Pulaski and Horman 2005, Gluch and Baumann 2004, Zemke and Pullman 2008) (Table 3.8).

Table 3.8. Contexts of VDPM.

Source	VDPM	Contexts
Preiser (2002)	Post Occupancy Evaluation (POE)	whole life cycle phases
Gluch and Baumann (2004)	Life Cycle Costing Analysis	whole life cycle phases
Kim et al. (2005)	Housing Performance Evaluation	finished building
Pulaski and Horman (2005)	Sustainable Value Engineering	whole life cycle phases
Gann, Salter, and Whyte (2003) Zemke and Pullman (2008)	Design Quality Indicator (DQI)	whole life cycle phases
Abdelrahman, Zayed, and Elyamany (2008) Yu, Wang, and Wang (2012)	Best Value	tendering phase
Ali and Al Nsairat (2009)	Green Building Assessment Tool	finished building
Lee and Lee (2009)	Building Energy Performance Evaluation Model	finished building
Wong, Lam, and Chan (2009)	Balance Scorecard	finished building
Cariaga, El-Diraby, and Osman (2007) Marzouk (2011) Moon, Ha, and Yang (2011)	Value Engineering/Analysis	design and construction
Hartkopf and Loftness (1999) Wong and Jan (2003) Oyedele et al. (2012)	Total Building Performance	finished building
Kale, İlal, and Ülkeryıldız (2012)	Entropry Based Model	whole life cycle phases
Ristimäki et al. (2013)	Life Cycle Management	whole life cycle phases

Secondly, in terms of the collection and the measurement of value indicators, VDPM could be classified into three types of measurements, which are (1) objective (O), (2) subjective (S), and (3) both objective and subjective (O and S). In general, while objective measurements evaluate the design performance of buildings using quantitative methods such as mathematical models, software, and measurement devices etc., subjective measurements evaluate the design performance of buildings using predefined or learned rules (Yavuz, Doğan, and Kale 2014). Accordingly, in the literature of the built environment, VDPM could be classified according to collecting and measuring value indicators; (1) subjective (Gann, Salter, and Whyte 2003, Zemke and Pullman 2008), (2) objective (Gluch and Baumann 2004, Kim et al. 2005, Pulaski and Horman 2005, Lee and Lee 2009, Ali and Al Nsairat 2009, Marzouk 2011, Moon, Ha, and Yang 2011, Ristimäki et al. 2013) and (3) objective and subjective measurements (Preiser 2002, Wong and Jan 2003, Cariaga, El-Diraby, and Osman 2007, Abdelrahman, Zayed, and Elyamany 2008, Wong, Lam, and Chan 2009, Kale, İlal, and Ülkeryıldız 2012, Yu, Wang, and Wang 2012, Santoyo-Castelazo and Azapagic 2014) (Table 3.9).

Table 3.9. Collection and Measurement Approaches of Value Indicators.

Source	**VDPM**	**Collection and Measurement of Value Indicators**		
		O	**S**	**O and S**
Preiser (2002)	Post Occupancy Evaluation(POE)			√
Gluch and Baumann (2004)	Life Cycle Costing Analysis	√		
Kim et al. (2005)	Housing Performance Evaluation	√		
Pulaski and Horman (2005)	Sustainable Value Engineering	√		
Gann, Salter, and Whyte (2003) Zemke and Pullman (2008)	Design Quality Indicator (DQI)		√	
Abdelrahman, Zayed, and Elyamany (2008) Yu, Wang, and Wang (2012)	Best Value			√
Ali and Al Nsairat (2009)	Green Building Assessment Tool	√		
Lee and Lee (2009)	Building Energy Performance Evaluation Model	√		
Wong, Lam, and Chan (2009)	Balance Scorecard			√
Cariaga, El-Diraby, and Osman (2007)	Value Engineering			√
Marzouk (2011) Moon, Ha, and Yang (2011)	Value Engineering	√		
Hartkopf and Loftness (1999) Wong and Jan (2003) Oyedele et al. (2012)	Total Building Performance			√
Kale, İlal, and Ülkeryıldız (2012)	Entropy Based Model			√
Ristimäki (2013)	Life Cycle Management	√		
Santoyo-Castelazo and Azapagic (2014)	Life Cycle Assessment	√		

Thirdly, how VDPM analyze the value indicators is also important after collecting and measuring indicators. In general, qualitative methods are considered as opaque analysis methods, which are removed from transparency because they evaluate the product or the process under learned values, norms and rules (Yavuz, Doğan, and Kale 2014). However, quantitative methods include mathematical tools, computer software, and measurement compliances during the analysis of value indicators, which are preferable to get verified results and the capability of comparing results (Yavuz, Doğan, and Kale 2014). In the literature of the built environment, numerous methods with their VDPM can be listed as; Simple Multicriteria Assessment Algorithm with Design Quality Indicator (Gann, Salter, and Whyte 2003), Analytical Network Process (ANP) with Total Building Performance (Wong and Jan 2003), LCC Oriented Environmental Accounting Tools with Life Cycle Costing Analysis (Gluch and Baumann 2004), Analytical Hierarchy Process with Housing Performance Evaluation (Kim et al. 2005), Continuous Value Enhancement Process with Sustainable Value Engineering (Pulaski and Horman 2005), Functional Analysis System Technique (FAST) diagram, Quality Function Deployment and Data Envelopment Analysis (DEA) with Value Engineering (Cariaga, El-Diraby, and Osman 2007), Weighted Average Method and Analytical Hierarchy Process with Best Value (Abdelrahman, Zayed, and Elyamany 2008), Analytical Hierarchy Process (AHP) with Green Building Assessment Tool (Ali and Al Nsairat 2009), Quality Function Development and Design Quality Indicator Tool with Balance Scorecard (Wong, Lam, and Chan 2009), ELECTRE III with Value Engineering (Marzouk 2011), CVE-IIS tool with Value Engineering (Moon, Ha, and Yang 2011), Entropy and Multi-Attribute Decision Making Methods with an Entropy Based Model (Kale, İlal, and Ülkeryıldız 2012), Life Cycle Costing and Life Cycle Assessment with Life Cycle Management (Ristimäki et al. 2013), Multi Criteria Decision Analysis with Life Cycle Assessment (Santoyo-Castelazo and Azapagic 2014) (Table 3.10).

Table 3.10. VDPM and Methods.

Source	**Models**	**Methods**
Gann, Salter, and Whyte (2003)	Design Quality Indicator	Simple Multicriteria Assessment Algorithm
Wong and Jan (2003)	Total Building Performance	Analytical Network Process (ANP)
Gluch and Baumann (2004)	Life Cycle Costing Analysis	LCC Oriented Environmental Accounting Tools
Kim et al. (2005)	Housing Performance Evaluation	Analytical Hierarchy Process
Pulaski and Horman (2005)	Sustainable Value Engineering	Continuous Value Enhancement Process
Cariaga, El-Diraby, and Osman (2007)	Value Engineering	Functional Analysis System Technique (FAST) diagram Quality Function Deployment Data Envelopment Analysis (DEA)
Abdelrahman, Zayed, and Elyamany (2008)	Best Value	Weighted Average Method Analytical Hierarchy Process
Ali and Al Nsairat (2009)	Green Building Assessment Tool	Analytical Hierarchy Process (AHP)
Wong, Lam, and Chan (2009)	Balance Scorecard	Quality Function Development Design Quality Indicator Tool
Marzouk (2011)	Value Engineering	ELECTRE III
Moon, Ha, and Yang (2011)	Value Engineering	CVE-IIS tool
Kale, İlal, and Ülkeryıldız (2012)	Entropy Based Model	Entropy and Multi-Attribute Decision Making Methods
Ristimäki et al. (2013)	Life Cycle Management	Life Cycle Costing Life Cycle Assessment
Santoyo-Castelazo and Azapagic (2014)	Life Cycle Assessment	Multi Criteria Decision Analysis

Moreover, methods, which are developed for the measurement and the analysis of value indicators, could be defined under five categories for VDPM. The first category of methods evaluate the value indicators that consist of cost property of building such as LCC Oriented Environmental Accounting Tools (Gluch and Baumann 2004). The second category of methods evaluate environmental impact indicators such as Analytical Network Process (ANP) (Wong and Jan 2003, Chen et al. 2006), Data Envelopment Analysis (DEA) (Lee and Lee 2009, Grösche 2009, Lu, Ashuri, and Shahandashti 2014). The third category of methods evaluate quality indicators such as Simple Multicriteria Assessment Algorithm (Gann, Salter, and Whyte 2003), and Analytical Hierarchy Process (AHP) (Kim et al. 2005). The fourth category of methods evaluate the value indicators, which consist of tangible properties with cost property such as Functional Analysis System Technique (FAST) diagram, Quality Function Deployment and Data Envelopment Analysis (DEA) (Cariaga, El-Diraby, and Osman 2007), Analytical Hierarchy Process (AHP) (Ali and Al Nsairat 2009), ELECTRE III (Marzouk 2011), CVE-IIS tool (Moon, Ha, and Yang 2011), and Life Cycle Costing and Life Cycle Assessment (Ristimäki et al. 2013). Finally, the fifth category of methods evaluate indicators that consist of quality and cost properties such as Weighted Average Method and Analytical Hierarchy Process (Abdelrahman, Zayed, and Elyamany 2008), Quality Function Development (Wong, Lam, and Chan 2009), Entropy Based Model (Kale, İlal, and Ülkeryıldız 2012), and Price Elasticity of Quality Model (PEQ) (Ristimäki et al. 2013) (Table 3.11).

From both Table 3.7 and Table 3.8, it could be said that there is an interest in developing new methods for VDPM to assess value of buildings. Generally, current studies begin to focus on measuring hybrid based indicators using different quantitative methods for VBED.

Table 3.11. Value Indicators and Methods.

		Types of Value Indicators				
				Hybrid Value Indicators		
Source	**Methods**	Cost Property	Environmental Impact	Quality	Tangible Properties with Cost Property	Quality and Cost Properties
Gann, Salter, and Whyte (2003)	Simple Multicriteria Assessment Algorithm			√		
Gluch and Baumann (2004)	LCC Oriented Environmental Accounting Tools	√				
Kim et al. (2005)	Analytical Hierarchy Process (AHP)			√		
Wong and Jan (2003) Chen et al. (2006)	Analytical Network Process (ANP)		√			
Cariaga, El-Diraby, and Osman (2007)	Functional Analysis System Technique (FAST) diagram Quality Function Deployment Data Envelopment Analysis (DEA)				√	
Abdelrahman, Zayed, and Elyamany (2008)	Weighted Average Method Analytical Hierarchy Process					√
Ali and Al Nsairat (2009)	Analytical Hierarchy Process (AHP)				√	
Wong, Lam, and Chan (2009)	Quality Function Development					√
Marzouk (2011)	ELECTRE III				√	
Kale, İlal, and Ülkeryıldız (2012)	Entropy and Multi-Attribute Decision Making Methods					√
Moon, Ha, and Yang (2011)	CVE-IIS tool				√	
Yu, Wang, and Wang (2012)	Price Elasticity of Quality Model (PEQ)					√
Ristimäki et al. (2013)	Life Cycle Costing Life Cycle Assessment				√	
Lee and Lee (2009) Grösche (2009), Lu, Ashuri, and Shahandashti (2014)	Data Envelopment Analysis (DEA)		√			

It could be concluded from this chapter that there are different VBED approaches for valuing buildings with respect to different properties of buildings. Accordingly, different VDPM and analysis methods have been developed to assess the value of buildings. Moreover, the built environment also needs an agreement on VDPM in terms of the choice of methods during analysis of value indicators. The choice of methods should also be considered in terms of the principle of simplicity. The simplicity at a desired level leads models to get a general opinion and to evaluate performances of buildings in an efficient way (Yavuz, Doğan, and Kale 2012). Thus, VDPM could be defined as models that assess the value of buildings with respect to performance of buildings in different life cycle phases by collecting, measuring and analyzing value indicators using simple and practical methods. According to the literature review, VDPM could be achieved in an effective way considering four objectives, which are;

1. Defining hybrid indicators, which focus on quality and cost properties of buildings to get quantified and comparable results,

2. Collecting and measuring value indicators considering both objective and subjective approaches, which leads to including the involvement of stakeholder values, expectations in evaluations,

3. Applicability of VDPM, which could be used in different contexts and for different types of building projects,

4. Usage of quantitative methods in analysis of value indicators, which should be developed within the framework of the simplicity principle for understanding results of VBED in an effective way.

CHAPTER 4

THE DEVELOPMENT OF A DESIGN PERFORMANCE MODEL

In the literature of the built environment, only few studies focus on each of the four main objectives of VDPM that are proposed at the end of the third chapter. To develop new value-driven performance models (VDPM) for valuing design of buildings, it is important to investigate current VDPM in the literature and to see how they conceptualize their frameworks in terms of considering the proposed objectives.

Firstly, with respect to the first objective, there are the studies of Cariaga, El-Diraby, and Osman (2007), Wong, Lam, and Chan (2009), Abdelrahman, Zayed, and Elyamany (2008), Yu, Wang, and Wang (2012), Kale, İlal, and Ülkeryıldız (2012) that define the hybrid value indicators based on quality and cost property of buildings. Developments in the current literature enlarge the framework of the cost property of buildings by introducing green costs of buildings, which calculate the cost of construction material in terms of carbon emissions (Ristimäki et al. 2013). Because the green cost is a new and developing concept in the literature, it is not possible to calculate the green cost of a building considering whole life cycle phases for now. Moreover, studies in the literature constitute their indicator groups according to their objectives. Accordingly, the aim of the proposed model in this study is to develop a alternative indicator group considering developments in the literature. Therefore, DQI and Life Cycle Cost Analysis (LCCA) methods are examined to construct hybrid value indicators that consist of quality and cost properties of buildings for valuing their design.

The second objective of VDPM is to collect and to measure indicators considering both objective and subjective approaches. With respect to the second objective, Post Occupancy Evaluation (POE) (Preiser 2002), Balance Scorecard Methodology (Wong, Lam, and Chan 2009), Best Value Methodology (Abdelrahman, Zayed, and Elyamany 2008, Yu, Wang, and Wang 2012), Value Engineering (Cariaga, El-Diraby, and Osman 2007), Total Building Performance (Hartkopf and Loftness 1999, Wong and Jan 2003, Oyedele et al. 2012) and Entropy Based Model (Kale, İlal, and Ülkeryıldız 2012) have been studied in the literature of the built environment. However, their approaches on the third objective have changed. The third objective of VDPM is the applicability of VDPM for use in different contexts and for different types of building projects (Table 3.8).

Finally, the fourth objective highlights the usage of quantitative methods in analysis of value indicators, which should be developed within the framework of the simplicity principle for understanding results of VBED in an efficient way. With respect to the fourth objective, studies that also consider the previous objectives can be found in the literature of the built environment. For instance, Wong, Lam, and Chan (2009) propose the hybrid methods by combining QFD and Quality Indicator Tool. Another study that focuses on other hybrid methods such as Weighted Average Method and Analytical Hierarchy Process was proposed by Abdelrahman, Zayed, and Elyamany (2008). Furthermore, Entropy and Multi-Attribute Decision Making methods are proposed by Kale, İlal, and Ülkeryıldız (2012). Within the framework of the fourth objective, a performance efficiency measurement method, which is Data Envelopment Analysis (DEA), is used in this study because it is a simple and practical method to evaluate design performance and assess the design value of buildings.

In conclusion, this chapter aims to explain the development of the VDPM, which is proposed in this thesis with respect to pre-defined objectives of VDPM in the previous chapter. Design Quality Indicator (DQI) and Life Cycle Cost Analysis (LCCA) methods are examined to constitute value indicators of the developed model. Furthermore, Data Envelopment Analysis (DEA) method is chosen to analyze value indicators for evaluating their design performances.

4.1. Design Quality Indicator

Design Quality Indicator (DQI) is a method that was first introduced in Rethinking Construction by The Construction Industry Council (CIC) to enhance the design quality of products for their stakeholders (Gann, Salter, and Whyte 2003). In general, DQI informs each stakeholder with respect to their values and expectations on tangible and intangible properties of building rather than getting certain results (Gann, Salter, and Whyte 2003). Additionally, DQI highlights the role of stakeholders to add value to buildings and it makes the process of evaluation more realistic (Gann, Salter, and Whyte 2003). The general intent of DQI is to increase the design quality and the value of the building design (Devine-Wright, Thomson, and Austin 2003). Because DQI is respectful of each expectation of stakeholders from the buildings, it is considered to be a more transparent assessment tool than previous methods such as PROBE, HQI and BREEAM that only consider the values of professionals (Gann, Salter, and Whyte 2003).

In general, DQI method is formed by three main components such as (1) "conceptual framework", (2) "data gathering tool" and (3) "weighting mechanism" (Gann, Salter, and Whyte 2003). Moreover, the design quality of the product is assessed with the contemporary explanation of "Vitruvian framework" (Gann, Salter, and Whyte 2003). Accordingly, the main indicators and their sub-indicators are (1) functionality, which includes three sub-indicators; (1.1) access, (1.2) space, and (1.3) use, (2) build quality, which includes three sub-indicators; (2.1) performance, (2.2) engineering systems, (2.3) construction and (3) impact, which includes four sub-indicators; (3.1) urban and social integration, (3.2) internal environment, (3.3) form and materials, (3.4) identity and character (Thomson et al. 2003). However, it does not show the main reasons of stakeholder in their responses (Devine-Wright, Thomson, and Austin 2003). It could be said that DQI is considered as a representation technique that is easy to analyze and shows values of stakeholders and could be used in every life cycle phase of building projects such as during procurement, design phases, construction processes etc. to add value to the buildings and to inform stakeholders (Gann, Salter, and Whyte 2003).

4.2. Life Cycle Cost Analysis

Besides the evaluation of the design quality, it is also important to consider it as a part of the capital investment (Zemke and Pullman 2008). To be able to understand how cost property is placed in assessing design value of buildings, several statements are made to highlight the importance of the relationship between quality and cost property of building. While Jefferiss Matthews states that "architecture is wholly related with art and art is related with economics and highlights that without economic value architecture does not mean anything virtually" (Loe 2000, 5), John Lyall states that "value of architecture from the angle that good design makes economic sense" (Loe 2000, 2). In addition to understanding the relationship between quality and cost property, it is also important to clarify how cost property is considered during evaluations. According to Fuller (2010), from the beginning to end of building projects, there are several types of cost that need to be considered by stakeholders such as "initial costs (purchase, acquisition, construction costs), fuel costs, operation, maintenance, and repair costs, replacement costs, residual values (resale or salvage values or disposal costs), and finance charges (loan interest payments, and non-monetary costs)".

Cost property of products is not separated from valuing products. For instance, beginning with the 18th century, economists have been also studied on the concept of value (Loe 2000). Generally, cost related issues have been used in the value-based evaluation of design in two ways: (1) "design-for-cost" and (2) "design-to-cost" (Asiedu and Gu 1998). Thus, the cost property is related to the quality and this relationship begins to define the design value of buildings in the built environment.

If the cost property of a building is not considered in detail, the project could not be achieved within the expected quality (Potts and Ankrah 2013). In the literature of the built environment, Life Cycle Cost Analysis (LCCA) or Life Cycle Costing is a method that is preferred for cost analysis of buildings.

Defining types of cost property is essential to analyze their effect on defining design value. Accordingly, LCCA is a helpful method to analyze different types of cost of building projects in the built environment. In the literature, there are several definitions to define LCCA. For instance, ISO15686 (2006) defines Life Cycle Costing as "a tool and technique which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors both in terms of initial capital costs and future operational and asset replacement costs...". CIPS (2013, 3) defines LCCA as it "takes account of the total costs of making or purchasing and then owning (or leasing), operating, maintaining and managing the requirement (including its end of life, whether that involves de-commissioning, disposal or re-sale) over a specified period of time". Ristimäki et al. (2013, 169) define LCCA as "a valuable financial approach for evaluating and comparing different building designs in terms of initial cost increases against operational cost benefits with a long-term perspective" (Table 4.1).

Table 4.1. Definitions of LCCA.

Source	**Definition of LCCA**
ISO 15686 (2006)	A tool and technique which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors both in terms of initial capital costs and future operational and asset replacement costs
CIPS (2013)	It takes account of the total costs of making or purchasing and then owning (or leasing), operating, maintaining and managing the requirement (including its end of life, whether that involves de-commissioning, disposal or re-sale) over a specified period of time
Ristimäki et al. (2013)	A valuable financial approach for evaluating and comparing different building designs in terms of initial cost increases against operational cost benefits with a long-term perspective

In the literature of LCCA, firstly it was introduced by the US Department of Defense in the mid-1960s and was developed for building projects in the 1980s (Gluch and Baumann 2004). Recently, in the construction industry, LCCA has been used for calculation of various types of cost of buildings in different life cycle phases (Gluch and Baumann 2004).

In general, LCCA consists of three main steps: (1) "analyzing cost structure", (2) "cost estimating", and (3) "discounting" (CIPS 2013, 4). Throughout life cycle phases of buildings, cost varies because of the factors: "differences in time (inflation), quantitative, quantitative and locational differences" (Potts and Ankrah 2013, 52). Accordingly, four steps of LCCA are also defined in the paper of The Construction Excellence: (1) establishing costs, (2) determining when they evolve, (3) applying discounted cash-flow analysis, and (4) controlling the parameters (Potts and Ankrah 2013). Thus, LCCA requires collaboration with the concepts of engineering economics for analyzing the projects (Fuller and Petersen 1996).

The discipline of engineering economics is integrated with the LCCA to define cost of projects under a common basis considering differences in time (Watts and Chapman 2008). In engineering economics, there are three main cash flow concepts such as (1) time value of money, (2) cash flow structure and diagrams, and (3) interest calculations (Watts and Chapman 2008). Firstly, time value of money is the changing value of money, which occurs because of inflation and deflation (Watts and Chapman 2008). Secondly, cash flow diagrams, which is used for the representation of the flow of money (Watts and Chapman 2008). Finally, interest calculations, which are used for converting cash flows under a common time, helping define relations between time and cost (Watts and Chapman 2008, Kenley 2003). Furthermore, cash flow concepts need to include defined series of time to measure different time value of money (Yaffey 1989).

In general, money has two values: (1) present value and (2) future value. In addition, there are series payments that involve in between two values of money (Watts and Chapman 2008). The general LCCA models are defined for indicating LCC as the sum of recurring and nonrecurring costs (Dhillon 2010). During the calculations of LCCA, whole payments are generally transformed into the present or annual value of cost (Watts and Chapman 2008). In this manner, interest calculations allow the transformation of the value of money to the desired value.

In the built environment, LCC of a building is specifically defined as the sum of initial (capital) cost, operation cost, maintenance and repair cost, and demolition cost. (Dhillon 2010, Mearig, Coffee, and Morgan 1999). Firstly, the initial cost is the sum of all costs required to start the construction of buildings. According to Mearig, Coffee, and Morgan (1999, 18), the initial costs are considered as “initial investment cost; construction management, land acquisition, site investigation, design services, construction, equipment, technology, indirect/administration, art, contingency”, operation costs are considered as “annual costs; heating fuel, electricity, water and sewage, garbage disposal, leasing, insurance, other”, finally, maintenance and repair costs are the costs related with “site improvements, site utilities, foundation/substructure, superstructure, exterior wall systems, exterior windows, exterior doors, roof systems, interior partitions, interior doors, interior floor finishes, interior wall finishes, interior ceiling finishes, interior specialities, conveying systems, plumbing piping".

In conclusion, LCCA is an economic method, which is used for financial analysis (Gluch and Baumann 2004, Ristimäki et al. 2013). Throughout the life cycle of a building, there are many cost factors affecting the value of buildings whereas the cost by itself is a changing value in time. Accordingly, LCCA and concepts of engineering economics are helpful and important methods to define time values of different types of cost under a common value to be able to define LCC of buildings.

4.3. Data Envelopment Analysis

There are numerous studies in various disciplines to define and measure the relative performance efficiency levels of units. Although there are different approaches, Data Envelopment Analysis (DEA) is the prominent approach in the literature (Charnes, Cooper, and Rhodes 1978, Banker, Charnes, and Cooper 1984). The main reasons for being the prominent approach can be stated as (1) the lack of preliminary acceptance, (2) the flexibility and (3) the simplicity. Data Envelopment Analysis (DEA) method is a deterministic, non-statistical, non-parametric technique, which measures relative performance efficiency levels of units without considering any assumption in the functional forms and weighting to evaluate performance of units. (Tsolas 2013, Ramanathan 2003, McCabe, Tran, and Ramani 2005). Furthermore, it is also a linear programming-based method, which evaluates relative performance efficiency levels of the systems (production, processes or products), which reveal similar output(s) using similar input(s) (Ramanathan 2003).

According to the terminology of DEA, any product, process etc. is considered as the selection of data measurement units (DMU), which are individuals in the evaluation group (Lin and Huang 2009). Moreover, the criteria for defining inputs and outputs are required to be numerical data, which reflect the interest of the user (El-Mashaleh 2010). DEA does not require any functional form to calculate maximum performance efficiency of each project relative to other projects but it creates a frontier for combining each project with reference to the frontier/surface such as lying on or below (Charnes, Lewin, Seiford 1994).

Frontier (Surface) Analysis is used for measuring efficiencies and includes several types of efficiency frontiers such as theoretical frontier, empirical frontier, and practical frontier. Efficiency frontier envelops the available data and calls the efficient data on the line and situates inefficient data out of line (Ramanathan 2003). Theoretical frontier indicates the absolute maximum possible production, which is hard to define mathematically (McCabe, Tran, and Ramani 2005). Empirical frontier connects all 'relatively best' projects (McCabe, Tran, and Ramani 2005). Practical frontier is an improved frontier of the empirical frontier, which closes empirical frontier to theoretical framework (McCabe, Tran, and Ramani 2005) (Figure 4.1).

To consider a project as efficient, the ratio of weighted outputs to weighted inputs should be larger than other projects (Ozbek, de la Garza, and Triantis 2012). However, there are many types of efficiency in the terminology of DEA. For instance, relative efficiency is that project efficiencies are relative to best performing project(s) efficiencies and is found as the ratio of best possible performance to actual performance for estimating efficiency of inefficient projects (Ramanathan 2003). Allocative (Price) efficiency indicates how DEA can be used to define type of inefficiency for treatment when all information is known about prices and is calculated considering technical and overall efficiency (Cooper, Seiford, and Tone 2007). Overall efficiency is for assessing whether the overall project operates at an optimum level or not and is calculated by multiplying allocative efficiency and technical efficiency (Lin and Tan 2014). Technical efficiency represents the efficient utilization of each project with respect to inputs and outputs where the utilization of inputs is efficient to maximize outputs and is calculated by multiplying pure technical efficiency and scale efficiency (Lin and Tan 2014, Tsolas 2013). Scale efficiency measures optimality and is defined by the difference between technical efficiency and pure technical efficiency (Tsolas 2013, Lin and Tan 2014). Pure technical efficiency evaluates the performance without scale (Lin and Tan 2014). Radial (proportional) efficiency calculates the efficiency of a product by proportionally decreasing inputs or proportionally increasing outputs (Cooper, Seiford, and Tone 2007, Hirofumi 2014).

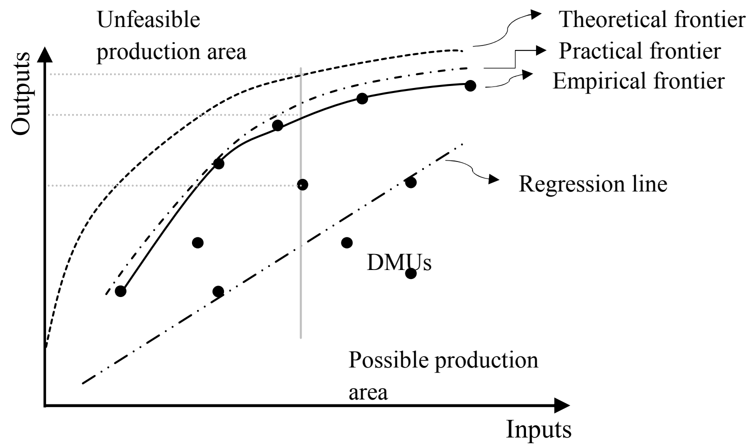


Figure 4.1. Empirical frontier, practical and theoretical frontier.
(Source: McCabe, Tran, and Ramani 2005, Sowlati 2001)

Two main characteristics of DEA while measuring the relative performance efficiency levels of projects are (1) the envelopment surfaces and (2) the orientation (McCabe, Tran, and Ramani 2005). In DEA, the relative performance efficiency level of a project is defined by envelopment surfaces. Relative performance efficiency level of the products is defined according to relative distance of the products to the envelopment surface. While the projects that are on the envelopment surface are considered as efficient or best performing, others are considered as inefficient. Generally, return to scale (RTS) characterization determines the product's inputs and outputs of products in terms of reaching the optimality (Lin and Tan 2014). The scale characterization is defined according to the sum of weights that are attained by inputs and outputs. Moreover, the scale characterization could be defined in three ways; (1) increasing return to scale (IRS) where the sum of weights is smaller than 1, (2) decreasing return to scale (DRS) where the sum of weights is larger than 1, and (3) constant return to scale (CRS) where the sum of weights is equal to 1 (Cooper, Seiford, and Tone 2007, Özden 2008). Different types of DEA create different RTS envelopment surfaces to analyze the efficiencies of projects in different manners. For instance, two envelopment surfaces are (1) Constant Return to Scale (CRS) envelopment surface (evaluated by CCR) (Figure 4.3), which is represented with a line starting from origin and passing through the first project and (2) Variable Return to Scale (VRS) envelopment surface (evaluated by BCC models) (Figure 4.4), which envelops projects by connecting the outermost projects including the one approaching the CRS surface (McCabe, Tran, and Ramani 2005). While inputs and outputs are increased and decreased proportionally in CRS characterization, VRS characterization does not require this assumption (Martić, Novaković, and Baggia 2009). Rather than having a linear production frontier as in the CCR model, the BCC model has the production frontier spanned by the convex hull of existing projects that has VRS (variable return to scale) characterization (Martić, Novaković, and Baggia 2009).

Generally, there are four types of DEA in the literature, which are (1) Charnes-Cooper-Rhodes (CCR) model, (2) Banker-Charnes-Cooper (BCC) model, (3) Additive (ADD) model and (4) Hybrid (SBM) model (Cooper, Seiford, and Tone 2007).

Firstly, CCR model indicates each project's virtual input or output (as x, y) with their weights (as v, u) and defines the efficiency after determining the weights using linear programing to maximize the ratio of virtual output to virtual inputs (Cooper, Seiford, and Tone 2007). Technical efficiency (TE) of products is measured by CCR model (Lin and Tan 2014). The criteria to identify a project as CCR-efficient are: (1) being radial efficient, (2) having zero slack, and (3) no input excesses and no output shortfalls (Cooper, Seiford, and Tone 2007). Accordingly, CCR model is used for combining technical and scale efficiency and evaluates the radial (proportional) efficiency. Additionally, CCR model does not consider input excesses and output shortfalls (having zero slack) (Lin and Huang 2009, Cooper, Seiford, and Tone 2007) (Figure 4.2).

Secondly, BCC model aims to obtain the weights that maximize the efficiency of each project under evaluation (McCabe, Tran, and Ramani 2005). Thus, BCC models consist of performance efficiency score, and input-output weights (McCabe, Tran, and Ramani 2005). BCC model measures the pure technical efficiency (PTE) by decomposing overall technical efficiency (TE) and finding scale efficiency, which is the difference between TE and PTE (Lin and Tan 2014, Tsolas 2013).

Thirdly, however, Additive (ADD) models have the same production possibility set and variants as CCR and BCC models, but ADD model considers the slacks. The slack is to have input excesses and output shortfalls, which are called the translation invariance in their objective functions (Cooper, Seiford, and Tone 2007) (Figure 4.2). Additive model deals with inefficient projects which cannot be considered by CRS model (Cooper, Seiford, and Tone 2007).

Fourthly, Hybrid (SBM) models are introduced for overcoming the deficiencies that occur in CCR and ADD models but they are not translation invariant, which deals with lateral shifts of constraints to convert them from negative to positive (Cooper, Seiford, and Tone 2007).

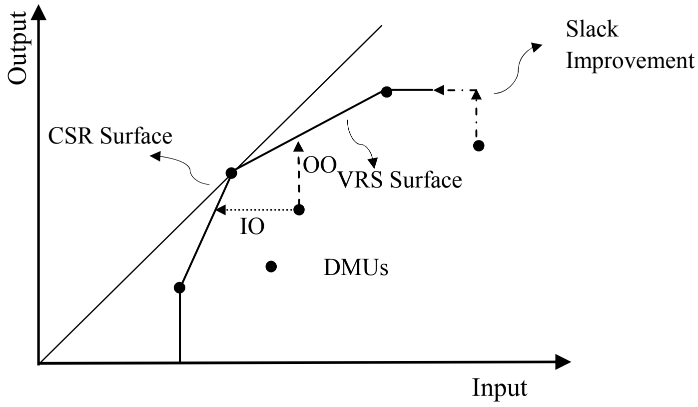


Figure 4.2. Envelopment surfaces, slack improvement and orientation.
(Source: McCabe, Tran, and Ramani 2005)

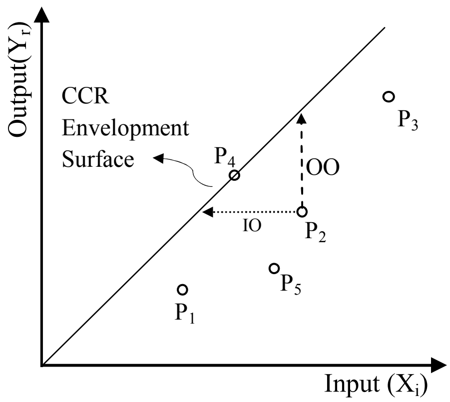


Figure 4.3. Input Oriented (IO) CCR and Output Oriented (OO) CCR DEA Models.

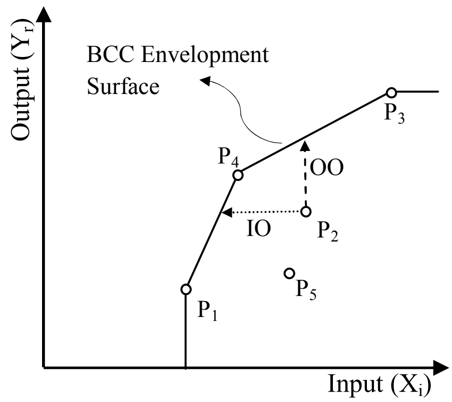


Figure 4.4. Input Oriented (IO) BCC and Output Oriented (OO) BCC DEA Models

Another important aspect of DEA is the concept of orientation. It can indicate the direction of inefficient projects for approaching the efficient frontier in two ways: (1) an increase in its output level while maintaining the same input level (output oriented) or (2) a decrease in its input level while maintaining the same output level (input oriented) (McCabe, Tran, and Ramani 2005). In both CCR and BCC models, the projects that have a value of performance efficiency score (S) equal to one (1) are considered as the successful. While input orientation performance efficiency scores (S) are represented in the range between 0 and 1 ($0 \leq S \leq 1$), output orientation performance efficiency scores are represented in the range between 1 and infinity ($1 \leq S \leq \infty$) and any S value other than one (1) is considered as the unsuccessful in both orientations (McCabe, Tran, and Ramani 2005). For instance, Figure 4.3 and Figure 4.4 indicate the envelopment surfaces to benchmark the relative performance efficiency levels of five different projects (P_1, P_2, P_3, P_4 and P_5), which consist of an input and an output. The projects situated on the envelopment surface of CCR model (P_3 and P_4) are considered as successful, the other projects (P_1, P_2 and P_5), which are not on the envelopment surface are considered as unsuccessful (Figure 4.3). The projects that have low S (P_1, P_2 and P_5) could be improved with input oriented (IO) or output oriented (OO) strategies (Figure 4.3). For an IO strategy, the quantity and quality of the outputs of the unsuccessful projects (P_1, P_2 and P_5) are fixed in the vertical axis and quality and quantity of the inputs are decreased in the horizontal axis. For an OO strategy, the quantity and quality of the inputs of the unsuccessful projects (P_1, P_2 and P_5) are fixed in the horizontal axis and quality and quantity of the outputs are increased in the vertical axis. The same evaluation could also be applicable to the BCC model (Figure 4.4).

It could be concluded from the above explanations, that the performance efficiency level of a project could be improved according to different application opportunities offered by DEA.

DEA, as with every linear programming problem, is a method working in the fractional base; it can be expressed in two different bases as primal and dual. For instance, according to the concept of duality, if the objective function of the primal DEA model is to maximize the ratio of virtual outputs and virtual inputs, dual expression of this objective is to minimize the virtual inputs of the model so that although the objective functions are different, the best value in the primal model and the best value in the dual model are the same (Özden 2008). The difference between primal and dual DEA is that the dual model adds a hypothetical variable to existing units during the calculation of relative performance efficiency levels of products (Zhu 2003, Martić, Novaković, and Baggia 2009). The dual models could cause unfeasible results when the hypothetical units are not correctly selected (Zhu 2003). In this study, the mathematical expression of the four primal CCR and BCC models that are indicated above could be defined as (Zhu 2003):

Input Oriented CCR Model - (IO-CCR);

$$\mathrm{Max} \sum_{r=1}^{s} u_r Y_{rk} \tag{4.1}$$

$$\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} \upsilon_i X_{ij} \leq 0 \tag{4.2}$$

$$\sum_{i=1}^{m} \upsilon_i X_{ik} = 1 \tag{4.3}$$

$$u_r \geq \varepsilon < 0 \quad r = 1,2,\dots,s \tag{4.4}$$

$$\upsilon_i \geq \varepsilon < 0 \quad i = 1,2,\dots m \tag{4.5}$$

Output Oriented CCR Model - (OO-CCR);

$$\mathrm{Min} \sum_{i=1}^{m} v_i X_{ik} \tag{4.6}$$

$$\sum_{i=1}^{m} v_i X_{ij} - \sum_{r=1}^{s} u_r Y_{rj} \geq 0 \tag{4.7}$$

$$\sum_{r=1}^{s} u_r Y_{rk} = 1 \tag{4.8}$$

$$u_r \geq \varepsilon < 0 \quad r = 1,2,\dots,s \tag{4.9}$$

$$\upsilon_i \geq \varepsilon < 0 \quad i = 1,2,\dots m \tag{4.10}$$

Input Oriented BCC Model - (IO-BCC);

$$\text{Max} \sum_{r=1}^{s} u_r\, Y_{rk} + u_k \tag{4.11}$$

$$\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} \upsilon_i X_{ij} + u_k \leq 0 \tag{4.12}$$

$$\sum_{i=1}^{m} \upsilon_i X_{ik} = 1 \tag{4.13}$$

$$u_r \geq \varepsilon < 0 \quad r = 1,2,\dots,s \tag{4.14}$$

$$\upsilon_i \geq \varepsilon < 0 \quad i = 1,2,\dots m \tag{4.15}$$

$$u_k \text{ free on sign} \tag{4.16}$$

Output Oriented BCC Model - (OO-BCC);

$$\text{Min} \sum_{i=1}^{m} v_i\, X_{ik} + v_k \tag{4.17}$$

$$\sum_{i=1}^{m} \upsilon_i X_{ij} - \sum_{r=1}^{s} u_r Y_{rj} + v_k \geq 0 \tag{4.18}$$

$$\sum_{i=1}^{m} u_r Y_{rk} = 1 \tag{4.19}$$

$$u_r \geq \varepsilon < 0 \quad r = 1,2,\dots,s \tag{4.20}$$

$$\upsilon_i \geq \varepsilon < 0 \quad i = 1,2,\dots m \tag{4.21}$$

$$v_k \text{ free to sign} \tag{4.22}$$

For Equations (4.1) to (4.22);

- Max: Maximization
- Min: Minimization
- u_r: r^{th} output weights estimated of system k
- v_i: i^{th} input weights estimated of system k
- Y_{rk}: r_{th} output of system k
- X_{ik}: i^{th} input of system k
- Y_{rj}: r^{th} output of system j
- X_{ij}: i^{th} input of system j
- ε: a convenient small positive number

In the literature, DEA method was first proposed by Charnes, Cooper, and Rhodes (1978) but has been developed and various theoretical changes have been made by many researchers according to different needs of numerous disciplines until today including the built environment (Cook and Seiford 2009). There have been many recent studies that apply DEA methods for various reasons such as developing strategies, making selections, benchmarking, measuring performance efficiency and evaluating performances of processes, products etc. in the life cycle(s) (Table 4.2).

As seen in Table 4.3, in the literature of the built environment, BCC and CCR DEA models are generally used to evaluate performance of DMUs such as buildings, contractors, stakeholders, companies, materials, bids etc. According to Table 4.3, the number of samples (DMUs) is in a range between 9 and 4212, the number of inputs is between 1 and 7 and the number of outputs is between 1 and 16.

In conclusion, the principle of the DEA method is to measure the relative performance efficiency levels of multiple inputs and outputs by focusing on minimization of inputs and maximization of outputs (Lin and Huang 2009).

Table 4.2. DEA Methods.

Source	Objective of DEA	DEA Types	Orientation	Number (of)		
				Sample (s)	Input (s)	Output (s)
Pilateris and McCabe (2003)	financial evaluation of contractors	Both CCR and BCC	Both IO and OO	1310	4	4
McCabe, Tran, and Ramani (2005)	contractor prequalification	BCC	OO	16	3	2
Vitner et al. (2006)	comparing project efficiency	sequential	-	11	4	8
Cariaga, El-Diraby, and Osman (2007)	selecting efficient design alternatives	BCC	IO	10	1	7
El-Mashaleh, Edward Minchin Jr., and O'Brien (2007)	benchmarking construction firm performance	CCR	Both IO and OO	21	2	5
Xue et al. (2008)	measuring productivity of construction industry	CCR	IO	9	2	1
Juan (2009)	selecting and performance evaluation of housing refurbishment contractors	CCR	IO	22	5	5
Grösche (2009)	measuring residential energy efficiency	CCR	IO	4212	1	6
Lee and Lee (2009)	benchmarking energy performance	BCC	IO	47	1	2
Lin and Huang (2009)	deriving baseline productivity (BP)	Both CCR and BCC	OO	37	1	2
El-Mashaleh (2010)	creating a favorable frontier for favorable bidding opportunities and evaluating new bidding opportunities	BCC	OO	40	5	5
El-Mashaleh, Rababeh, and Hyari (2010)	benchmarking safety performance of construction contractors	CCR	IO	45	1	5
Horta, Camanho, and Da Costa (2010)	construction companies performance measurement	weighted restricted	IO	20	4	5
Ozbek, de la Garza, and Triantis (2010a)	efficiency measurement of road maintenance	BCC	Both IO and OO	229	3	1

(cont. on next page)

Table 4.2 (cont.)

Ozbek, de la Garza, and Triantis (2010b)	formulating better strategies for planning and executing bridge maintenance activities	BCC	IO	21	3	1
Tatari and Kucukvar (2011)	evaluating alternative construction materials and for guiding decision makers during material selection	CCR	IO	11	9	1
Ozbek, de la Garza, and Triantis (2012)	efficiency measurement of the maintenance of paved lanes	BCC	IO	24	3	1
El-Mashaleh (2013)	making bid or not bid decisions	BCC	Both IO and OO	39	1	12
Deng and Smyth (2013)	comparing firms performances	CCR	IO	265	-	-
Tsolas (2013)	firm performance measurement	BCC	Both IO and OO	16	4	2 and 1
Lin and Tan (2014)	measuring the organizational and individual performance in the building administration authorities	CCR	IO	12	2	2
El-Mashaleh and Edward Minchin Jr. (2014)	selection of concessionaire	CCR	IO	7	7 and 5	2
Abbasian-Hosseini et al. (2014)	identifying the improvement direction (benchmarks) for specialty trades of a project.	CCR	OO	12	3	2
Lu, Ashuri, and Shahandashti (2014)	performing building energy benchmarking	BCC	OO	90	1	7
Wang et al. (2014)	building energy performance benchmarking	CCR	IO	31	1	2

4.4. The Developed DEA Performance Model

The developed value driven performance model (VDPM) is structured on Design Quality Indicator (DQI) (Gann, Salter, and Whyte 2003), Life Cycle Cost Analysis (LCCA) (Gluch and Baumann 2004) and Data Envelopment Analysis (DEA) (Charnes, Cooper, and Rhodes 1978, Banker, Charnes, and Cooper 1984) methods. Firstly, DQI is examined and developed to define indicators of the design quality of buildings. Secondly, LCCA is chosen to measure LCC of building projects. Finally, DEA is used to evaluate design performances of buildings and to measure their design values. The proposed model consists of three main steps, which are (1) the collection and the measurement of value indicators, (2) the analysis of value indicators, (3) results and discussion.

Firstly, in the literature of the built environment, studies focus on the defining value indicators in two main axes to VBED of buildings. While the studies in the first axis focus on the inputs (Xi) (sources), other studies located in the second axis focus on the outputs (Yr) (end products) to evaluate design performances of buildings (Yavuz, Doğan, and Kale 2014). Although input oriented (IO) design performance evaluations focus on different types of sources such as finance, human, social interaction, information etc., the financial sources are the commonly used sources in the studies of design performance evaluation (Yavuz, Doğan, and Kale 2014). Furthermore, LCCA is seen as the main method for measuring the financial sources in these studies (Yavuz, Doğan, and Kale 2014). Output oriented (OO) design performance evaluations consider numerous tangible and intangible properties of buildings, which are defined in many studies to define design quality of different types of buildings (e.g., Al-Azzawi and Al-Mallak 2013, Soetanto et al. 2006, Stringer, Dunne, and Boussabaine 2012, Wong, Lam, and Chan 2009, Zemke and Pullman 2008, Sanoff 2001, Gann, Salter, and Whyte 2003).

This model focuses on the life cycle cost (LCC) of a project as the input (X_1). For the outputs of the proposed model, DQI method is adopted to define value indicators of the design quality of buildings because of three main reasons, which are (1) ease of transforming qualitative data to quantitative data, (2) being an appropriate model for measuring design quality and (3) usability by different stakeholders. In the original DQI method, the main three indicators and their sub-indicators are defined within a "Vitruvian framework" (Gann, Salter, and Whyte 2003). Firstly, the first main indicator, which is functionality (Y_1), is defined with its three sub-indicators; access ($Y_{1.1}$), space ($Y_{1.2}$) and use ($Y_{1.3}$). Secondly, the second main indicator, which is the build quality (Y_2), is defined with its three sub-indicators; performance ($Y_{2.1}$), engineering systems ($Y_{2.2}$) and construction ($Y_{2.3}$). Finally, the third main indicator, which is impact (Y_3), is defined with its four sub-indicators; urban and social integration ($Y_{3.1}$), internal environment ($Y_{3.2}$), form and materials ($Y_{3.3}$) identity and character ($Y_{3.4}$) (see Appendix A). In the original DQI method, three main indicators and their sub-indicators are defined within a "Vitruvian framework" including 96 items/statements, which stakeholders are asked to rate on a six-point Likert type scale (e.g., Gann, Salter, and Whyte 2003, Zemke and Pullman 2008, Kale, İlal, and Ülkeryıldız 2012). Thus the proposed model focuses on three outputs, which are the main indicators of DQI method; functionality (Y_1), quality (Y_2) and impact (Y_3) to define design quality of buildings.

Accordingly, an Excel-based design performance evaluation questionnaire was designed for the collection of the value indicators. In the questionnaire, the input of the proposed model, which is the LCC, is defined under three items: (1) initial cost, (2) operation cost, (3) maintenance and repair cost of buildings. Demolition costs are not included because they are the same for the similar type of buildings. For the outputs of the proposed model the items of sub-indicators of the original DQI are redefined in the questionnaire. This is because of two main reasons. The first reason is that DQI method has some general items that should be extended and supported by other items. The second reason is that DQI method includes some implicitly environmentally cost related items that should be removed to define quality properties of buildings. Accordingly, in the questionnaire, the studies of Al-Azzawi and Al-Mallak (2013), Soetanto et al. (2006), Stringer, Dunne, and Boussabaine (2012), Wong, Lam, and Chan (2009), Zemke and Pullman (2008), Sanoff (2001) were also taken as a reference to define items. After defining the items that are stated in the design performance evaluation questionnaire, the pilot studies were applied to two civil engineers and three architects to test the clarity and the comprehensibility of items and general explanations by asking their level of satisfaction with the questionnaire.

After collecting the value indicators, their measurement includes two steps. The first step is to calculate LCC of the selected building projects, which is the only input of the proposed model. The second step is measuring the level of design quality of selected projects according to three main indicators. These indicators are functionality (Y_1), build quality (Y_2) and impact (Y_3) of selected building projects, which are the three outputs of the proposed model.

The first step is to calculate LCC of the building. The only input of the proposed model which is LCC of buildings is calculated as its annual value considering concepts of engineering economics. Accordingly, the annual LCC of a building ($C_{TANNUAL}$) is calculated using Equations (4.23) to (4.25) where C_1 is the annual value of the initial cost (C_i), which is the present cost, C_2 is the annual value of the operating cost (C_o), which is the annual cost, C_3 is the annual value of the maintenance and repair cost (C_{MR}), which is the future cost, N is the number of interest periods and i is the interest rate. Maintenance and repair costs could also be defined annually. In this situation, any conversion is not required to change time value of maintenance and repair costs to define annual LCC.

$$C_T = C_I + C_O + C_{MR} \tag{4.23}$$

$$C_T = C_1 + C_2 + C_3 \tag{4.24}$$

$$C_{T_{ANNUAL}} = \left\{ C_I \times \left[\frac{i \times (1+i)^N}{(1+i)^N - 1} \right] \right\} + C_2 + C_3 \tag{4.25}$$

The second step of the measurement of the value indicators is to measure the design quality of selected building projects. Accordingly, three main indicators (outputs of the proposed model) and their sub-indicators for each output are defined according to items that indicate different types of properties of buildings. In this respect, firstly three main indicators are developed as outputs (Y_1, Y_2 and Y_3). Secondly, the sub-indicators are defined by the items that are rated by stakeholders of projects. Accordingly, items are designed to be graded subjectively with the seven-point Likert scale (1 = completely disagree, 7 = completely agree) in the Excel-based questionnaire. Seven-point Likert scale helps to transform the qualitative scale to a quantitative scale. After that, the performance of outputs of buildings is calculated taking the arithmetic mean of the sub-indicators of the main indicators according to Equation (4.26).

$$Y_1 = \frac{1}{3}\sum_{j_1=1}^{3} Y_{1j_1}$$

$$Y_2 = \frac{1}{3}\sum_{j_2=1}^{3} Y_{2j_2} \qquad (4.26)$$

$$Y_3 = \frac{1}{4}\sum_{j_3=1}^{4} Y_{3j_3}$$

Secondly, after collecting and measuring the input and outputs, the next step is deciding which types of DEA method are used for design performance evaluation. The stakeholders of the building projects could prefer to evaluate design performance under two conditions. The first condition is keeping the outputs (functionality, build quality and impact) constant and decreasing the input (cost). The second condition is keeping the input constant and increasing the outputs. The expectations of stakeholders lead to constructing the model in a flexible way. Thus, the proposed value-driven performance model presents the results of design performances of buildings both in IO-BCC, which is used for the first condition and OO-BCC, which is used for the second condition to meet the expectations of stakeholders.

The final step of the developed model is to examine the results and to discuss them. In this step, three main stages are defined to develop design strategies. These are;

1. Comparing relative design performance efficiency levels of projects
2. Indicating and selecting the reference project(s), which are best performing (successful) projects, as opposed to the less performing (unsuccessful) projects
3. Developing IO and OO strategies to improve design performance of the relatively unsuccessful projects.

CHAPTER 5

THE APPLICATION OF THE DEVELOPED MODEL

This chapter consists of five sections. In the first section, the case study is explained in detail by defining the aim of choosing the selected projects with their project narratives. In the second and the third sections, the definition of the input (life cycle cost) and the outputs (design quality indicators) of the DEA performance model are defined in terms of the collection and the measurement of inputs and outputs (value indicators). In the fourth section, the results of the analysis of Efficiency Measurement System (EMS), a DEA model, are indicated. Finally, the discussion section focuses on two important issues. Firstly, the relationship between the concept of design value and the DEA model efficiency are explained by highlighting the existing body of knowledge. Secondly, how quantitative results are improved to be quantitative results to improve the design value of housing projects is examined. In conclusion, this chapter examines an application of the DEA performance model which analyzes the design value of building projects with respect to the expectations of their stakeholders.

5.1. Case Study

The case study is applied on eight housing projects of a design and construction firm in İzmir that deals with the turnkey and percentage types of project. Each of the housing projects is designed differently by presenting high design quality to their customers. These factors affect the selection of these eight projects because the owners of the firm are involved in and responsible for every life cycle phase of the housing projects from the initial design phase to the after-sale phase. Generally, the housing projects are located in Sahilevleri, Güzelbahçe and Limanreis districts where the same types of housing projects are located. In this section, the details of the housing projects are explained to understand them in terms of their locations, sizes and architectural details.

Project 1 (P_1) is a housing project that is located in Limanreis and was finished in 2014. P_1 consists of three blocks. The first block is 215 m² and 4+1. The second block is 177 m². Finally, the third block is 177 m² and 3+1.

Project 2 (P_2) is a housing project that is located in Sahilevleri and was finished in 2014. It is 4+1 and is located on a 2183 m² plot including 245m² closed space with 75 m² terrace.

Project 3 (P_3) is a housing project that is located in Sahilevleri near the seaside and finished in 2013. It is 433 m² and 5+1.

Project 4 (P_4) is a housing project that is located in Sahilevleri and was finished in 2013. It is 247 m² and 4+1.

Project 5 (P_5) is a housing project that is located in Sahilevleri near to P4 and was finished in 2011. It is 345 m² and 5+1.

Project 6 (P_6) is a housing project that is located in Güzelbahçe and was finished in 2013. It consists of three blocks in a 1410 m² closed area.

Project 7 (P_7) is a housing project that is located in Sahilevleri near to the seaside and finished in 2013. It is 327 m² and 4+1.

Project 8 (P_8) is a housing project that is located in Sahilevleri and was finished in 2011. It is 316 m² and 5+1.

More details of the eight projects including exterior photos, site plans and plans are in Appendix B.

5.2. Definition of the Input of the DEA Performance Model

The input of the DEA performance model is defined by the annual LCC of housing projects. Initial costs, operation costs, maintenance and repair costs of projects are defined by questionnaire indicating the type of costs, the date, periods and the amount of costs, which are shown in Table 5.1.

According to Table 5.1, the initial costs of housing projects consist of two types of costs. The first type of initial costs occurs because of the land-acquisition and the second type of initial costs is the sum of the total cost from the building permits to the end of the projects. In addition to this, the operation, maintenance and repair costs of the projects are defined by the architect approximately in their annual costs that occur in a ten-year period of time.

Table 5.1. Inputs of Projects.

Housing Projects	Initial Costs				Operation Costs	Maintenance and Repair Costs
	Date of Land-Acquisition	Amount (₺)	Date of The End of Projects	Amount (₺)	Annual Amount (₺)	Annual Amount (₺)
P1	07.10.2011	576,670	07.02.2014	974,701	750	5,400
P2	03.08.2012	546,000	04.07.2014	867,774	400	3,000
P3	01.08.2008	404,951	04.01.2013	623,892	300	1,500
P4	07.01.2011	413,725	07.06.2013	361,787	250	1,500
P5	05.06.2009	390,000	05.08.2011	333,476	300	1,500
P6	01.07.2011	468,000	04.10.2013	686,467	2100	1,000
P7	05.03.2010	700,000	04.11.2011	480,564	400	2,000
P8	02.10.2009	274,500	01.07.2011	317,000	250	2,000

Within the framework of this study, LCC of projects are defined annually within a period of ten years, which is between January 2015 and January 2025. During the calculation, two main steps are followed. In the first step, principles of engineering economics are used to convert initial costs to their future costs on January 2015. In the second step, the annual LCC are calculated.

For the initial costs of projects, to be able to define their annual cost values within the defined period, they need to be defined at their future cost values on January 2015 (Table 5.2). In the calculations, the interest rate per period (i) is taken to be the variable interest rates of mortgage loans, which are compounded monthly, and determined by the Central Bank of The Republic of Turkey (see Appendix C). The annual value of total initial costs on January 2015 is calculated between January 2015 and January 2025 (Table 5.3). Interest rate per period is assumed to be fixed and compounded annually while converting total initial cost values determined on January 2015 to annual cost values for the period of ten years. Accordingly, Table 5.2 and Table 5.3 show the calculation of the annual initial cost (C_1) of projects between January 2015 and January 2025. The annual LCC of projects is used for the data analysis. Monthly LCC (C_{1M}) values are also listed in Table 5.3 for defining the input (cost) values of the developed model.

Table 5.2. Initial Costs on Jan. 2015 (C_i).

$C_i = (C_{i1}\times(1+i_1)\times(1+i_2)\times\ldots\times(i+i_n)) + (C_{i2}\times(1+i_1)\times(1+i_2)\times\ldots\times(i+i_m))$					
Housing Projects	**Date of Land-Acquisition**	**Amount on Jan. 2015 (C_{i1}) (₺)**	**Date of The End of Projects**	**Amount on Jan. 2015 (C_{i2}) (₺)**	**Total Initial Cost Value on Jan. 2015 (C_i) (₺)**
P1	07.10.2011	837,683.01	07.02.2014	1,087,330.71	1,925,013.72
P2	03.08.2012	1,144,551.91	04.07.2014	916,971.96	2,061,523.87
P3	01.08.2008	906,481.77	04.01.2013	773,322.46	773,322.46
P4	07.01.2011	650,807.29	07.06.2013	431,224.28	1,082,031.57
P5	05.06.2009	743,493.59	05.08.2011	494,542.48	1,238,036.07
P6	01.07.2011	700,772.79	04.10.2013	793,654.55	1,494,427.34
P7	05.03.2010	1,205,297.11	04.11.2011	690,892.13	1,896,189.24
P8	02.10.2009	497,398.11	01.07.2011	474,668.75	972,066.86

Table 5.3. Annual and Monthly Initial Costs between Jan. 2015 and Jan. 2025.

$(C_1)=(C_i)\times((i\times(1+i)^N)/(1+i)^N-1))$				
Housing Projects	**Interest Rate per Period (i)**	**Number of Interest Periods (N)**	**Initial Cost on January 2015 (C_i) (₺)**	**Annual Initial Cost (C_1) (₺)**
P1	0,1092	10	1,925,013.72	325,774.36
P2	0,1092	10	2,061,523.87	348,876.28
P3	0,1092	10	1,679,804.23	284,277.01
P4	0,1092	10	1,082,031.57	183,114.61
P5	0,1092	10	1,238,036.07	209,515.6
P6	0,1092	10	1,494,427.34	252,905.27
P7	0,1092	10	1,896,189.24	320,896.33
P8	0,1092	10	972,066.86	164,505.04
Housing Projects	**Interest Rate per Period (i)**	**Number of Interest Periods (N)**	**Initial Cost on January 2015 (C_i) (₺)**	**Monthly Initial Cost (C_{1M}) (₺)**
P1	0,0091	120	1,925,013.72	26,429.97
P2	0,0091	120	2,061,523.87	28,304.22
P3	0,0091	120	1,679,804.23	23,063.3
P4	0,0091	120	1,082,031.57	14,856.03
P5	0,0091	120	1,238,036.07	16,997.93
P6	0,0091	120	1,494,427.34	20,518.12
P7	0,0091	120	1,896,189.24	26,034.21
P8	0,0091	120	972,066.86	13,346.24

The operation (C_2), maintenance and repair (C_3) costs of projects are indicated in their annual values by the architect for the period of ten years. Thus, the operation, maintenance and repair costs do not require any calculation for the conversion of their time value.

As a result, Table 5.4 indicates the annual value of LCC ($C_{TANNUAL}$) of projects in a 10-year period between January 2015 and January 2025.

Table 5.4. Annual LCC of Housing Projects.

$C_{T_{ANNUAL}} = C_1 + C_2 + C_3$				
Housing Projects	C_1 (₺)	C_2 (₺)	C_3 (₺)	$C_{T_{ANNUAL}}$ (₺)
P1	325,774.36	750	5,400	331,924.36
P2	348,876.28	400	300	349,576.28
P3	284,277.01	300	1,500	286,077.01
P4	183,114.61	250	1,500	184,864.61
P5	209,515.6	300	1,500	211,315.6
P6	252,905.27	2,100	1,000	256,005.27
P7	320,896.33	400	2,000	323,296.33
P8	164,505.04	250	2,000	166,755.04

5.3. Definition of Outputs of DEA Performance Model

The outputs of the DEA performance model are functionality (Y_1), build quality (Y_2) and impact (Y_3). The outputs in this case study are defined by the owner of the firm who is also responsible for the design, construction and expectations of the clients of the housing projects. After the application of the questionnaire, design quality indicators are measured according to Equation (4.26). Accordingly, the quantitative responses of the three design quality indicators, which are the rounded values of the actual values, are shown quantitatively in Table 5.5, Table 5.6, and Table 5.7.

Table 5.5. Questionnaire Responses for Functionality.

$$Y_1 = \frac{1}{3}\sum_{j_1=1}^{3} Y_{1j_1}$$

Housing Projects	Access (Y_{11})	Space (Y_{12})	Use (Y_{13})	**Functionality ($\boldsymbol{Y_1}$)**
P1	6,07	6,27	6,08	**6,14**
P2	5,36	6,18	6,69	**6,08**
P3	6,29	6,45	6,15	**6,30**
P4	4,71	6,45	6,38	**5,85**
P5	4,71	6,64	6,62	**5,99**
P6	4,79	6,09	6,62	**5,83**
P7	4,57	6,73	6,31	**5,87**
P8	5,50	6,36	6,46	**6,11**

Table 5.6. Questionnaire Responses for Build Quality.

$$Y_2 = \frac{1}{3}\sum_{j_2=1}^{3} Y_{2j_2}$$

Housing Projects	Performance (Y_{21})	Engineering Systems (Y_{22})	Construction (Y_{23})	**Build Quality ($\boldsymbol{Y_2}$)**
P1	6,13	5,38	6,79	**6,10**
P2	6,07	5,38	6,57	**6,01**
P3	6,13	5,46	6,64	**6,08**
P4	6,27	5,46	6,79	**6,17**
P5	6,13	5,46	6,71	**6,10**
P6	6,00	5,38	6,86	**6,08**
P7	6,33	5,46	6,64	**6,15**
P8	6,53	5,46	6,71	**6,24**

Table 5.7. Questionnaire Responses for Impact.

$$Y_3 = \frac{1}{4}\sum_{j_3=1}^{4} Y_{3j_3}$$

Housing Projects	Urban and Social Integration (Y_{31})	Internal Environment (Y_{32})	Form and Materials (Y_{33})	Identity and Character (Y_{34})	**Impact ($\boldsymbol{Y_3}$)**
P1	6,31	6,77	6,63	6,50	**6,55**
P2	6,31	6,77	6,50	6,36	**6,48**
P3	6,85	6,54	6,75	6,71	**6,71**
P4	6,38	6,69	6,75	6,36	**6,55**
P5	6,38	6,62	6,75	6,36	**6,53**
P6	6,15	6,69	4,88	6,29	**6,00**
P7	6,62	6,85	6,75	6,36	**6,64**
P8	6,38	6,77	6,75	6,29	**6,55**

5.4. Results of the DEA Performance Model

The case study aims to examine the eight housing projects in terms of their relative design performance efficiencies. During the evaluation of the input and outputs, Efficiency Measurement System (EMS) model is used for defining the relative design performance efficiency of the housing projects. The aim of evaluating design performances of housing projects is to inform the stakeholders about the least rated projects and to improve the least rated housing projects relative to the design performance efficiency of the best rated projects individually.

The collected data, which are annual LCC ($C_{TANNUAL}$ or X_1) and three design quality indicators (Y_1, Y_2 and Y_3), are evaluated by EMS model considering two conditions. For the first condition, which is keeping outputs constant and decreasing the input, IO-BCC model is used. For the second condition, which is keeping input constant and increasing the outputs, OO-BBC is used. Accordingly, the results of the evaluation are shown in Table 5.8 for the first condition and Table 5.9 for the second condition. Rounded values of indicators are used for DEA analysis and design improvements. Results of the DEA analysis on actual values are also listed in Table 5.8 and Table 5.9.

Table 5.8. Results of IO-BCC.

Housing Projects	**Input**	**Outputs (rounded values)**			**IO-BCC**	
	X_1 (₺)	**Y_1**	**Y_2**	**Y_3**	**Performance Efficiency Scores**	**Reference Projects**
P1	331,924.36	6,14	6,10	6,55	0,560	3 (0,16) 8 (0,84)
P2	349,576.28	6,08	6,01	6,48	0,477	8 (1,00)
P3	286,077.01	6,30	6,08	6,71	1	2
P4	184,864.61	5,85	6,17	6,55	0,902	8 (1,00)
P5	211,315.6	5,99	6,10	6,53	0,790	8 (1,00)
P6	256,005.27	5,83	6,08	6,00	0,651	8 (1,00)
P7	323,296.33	5,87	6,15	6,64	0,723	3 (0,56) 8 (0,44)
P8	166,755.04	6,11	6,24	6,55	1	6
Housing Projects	**Input**	**Outputs (actual values)**			**IO-BCC**	
	X_1 (₺)	**Y_1**	**Y_2**	**Y_3**	**Performance Efficiency Scores**	**Reference Projects**
P1	331,924.36	6,14035964	6,101221001	6,550480769	0,563	3 (0,17) 8 (0,83)
P2	349,576.28	6,077089577	6,007570208	6,483516484	0,477	8 (1,00)
P3	286,077.01	6,298035298	6,079242979	6,712225275	1	2
P4	184,864.61	5,851148851	6,171306471	6,546016484	0,902	8 (1,00)
P5	211,315.6	5,988677989	6,103052503	6,526785714	0,789	8 (1,00)
P6	256,005.27	5,830669331	6,080586081	6,001717033	0,651	8 (1,00)
P7	323,296.33	5,868797869	6,145909646	6,64217033	0,728	3 (0,58) 8 (0,42)
P8	166,755.04	6,108391608	6,236385836	6,54739011	1	6

Table 5.9. Results of OO-BCC.

Housing Projects	Input	Outputs (rounded values)			OO-BCC	
	X1 (₺)	Y1	Y2	Y3	Performance Efficiency Scores	Reference Projects
P1	331,924.36	6,14	6,10	6,55	1,01018	3 (0,49) 8 (0,51)
P2	349,576.28	6,08	6,01	6,48	1,022935	3 (0,58) 8 (0,42)
P3	286,077.01	6,30	6,08	6,71	1	5
P4	184,864.61	5,85	6,17	6,55	1,00371	3 (0,15) 8 (0,85)
P5	211,315.6	5,99	6,10	6,53	1,012213	3 (0,37) 8 (0,63)
P6	256,005.27	5,83	6,08	6,00	1,026316	8 (1,00)
P7	323,296.33	5,87	6,15	6,64	1,0000000003	3 (0,56) 8 (0,44)
P8	166,755.04	6,11	6,24	6,55	1	6
Housing Projects	Input	Outputs (actual values)			OO-BCC	
	X1 (₺)	Y1	Y2	Y3	Performance Efficiency Scores	Reference Projects
P1	331,924.36	6,14035964	6,101221001	6,550480769	1,00971	3 (0,48) 8 (0,52)
P2	349,576.28	6,077089577	6,007570208	6,483516484	1,02307	3 (0,57) 8 (0,43)
P3	286,077.01	6,298035298	6,079242979	6,712225275	1	5
P4	184,864.61	5,851148851	6,171306471	6,546016484	1,00403	3 (0,15) 8 (0,85)
P5	211,315.6	5,988677989	6,103052503	6,526785714	1,01241	3 (0,37) 8 (0,63)
P6	256,005.27	5,830669331	6,080586081	6,001717033	1,02562	8 (1,00)
P7	323,296.33	5,868797869	6,145909646	6,64217033	1,00001	3 (0,58) 8 (0,42)
P8	166,755.04	6,108391608	6,236385836	6,54739011	1	6

According to Table 5.8 and Table 5.9, the relative design performance efficiencies of the selected housing projects are evaluated by defining and solving two different problems of linear programming that are IO-BCC (Equations (4.11) to (4.22)) and OO-BCC (Equations (4.1) to (4.10)) using EMS model. In both of the tables, the performance efficiency scores (S) of two housing projects (P_3 and P_8) equal 1, which means that they are the best rated, best performing, housing projects in both orientations. Additionally, the other six housing projects (P_1, P_2, P_4, P_5, P_6 and P_7) have lower S values than 1 in IO-BCC and have higher S values than 1 in OO-BCC. Thus, the six housing projects that have S values other than 1 are considered as the least rated, less performing, in both orientations.

Furthermore, in the column of the reference projects in Table 5.10 and Table 5.11, the reference projects are specifically indicated to the least rated projects. Accordingly, while P_8 is the reference six times to the least rated housing projects (P_1, P_2, P_4, P_5, P_6 and P_7) and P_3 is the reference two times to the least rated housing projects (P_1 and P_7) for IO-BCC, P_8 is the reference to six the least rated housing projects (P_1, P_2,

P_4, P_5, and P_7) and P_3 is the reference five times to the least rated housing projects (P_1, P_2, P_4, P_5 and P_7) for OO-BCC. Moreover, the numbers in parentheses highlight to what extent there is the resemblance (R) between the best rated and the least rated projects (Yavuz, Doğan, and Kale 2014, Atmaca et al. 2012).

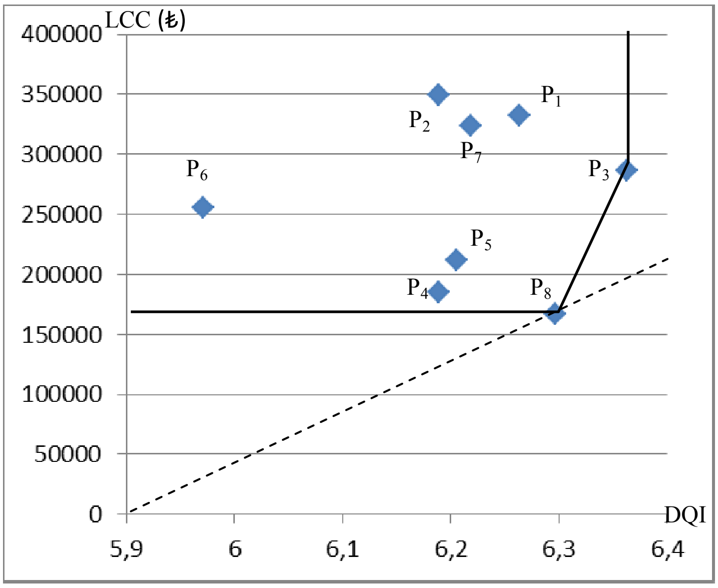


Figure 5.1. Graphical Representation of the Results.

The percentages of to what extent the least rated projects resembles (R) the best rated projects help for developing the strategies to improve the least rated projects (Atmaca et al. 2012). For instance, for the IO strategies for P_1, the sum of the 16% of the input of P_3 and 84% of the input of P_8 and for the OO strategies of P_1, the sum of 49% of each output of P_3 and 51% of each output of the P_8 indicates the target value for each input and outputs of P_1 for being a best rated project relative to reference projects (P_3 and P_8). Accordingly, the calculation of the target value (TV) of the actual value (AV) of each project and the percentages of potential improvements (PI) for the input (for IO strategies) and the output (for OO strategies) could be defined by Equation (5.1) and Equation (5.2) (Atmaca et al. 2012).

$$TV = (AV \text{ of } P_3 \times R) + (AV \text{ of } P_8 \times R) \quad (5.1)$$

$$PI = |(TV-AV)/AV| \times 100 \quad (5.2)$$

Accordingly, six least rated projects are aimed to be improved according to both OO strategies (Table 5.10) and IO strategies (Table 5.11) by taking the references to the best rated projects, which are P_3 and P_8.

Table 5.10. Target Values of the Least Rated Projects for Developing OO Strategies.

Housing Projects	**Outputs (O)**	**Actual Value (AV)**	**Target Value (TV)**	**Potential Improvement (%)**
P1	Y1	6,14	6,20	1,0
	Y2	6,10	6,16	1,0
	Y3	6,55	6,63	1,2
P2	Y1	6,08	6,22	2,3
	Y2	6,01	6,15	2,3
	Y3	6,48	6,64	2,5
P4	Y1	5,85	6,14	4,9
	Y2	6,17	6,21	0,7
	Y3	6,55	6,57	0,4
P5	Y1	5,99	6,18	3,2
	Y2	6,10	6,18	1,2
	Y3	6,53	6,61	1,3
P6	Y1	5,83	6,11	4,8
	Y2	6,08	6,24	2,6
	Y3	6,00	6,55	9,1
P7	Y1	5,87	6,21	5,9
	Y2	6,15	6,15	0,0
	Y3	6,64	6,64	0,0

According to target values with respect to OO strategies and their potential improvements are indicated in Table 5.10. If the actual values of all the least rated projects (P_1, P_2, P_4, P_5, P_6 and P_7) are increased to target values, the least rated projects are improved to become the best rated projects relative to P_3 and P_8.

Table 5.11. Target Values of the Least Rated Projects for Developing IO Strategies.

Housing Projects	Input	Actual Value	Target Value	Potential Improvement (%)
P1	X_1	₺331,924.36	₺185,846.56	44
P2	X_1	₺349,576.28	₺166,755.04	52
P4	X_1	₺286,077.01	₺166,755.04	10
P5	X_1	₺184,864.61	₺166,755.04	21
P6	X_1	₺211,315.6	₺166,755.04	35
P7	X_1	₺256,005.27	₺233,575.34	28

According to target values with respect to IO strategies and their potential improvements are indicated in Table 5.10. If the actual values of all the least rated projects (P_1, P_2, P_4, P_5, P_6 and P_7) are decreased to target values, the least rated projects are improved to become the best rated projects relative to P_3 and P_8.

5.5. Discussion

In the literature of the built environment, generally, the value of different types of projects is often defined objectively as the value of the proportion of the output of the projects, which is quality, to the input of the project, which is cost (Dell'Isola 1997, CRISP Commission 04/13 2005). Numerous studies have been conducted to investigate various inputs and outputs to assess the value. The outputs are commonly defined as what we could get from the project: its benefits and the required quality (CRISP Commission 04/13 2005, Thomson et al. 2003, Saxon 2005, Burt 1978). The inputs are indicated as what we could give in order to get the projects: sacrifices, least cost and expenses (e.g., time, people, money) (CRISP Commission 04/13 2005, Saxon 2005, Burt 1978, Thomson et al. 2003). Numerous studies contribute to enrich the concept of value by relying on (1) the satisfactions of the stakeholders, (2) the context and (3) the value type (Kelly, Male, and Graham 2004, Barima 2010, Devine-Wright, Thomson, and Austin 2003). In different contexts, different types of value definitions urged various types of inputs and outputs for projects, which are called value indicators. Several Value Assessment Methods (VAM) have been developed for achieving the maximum value depending on defined objectives (Table 2.4). Numerous value based evaluation approaches (VBE) have been developed by integrating different value-driven performance models (VDPM), which use different analysis methods to evaluate the value of projects and measure the performance efficiency of projects (Table 3.6 and Table 3.7). Beginning with the end of the 1990s, the built environment focused on increasing the design value of buildings depending on the expectations of different stakeholders as a reaction to the existing comprehension of the concept of value (Devine-Wright, Thomson, and Austin 2003, Gann, Salter, and Whyte 2003, Winch, Courtney, and Allen 2010). Different VDPM were developed in order to evaluate the performance efficiencies of buildings from different perspectives (Table 3.10). Regarding all developments in the built environment, the proposed DEA performance model aims to provide an evaluation of design quality and LCC performance of building projects. Design performance efficiency is calculated as the ratio of outputs (design quality indicators) to the input (annual LCC) (Ramanathan 2003). The results are used for developing strategies depending on the relative performance efficiencies.

There are also studies, which develop DEA based models, for various building related issues (Table 5.12). Vitner et al. (2006) proposed a DEA model for project benchmarking in design and construction phases. They defined the cost of the projects using Cost Breakdown Structure (CBS) method. According to results of the DEA, Vitner et al. (2006) defined projects on efficient frontier and explained the possible reasons why the least rated projects have higher budgets relative to lower budgeted (the best rated) projects considering both input and output performances of the projects.

Cariaga, El-Diraby, and Osman (2007) proposed a model for developing a decision support tool for stakeholders to select efficiently designed building components in pre-project planning and design phases. During the evaluations, FAST and QFD methods were used for defining outputs, LCC method was used for input (cost) of the model and DEA method was used for indicating best performing designs according to customer requirement efficiency index (CREI) (Cariaga, El-Diraby, and Osman 2007).

Tatari and Kucukvar (2011) developed a DEA model for evaluating eco-efficiency for the selection of construction materials. During the evaluations, LCCA method was used to indicate the output and Life Cycle Assessment (LCA) method was used to indicate the ten inputs of the model. According to the results of the DEA model, the percent improvement analysis was applied to decrease values of the selected inputs in order to reach to the best efficiency (Tatari and Kucukvar 2011).

Grösche (2009) developed a DEA method for defining and improving energy efficiencies of residences. According to the results of the DEA, the selected indicators were defined and regression analysis was applied to them for enhancing the energy efficiency of residences (Grösche 2009).

Lee and Lee (2009) developed a DEA model for evaluating energy performances of forty-seven government office buildings. Other than the traditional models, Lee and Lee (2009) defined scale and management factors dividing overall energy efficiency into pure technical efficiency and scale efficiency. According to the results, for improving management factors, minimum energy consumptions were rated in different scales and the results were discussed (Lee and Lee 2009).

Lu, Ashuri, and Shahandashti (2014) evaluated overall, peer and self-efficiency values of each property for every month in a year and discuss the differences in the efficiency scores by developing a DEA model. The proposed model was expected to monitor and improve energy benchmarking of multifamily properties of buildings (Lu, Ashuri, and Shahandashti 2014).

Wang et al. (2014) developed a DEA model for calculating and comparing overall, scale and management efficiencies of one-story residential buildings. The study aimed to indicate low energy performing (successful) buildings for increasing the overall efficiencies, by improving the inefficient management efficiency values (Wang et al. 2014).

Table 5.12. DEA Models Related to Buildings.

Sources	Objective of DEA Models	Inputs and Outputs	Context	Methods used for Inputs and Outputs
Vitner et al. (2006)	interpreting outcomes for project benchmarking	inputs: cost, work content, level of monitoring, level of uncertainty outputs: design yield, operation yield, training yield, documentation yield, project management yield	design and construction phases	Cost Breakdown Structure (CBS) (cost output)
Cariaga, El-Diraby, and Osman (2007)	developing a decision support tool for stakeholders to select efficiently designed building components	input: cost outputs: provide smartness, attract new students, offer aesthetics, conserve energy, maintain flexibility, provide comfortable space	pre-project planning, design phase	FAST and QFD (for outputs) LCC (for input)
Tatari and Kucukvar (2011)	evaluating eco-efficiency for the selection construction materials	inputs: ten environmental impact categories of wall finishes output: LCC	material selection	LCC (for output) Life Cycle Assessment (LCA) (for input)
Grösche (2009)	residential energy efficiency improvements	input: total energy consumption serves outputs: living space persons electric appliances fridges, freezers heating degree days cooling degree days	finished residential buildings	BEES
Lee and Lee (2009)	measuring energy efficiency of buildings	input: climate-adjusted energy consumption outputs: floor area number of occupants (scale factors)	finished residential buildings	-

(cont. on next page)

Table 5.12. (cont.)

Lu, Ashuri, and Shahandashti (2014)	energy efficiency benchmarking of multifamily properties	input: 12 month energy consumptions outputs: number of apartments age of properties number of buildings number of residents number of bedrooms number of washing machines number of parking lots	finished office buildings	-
Wang et al. (2014)	benchmarking energy efficiency of buildings	input: the degree day normalized energy use intensity (DEUI) outputs: number of occupants the floor area	finished residential buildings	-

As seen in Table 5.12, the existing studies, which use DEA method, define different objectives such as benchmarking projects, decision support tool for design of building components, evaluating energy efficiency of materials and buildings etc. Furthermore, they focus on a specific life cycle phase (e.g., pre-project planning, material selection, design or construction phases), and a specific type of building project (e.g., residential, office) by considering various methods (e.g., CBS, FAST, QFD, LCC, BEES) for data collection, measurement, and analysis. In this thesis, the developed DEA model differs from the existing studies in terms of the mentioned factors: objective of model, context and types of projects, and selection of methods for data collection and measurement, and analysis. The developed model is proposed for evaluating design value of different types of buildings in whole life cycle phases of projects by using DQI and LCCA methods for data collection and measurement.

This thesis develops a DEA performance model by using the DQI method for indicating outputs (functionality, build quality, impact) and the LCCA method for indicating the input (annual LCC of the housing projects). According to the Table 5.14, rather than studies on various building related issues in the literature, the DEA performance model in this study is proposed for defining and improving the design value of projects based on one determined perspective (e.g., architect, constructor, occupant etc.) for different life cycle phases of a building project. The DEA model allows the development of strategies according to the selected perspective.

Specifically, in this case study, EMS is a DEA tool that is used for measuring relative design performance efficiencies of eight housing projects. The relative performance efficiencies of projects enable the development of many strategies for increasing the design value of housing projects. First of all, EMS calculation defines best performing (the best rated) projects. Secondly, the calculation also indicates the percentages of to what extent the least rated projects resemble (R) to the best rated projects. All these results of the calculation allow increasing design performance efficiencies of the least rated projects relative to the best rated projects. Thus, relatively the best performing projects are used for improving performances of outputs (design quality indicators), which increases the design quality of the least rated projects. They could also be used for improving the performance of the input (annual LCC) by indicating how much the LCC of the least rated projects needs to be decreased to achieve relatively maximum efficiency (the maximum design value). The capability of EMS, in terms of developing different strategies, allows the improvement of design value of housing projects by increasing design quality or decreasing LCC of housing projects according to different expectations of stakeholders.

5.5.1. Output Oriented Strategies

Findings provide the architect with the required information about deriving the general deficiencies of the least rated projects in terms of design quality. After analyzing value indicators in EMS, how these quantitative results transform into qualitative results is important for stakeholders to develop design (output oriented) strategies. The output oriented strategies, which increase the design performance of housing projects, are explained by arguing the range of tables between Table 5.13 and Table 5.23. Four types of information are included from Table 5.13 and Table 5.22: (1) responses in the questionnaire, which include the quantitative expressions of the items of sub-indicators, (2) actual values (AV) and (3) target values (TV) of main indicators, and (4) the highlighted items, which have lower points than seven, are the potential items that are used for design quality improvements. Table 5.23 is developed to inform the architect about the best rated items by the respondents. In Table 5.23, the numbers of all the seven-point evaluated items are rated to the total item numbers of the selected sub-indicator to calculate the overall success of each project. During these calculations, all the items evaluated by the seven-point Likert scale are assumed as the best rated and other items are assumed as the least rated. Furthermore, the averages are also calculated to indicate the overall success of each project with respect to the main and sub-indicators.

Table 5.13. Items of Access.

Items of $Y_{1.1}$	1	2	3	4	5	6	7	8	9	10	11	12	13	14	AV	TV
P1	7	7	6	7	5	7	7	4	6	6	7	7	7	2	6,14	6,20
P2	5	7	6	6	6	5	3	3	4	5	6	7	7	5	6,08	6,22
P3	7	7	7	6	6	7	7	4	5	5	7	7	7	6	-	-
P4	4	7	5	6	4	5	5	2	4	3	5	7	7	2	5,85	6,14
P5	4	7	5	6	4	5	5	2	4	3	5	7	7	2	5,99	6,17
P6	5	7	4	5	3	4	3	2	4	5	5	7	7	6	5,83	6,11
P7	3	7	5	6	4	5	5	2	4	5	5	6	5	2	5,87	6,21
P8	7	7	6	6	6	5	3	3	4	5	6	7	7	5	-	-

Table 5.14. Items of Space.

Items of $Y_{1.2}$	1	2	3	4	5	6	7	8	9	10	11	AV	TV
P1	7	7	7	7	7	4	7	5	7	5	6	6,14	6,20
P2	7	7	5	7	5	6	7	5	7	5	7	6,08	6,22
P3	7	6	7	7	7	5	7	4	7	7	7	-	-
P4	7	7	5	7	7	5	7	5	7	7	7	5,85	6,14
P5	7	7	7	7	6	6	7	5	7	7	7	5,99	6,17
P6	7	6	5	7	6	5	7	5	7	7	5	5,83	6,11
P7	7	7	7	7	7	6	7	5	7	7	7	5,87	6,21
P8	7	6	7	7	6	5	7	4	7	7	7	-	-

Table 5.15. Items of Use.

Items of $Y_{1.3}$	1	2	3	4	5	6	7	8	9	10	11	12	13	AV	TV
P1	7	7	7	5	5	7	6	7	6	7	5	3	7	6,14	6,20
P2	7	7	7	7	6	7	6	7	7	7	5	7	7	6,08	6,22
P3	7	7	7	6	5	7	5	7	6	7	5	4	7	-	-
P4	7	7	7	7	5	7	5	7	7	5	7	5	7	5,85	6,14
P5	7	7	7	7	6	7	5	7	7	7	5	7	7	5,99	6,17
P6	7	7	7	7	6	7	5	7	7	7	5	7	7	5,83	6,11
P7	7	7	7	6	5	7	5	7	6	7	5	6	7	5,87	6,21
P8	7	7	7	7	5	7	5	7	7	7	5	6	7	-	-

Table 5.16. Items of Performance.

Items of $Y_{2.1}$	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**AV**	**TV**
P1	7	6	6	7	7	7	7	7	7	7	7	6	5	4	2	6,10	6,16
P2	5	7	7	7	7	7	7	5	7	7	7	6	5	5	2	6,01	6,15
P3	5	7	7	7	7	7	7	7	7	7	5	6	6	5	2	-	-
P4	6	7	7	7	7	7	7	7	7	7	5	6	6	6	2	6,17	6,21
P5	5	7	7	7	7	7	7	7	7	7	5	6	6	5	2	6,10	6,18
P6	7	6	6	7	7	7	7	7	7	6	6	6	5	4	2	6,08	6,24
P7	6	7	7	7	7	7	7	7	7	7	7	6	6	5	2	6,15	6,15
P8	7	7	7	7	7	7	7	7	7	7	7	6	7	6	2	-	-

Table 5.17. Items of Engineering Systems.

Items of $Y_{2.2}$	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**AV**	**TV**
P1	3	7	7	6	7	1	6	5	2	7	7	7	5	6,10	6,16
P2	3	7	7	6	7	1	6	5	2	7	7	7	5	6,01	6,15
P3	3	7	7	7	7	1	6	5	2	7	7	7	5	-	-
P4	3	7	7	7	7	1	6	5	2	7	7	7	5	6,17	6,21
P5	3	7	7	7	7	1	6	5	2	7	7	7	5	6,10	6,18
P6	3	7	7	6	7	1	6	5	2	7	7	7	5	6,08	6,24
P7	3	7	7	7	7	1	6	5	2	7	7	7	5	6,15	6,15
P8	3	7	7	7	7	1	6	5	2	7	7	7	5	-	-

Table 5.18. Items of Construction.

Items of $Y_{2.3}$	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**AV**	**TV**
P1	7	7	6	7	7	7	6	7	7	7	7	7	7	6	6,10	6,16
P2	7	7	7	7	7	7	6	7	7	7	7	7	5	4	6,01	6,15
P3	7	7	7	7	7	7	6	7	7	7	7	7	7	3	-	-
P4	7	7	7	7	7	7	6	7	7	7	7	7	6	6	6,17	6,21
P5	7	7	6	7	7	7	6	7	7	7	7	7	7	5	6,10	6,18
P6	7	7	7	7	7	7	6	7	7	7	7	7	7	6	6,08	6,24
P7	7	7	5	7	7	7	6	7	7	7	7	7	7	5	6,15	6,15
P8	7	7	6	7	7	7	6	7	7	7	7	7	6	6	-	-

Table 5.19. Items of Urban and Social Integration.

Items of $Y_{3.1}$	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**AV**	**TV**
P1	4	6	7	7	7	5	4	7	7	7	7	7	7	6,55	6,63
P2	6	6	7	6	7	7	4	6	6	7	6	7	7	6,48	6,64
P3	7	7	7	7	7	7	5	7	7	7	7	7	7	-	-
P4	6	6	7	5	7	7	7	4	6	7	7	7	7	6,55	6,57
P5	6	6	7	5	7	7	7	4	6	7	7	7	7	6,53	6,61
P6	3	6	7	7	5	7	4	7	6	7	7	7	7	6,00	6,55
P7	6	7	7	7	6	7	4	7	7	7	7	7	7	6,64	6,64
P8	6	6	7	6	7	7	4	6	6	7	7	7	7	-	-

Table 5.20. Items of Internal Environment.

Items of $Y_{3.2}$	1	2	3	4	5	6	7	8	9	10	11	12	13	AV	TV
P1	7	7	7	7	6	7	7	5	7	7	7	7	7	6,55	6,63
P2	7	7	7	7	6	7	7	5	7	7	7	7	7	6,48	6,64
P3	7	7	7	7	7	7	7	5	5	7	6	7	6	-	-
P4	7	7	7	7	7	7	7	5	5	7	7	7	7	6,55	6,57
P5	7	7	7	7	6	7	7	5	5	7	7	7	7	6,53	6,61
P6	7	7	7	7	6	7	7	5	6	7	7	7	7	6,00	6,55
P7	7	7	7	7	7	7	7	5	7	7	7	7	7	6,64	6,64
P8	7	7	7	7	7	7	7	5	6	7	7	7	7	-	-

Table 5.21. Items of Form and Materials.

Items of $Y_{3.3}$	1	2	3	4	5	6	7	8	AV	TV
P1	7	7	7	7	7	7	7	4	6,55	6,63
P2	7	7	7	7	7	7	7	3	6,48	6,64
P3	7	7	7	7	7	7	7	5	-	-
P4	7	7	7	7	7	7	7	5	6,55	6,57
P5	7	7	7	7	7	7	7	5	6,53	6,61
P6	5	5	5	5	5	5	5	4	6,00	6,55
P7	7	7	7	7	7	7	7	5	6,64	6,64
P8	7	7	7	7	7	7	7	5	-	-

Table 5.22. Items of Identity and Character.

Items of $Y_{3.4}$	1	2	3	4	5	6	7	8	9	10	11	12	13	14	AV	TV
P1	5	7	7	7	6	7	5	7	6	7	7	6	7	7	6,55	6,63
P2	7	7	7	7	7	7	4	7	5	4	7	6	7	7	6,48	6,64
P3	5	7	7	7	7	7	6	7	7	7	7	6	7	7	-	-
P4	7	7	7	7	7	6	3	7	5	5	7	7	7	7	6,55	6,58
P5	7	7	7	7	7	6	3	7	5	5	7	7	7	7	6,53	6,61
P6	7	7	7	7	7	6	3	7	5	5	7	6	7	7	6,00	6,55
P7	7	7	7	7	7	7	3	7	5	5	7	6	7	7	6,64	6,64
P8	7	7	7	7	7	6	3	7	5	5	7	6	7	7	-	-

Table 5.23. Percentages of the Best rated Items of Sub-indicators.

Main Indicators and Sub-indicators		P1 (%)		P2 (%)		P4 (%)		P5 (%)		P6 (%)		P7 (%)		Averages of Sub-Indicators	Averages of Main Indicators
	Y1.1	57,1		21,4		21,4		21,4		21,4		7,1		25,0	
Y1	Y1.2	72,7	61,2	54,5	49,2	72,7	45,3	72,7	49,2	45,5	47,9	81,8	47,6	66,6	53,2
	Y1.3	53,8		76,9		69,2		76,9		76,9		53,8		67,9	
	Y2.1	60		60		60		60		46,7		66,7		58,9	
Y2	Y2.2	46,2	69,3	46,2	69,3	53,8	69,3	53,8	69,3	46,2	66,2	53,8	72,6	50	69,3
	Y2.3	78,6		78,6		78,6		78,6		85,7		78,6		79,8	
	Y3.1	69,2		46,2		61,5		61,5		61,5		76,9		62,8	
Y3	Y3.2	84,6	66,8	84,6	58,8	84,6	66,5	76,9	66,5	76,9	62,9	92,3	74,2	83,3	65,9
	Y3.3	87,5		87,5		87,5		87,5		0		87,5		72,9	
	Y3.4	64,3		71,4		71,4		71,4		64,3		71,4		69	
			65,8		59,1		60,4		61,6		59,0		64,8		62,8

The results guide the architect with respect to two perspectives: (1) understanding and comparing the existing design quality of projects, and (2) analyzing them for the design quality improvements for the least rated projects relative to the best rated projects (P_3, P_8).

In terms of the first perspective, according to the results that are indicated in Table 5.23, the architect could derive the following information for his projects.

- In general, almost 37% of the items could be developed for each project.
- The best rated main indicator, which requires less design improvements, is build quality (Y_2).
- The best rated sub-indicator is construction ($Y_{2.3}$).
- The least rated main indicator, which requires the most design improvement, is functionality (Y_1).
- The least rated sub-indicator is access ($Y_{1.1}$).
- The alignment of the least rated projects from the best rated to the least rated in terms of design quality is indicated as P_1, P_7, P_5, P_4, P_2, P_6.
- In terms of ‘functionality’ main indicator (Y_1), the most design improvements are required for access sub-indicator ($Y_{1.1}$) and for P_4.
- In terms of ‘build quality’ main indicator (Y_2), the most design improvement is required for engineering system sub-indicator ($Y_{2.2}$) and for P_6.

- In terms of 'impact' main indicator (Y_3), the most design improvement is required for urban and social integration sub-indicator ($Y_{3.1}$) and for P_2.

In terms of the second perspective, the architect could make decisions about where to start design improvements after analyzing the range of tables between Table 5.13 and Table 5.23. Depending on his decisions, Equation (5.3) could be used to guide calculations on how many items of the selected sub-indicator(s) should be developed.

$$N = (TV - AV) \times I \times N_s \times N_i \tag{5.3}$$

For Equation (5.3);

- N: Required number of the developing items
- TV: Target value
- AV: Actual value
- I: Percentage of the given importance to the sub-indicators by the evaluator (Sub-indicators should be developed until the sum of I reaches 100% within the selected main indicator.)
- N_s: Number of sub-indicators of the selected main indicator
- N_i: Number of the items of the selected sub-indicator

As an example, after analyzing the range of tables between Table 5.13 and Table 5.23, the architect prefers to investigate the design quality improvements of P_1 (a least rated project). To develop design quality performance of P_1, any highlighted items could be developed by the architect of housing projects until the actual value of P_1 reaches the target value of P_1.

To develop 'functionality' main indicator (Y_1) of P_1, any of the highlighted items such as access ($Y_{1.1}$), space ($Y_{1.2}$) and use ($Y_{1.3}$) could be preferred to be developed by the architect until satisfactory results could be attained for the value of functionality. Thus, the highlighted items related to the sub-item $Y_{1.1}$, which is access orientation, are as follows:

- Item 3: General accessibility to the house is convenient.
- Item 5: Deliveries such as food ordering, shipping, etc. can reach safely to the house.
- Item 8: Vision impaired people can access easily to the house.
- Item 9: Hearing impaired people can access easily to the house.

- Item 10: Wheelchair users can access easily to the house.
- Item 14: The routes around the house are arranged to consider traffic flow and traffic lights.

The highlighted items related to the sub-item $Y_{1.2}$, which is space orientation, are as follows:

- Item 6: There is enough amount of storage space.
- Item 8: Spaces are designed as flexible and the usage of spaces can be easily changed.
- Item 10: Various openings (windows, balconies, doors, etc.) are designed to improve the interior quality (entry of light, view, privacy, noise, heat, glare etc.).

The highlighted items related to the sub-item $Y_{1.3}$, which is use orientation, are as follows:

- Item 4: The house is safe for the user's activities.
- Item 5: The house can adapt to the changing needs of users.
- Item 7: The design of the house can respond to changes of use.
- Item 9: The structural system of the house allows changes of use.
- Item 11: Safety considerations should be given for both users and the public space (fire safety, chemical safety, etc.).
- Item 12: Exists are appropriate from the safety point of view.

To develop 'build quality' main indicator (Y_2) of P_1, any of the highlighted items such as performance ($Y_{2.1}$), engineering systems ($Y_{2.2}$), and construction ($Y_{2.3}$) could be preferred to be developed by the architect until satisfactory results are attained for the value of build quality. Thus, the highlighted items related to the sub-item $Y_{2.1}$, which is performance orientation, are as follows:

- Item 2: The house withstands wear and tear in use.
- Item 3: The house is easily maintained.
- Item 12: Air quality is adequate and appropriate for the intended use of the house.
- Item 13: The house is easy to operate.
- Item 14: Error notifications and complaints of the house is low.
- Item15: The house is appropriate for demolition and the recyclability.

The highlighted items related to the sub-item ($Y_{2.2}$), which is engineering systems orientation, are as follows:

- Item 1: Engineering system can be easily be replaced.
- Item 4: Engineering systems work quietly.
- Item 6: The house has a fire safety plan.
- Item 7: There is a system coordination between engineering systems.
- Item 8: Engineering system is suitable for human health.
- Item 9: Necessary security measures have been taken for engineering system,
- Item 13: The maintenance of access points to the house is done.

The items highlighted in gray related to sub-item of ($Y_{2.3}$), which is construction orientation, are as follows:

- Item 3: Safety factors are considered in the design.
- Item 7: The building can be constructed quickly.
- Item 14: Standard space design is used.

To develop 'impact' main indicator (Y_3) of P_1, any of the highlighted items such as urban and social integration ($Y_{3.1}$), internal environment ($Y_{3.2}$), forms and materials ($Y_{3.3}$), identity and character ($Y_{3.4}$) could be preferred to be developed by the architect until satisfactory results could be attained for the impact value. Thus, highlighted items related to the sub-item of $Y_{3.1}$, which is urban and social integration orientation, are as follows:

- Item 1: Environment in which the building is located is designed properly.
- Item 2: The house is located in a pleasant built environment.
- Item 6: The house contributes to the structural integrity of the neighborhood.
- Item 7: The house encourages local activity.

The highlighted items related to the sub-item ($Y_{3.2}$) which is internal environment orientation, are as follows:

- Item 5: Indoor natural light is appropriately high.
- Item 8: Indoor air quality is appropriate for healthy conditions.

The highlighted items related to the sub-item ($Y_{3.3}$) which is form and materials orientation, are as follows:

- Item 8: Parts of the house are easily recognizable and they define the function of the house.

The highlighted items related to the sub-item ($Y_{3.4}$) which is identity and character orientation, are as follows:

- Item 1: The house provides a sense of security,
- Item 5: The house is likely to be widely acclaimed for its quality,
- Item 7: The house will make you think,
- Item 9: The design and construction of the house are likely to contribute to the development of new knowledge,
- Item 12: The house responds to all requirements identified by the designers and experts.

Assuming that the architect decides to improve design quality performance of P_1 by equally improving the design quality of the sub-indicators, which have 70% lower percentage value than the best rated items (Table 5.24). Accordingly, Table 5.26 indicates how many items should be improved for the selected sub-indicators.

Table 5.24. Required Number of the Items for Design Improvements of P_1.

$N = (TV-AV) \times I \times N_s \times N_i$							
Main Indicators	**Sub-indicators**	Target Value (TV)	**Actual Value (AV)**	**Percentage of Improvement (I)**	**Number of Sub-indicators (N_s)**	**Number of Items (N_i)**	**Required Number of Items (N)**
Y1	Y1.1	6,20	6,14	50%	3	14	1,2
	Y1.3	6,20	6,14	50%	3	13	1,2
Y2	Y2.1	6,16	6,10	50%	3	15	1,3
	Y2.2	6,16	6,10	50%	3	13	1,2
Y3	Y3.1	6,63	6,55	50%	4	13	2,1
	Y3.4	6,63	6,55	50%	4	14	2,2

Table 5.24 indicates that improving one item of the selected sub-indicators ($Y_{1.1}$, $Y_{1.3}$, $Y_{2.1}$, $Y_{2.2}$) of Y_1 and Y_2 main indicators, and improving two items of the selected ($Y_{3.1}$ and $Y_{3.4}$) of Y_3 main indicator are sufficient to assign P_1 as the best rated projects. Accordingly, the architect could choose any highlighted item in the selected sub-indicator group, which he decides as crucial for proper design improvements.

To sum up, OO strategies are explained by taking P_1 as a sample project in order to analyze and improve its design quality performance. Similar OO strategies could be developed for all other least rated projects.

5.5.2. Input Oriented Strategies

The results of the developed DEA model allow the architect to analyze the life cycle costs (LCC) of his housing projects to produce cost (input oriented) strategies. IO strategies allow the stakeholders to improve design value of projects by decreasing their LCC values relative to the best rated projects (P_3 and P_8) without altering their design quality.

In this case study, because the housing projects purchase was done before the DEA analysis, the developed IO strategies could not be used actively to decrease their actual cost values (AV) with respect to the target values (TV). Furthermore, they can be used to support future housing projects by proposing cost strategies over analysis of existing housing projects.

Since the architect could not improve his projects by decreasing their costs in this case study, additional information on savings is included for further analysis. Savings of the existing housing projects are determined by the purchase prices, are calculated via Equation (5.4) (Table 5.27). Purchase prices are first converted to their future values on Jan. 2014 and then annual values for the period of ten years are calculated (Table 5.25 and Table 5.26).

The savings rate (SR) is calculated using Equation (5.4) where P_A is the annual value of purchase price (P) and C_1 is annual value of LCC for a ten-year period.

$$SR = |(P_A - C_1)/ C_1| \times 100 \quad (5.4)$$

Table 5.25. Purchase Prices on Jan. 2015.

$P' = P\times(1+i_1)\times(1+i_2)\times\ldots\times(i+i_n)$			
Housing Projects	**Date of Purchasing**	**Purchase Price (P) (₺)**	**Purchase Price on Jan. 2015 (P') (₺)**
P1	06.06.2014	7,050,000	7,527,917.57
P2	05.12.2014	3,150,000	3,178,980
P3	01.04.2011	2,190,000	3,363,590.89
P4	06.07.2012	1,220,000	1,602,218,25
P5	06.05.2011	1,200,000	1,828,073.3
P6	05.10.2012	5,220,000	6,649,825.84
P7	02.12.2011	1,500,000	2,132,618.68
P8	01.04.2011	975,000	1,497,489.09

Table 5.26. Annual Values of Purchase Prices on Jan. 2015.

$(P_A)=(P')\times((i\times(1+i)^N)/((1+i)^N-1))$				
Housing Projects	**Interest Rate per Period (i)**	**Number of Interest Periods (N)**	**Purchase Price on Jan. 2015 (P')(₺)**	**Annual Purchase Price (P_A) (₺)**
P1	0,1092	10	7,527,917.57	1,273,966.26
P2	0,1092	10	3,178,980	537,985.87
P3	0,1092	10	3,363,590.89	569,227.98
P4	0,1092	10	1,602,218.25	271,146.96
P5	0,1092	10	1,828,073.3	309,368.92
P6	0,1092	10	6,649,825.84	1,125,364.84
P7	0,1092	10	2,132,618.68	360,907.81
P8	0,1092	10	1,497,489.09	253,423.42

Table 5.27. LCC, Purchase Prices and Savings Analysis.

C_1 ($)	**AV (₺)**	**TV (₺)**	**PI (%)**	**PA (₺)**	**SR (%)**
P1	331,924.36	185,846.56	44	1,273,966,26	283,8
P2	349,576.28	166,755.04	52	537,985.87	53,9
P3	286,077.01	-	0	569,227.98	98,9
P4	184,864.61	166,755.04	10	271,146.96	46,7
P5	211,315.6	166,755.04	21	309,368.92	46,4
P6	256,005.27	166,755.04	35	1,125,364.845	339,6
P7	323,296.33	233,575.34	28	360,907.81	11,6
P8	166,755.04	-	0	253,423.42	51,9

According to Table 27, it could be argued that the best rated projects and their savings rates constitute a base for the least rated projects. The potential improvement percentages of the best rated projects equal to zero (0) and their savings rates are between 52% and 99%. It could be assumed that if potential improvement percentages (PI) increase, the savings rates also need to be higher than 99% for the least rated projects. Accordingly, however, P_1 and P_6 have higher PI than the best rated projects; their savings rates are also somewhat higher than the best rated projects. Thus, it could be argued that these three projects do not have IO improvements potentials. This assumption is not valid for the P_2, P_4, P_5 and P_7. Specifically, P_4, P_5 and P_7 have lower savings rates than the best rated projects so that they could be further investigated in terms of their LCC. For P_2, its savings rate is in between P_3 and P_8, so it could also be investigated, but any IO improvement might not be required.

In conclusion, how the developed DEA performance model contributes to increase the design value by emphasizing three main issues:

- Determining the potential items of design quality for the least rated projects,
- Revealing the existing deficiencies of the projects both between each other and individually,
- Outlining the overall performance by analyzing life cycle costs (LCC) and design quality indicators (DQI).

CHAPTER 6

CONCLUSION

In this thesis, one of the oldest and most explored subjects of the built environment literature, "design performance evaluation" is examined. A thorough literature review on the concept of value, value assessment methods, design value, value-based evaluation of design and value-driven performance models was conducted. This in-depth-review constituted the conceptual framework of the thesis upon which the methodology of the developed model was built. This thesis proposes a design performance evaluation model, which could improve design value by investigating the design performance expected by various stakeholders of the built environment. The study builds on four main steps, which constitute the conceptual and methodological framework of the thesis. First, a comparative review of the concept of value derived the definition of design value. Then, value-assessment methods and value-driven performance models are analyzed for the purposes of proposing proper value indicators for design value evaluation. Finally, a design performance model is developed and applied to housing projects whose efficiency measures are discussed in terms of design quality and cost-oriented strategies.

The first step depends on a deductive approach, where all commonalities on each and every defined concept of value were investigated. Thus, ten related scientific fields (e.g., psychology, anthropology, economics, manufacturing, customer value management, anthropology, engineering, marketing, philosophy and construction management) were reviewed to reveal the inherent purposes of value assessment methods to lead to a proper value-based evaluation of design. Then, a quantitative relationship is researched to develop a value-driven performance model depending on specific properties that could be given up in an effort to gain other benefits. Accordingly, definers for the concept of value are used to explain the concept of "design value". Design value is defined as a quantitative relationship between the design quality and the cost of the building. In order to quantify design value, a literature review is conducted for value-driven performance models (i.e., Post Occupancy Evaluation (POE), Life Cycle Costing Analysis, Housing Performance Evaluation, Sustainable Value Engineering, Design Quality Indicator (DQI), Best Value, Green Building Assessment Tool, Building Energy Performance Evaluation Model, Balance Scorecard, Value Engineering/Analysis, Total Building Performance, Entropy Based Model, Life Cycle Management, etc.) to determine the value indicators in the built environment. Hybrid value indicators, in all objective and subjective approaches of VDPM in various contexts are collected and analyzed.

The thesis aims to propose a model that could reconcile the conflicting views on different value indicators. The proposed model is distinctive in terms of eliminating the bipolar assumptions (e.g., subjective vs. objective) of the previous models smoothly. Four main value indicators (functionality, build quality, impact, life cycle cost) are determined and thus the body of the model is structured by an effective integration of DQI, LCCA and DEA principles. DEA is the most preferred method for efficiency measure research. In the proposed model, efficiency measure is the basic principle for design performance evaluation.

In this study, the performance model was applied to a housing case in order to test the capability of the model. The selected case consists of eight luxury housing projects built in İzmir. The required data were gathered by a questionnaire establishing DQI and cost values of the projects. Cost indicators defined by the annual LCC principle are based on the basic concepts of engineering economics. The design quality indicators (DQI) were assessed by the architect of the housing projects and are measured quantitatively on a seven-point Likert scale. Finally, all value indicators were analyzed by a DEA tool. Two characteristics of the DEA principle which are the envelopment surface and the input-output orientation contributed to a discussion of results in two opposite perspectives for potential design strategies. Target values of the indicators set by the best-rated projects were used to improve the matching values of the least rated project(s). Input and output oriented strategies were discussed for a potential increase in design value of projects selected as inefficiently performing by the proposed model.

Efficiency measure guides the architect in this study in three main directions: (1) functionality, (2) build quality, (3) impact. The architect could prefer either the three sub-indicators (e.g., space, use, access) to improve the "functionality" criteria if it is under-rated with regard to the best-rated projects by evaluating the relative efficiency scores of the three sub-indicators (e.g., access, space, use). If the "functionality" indicator is under-rated, the architect is given three alternative design improvement approaches depending on the three sub-indicators' (e.g., access, space, use) relative efficiency scores with regard to the best-rated projects. The comparative differences in the under-rated scores provide the architect with a panorama of design focus orientation. The overall picture accounts for all three indicators used to define design quality. This valuable information could be expanded for different stakeholders of the built environment via required modifications that could be adopted for different perspectives. This way the proposed model provides results for directing improvements on design deficiencies. The vice-versa process works for cost deficiencies.

The proposed DEA model could be used to assist all stakeholders of the built environment in design performance evaluation. The efficiency measures provided by the model can be used for benchmarking purposes by developing effective input-oriented (design quality focused) and output-oriented (cost minimization focused) strategies. Research on design performance evaluation is a proper asset to add value to the built environment by revealing the stakeholder satisfaction. Even though, in this thesis the model is tested and applied on housing projects by dwelling only on the perspective of the architect, other project types and stakeholder perspectives could be used for further research. The proposed DQI-LCCA-DEA performance model could also be developed into a software package for a fast and user-friendly analysis of real estate projects for marketing purposes.

REFERENCES

Abbasian-Hosseini, S., S. Hsiang, M. Leming, and M. Liu. 2014. "From Social Network to Data Envelopment Analysis: Identifying Benchmarks at the Site Management Level." *Journal of Construction Engineering and Management* no. 140 (8):04014028. doi:10.1061/(ASCE)CO.1943-7862.0000875.

Abdelrahman, M., T. Zayed, and A. Elyamany. 2008. "Best-Value Model Based on Project Specific Characteristics." *Journal of Construction Engineering and Management* no. 134 (3):179-188. doi:10.1061/(ASCE)0733-9364(2008)134:3(179).

AfsharGhotli, A., and A. Rezaei. 2013. "Value Management in Building Construction Industry of Northern Cyprus: Addressing a Theory and Practice Gap." In *AEI 2013*, 84-93. doi: 10.1061/9780784412909.009.

Akintoye, Akintola, Cliff Hardcastle, Matthias Beck, Ezekiel Chinyio, and Darinka Asenova. 2003. "Achieving Best Value in Private Finance Initiative Project Procurement." *Construction Management and Economics* no. 21 (5):461-470. doi: 10.1080/0144619032000087285.

Al-Azzawi, Ahmed, and Ahmed Salah Al-Mallak. 2013. Reducing Carbon Emissions by Using Design Quality Indicators (DQI) in United Kingdom Architecture and Construction Companies. In *Sustainable Building Conference,* Coventry University.

Ali, Hikmat H., and Saba F. Al Nsairat. 2009. "Developing a green building assessment tool for developing countries – Case of Jordan." *Building and Environment* no. 44 (5):1053-1064. doi: http://dx.doi.org/10.1016/j.buildenv.2008.07.015.

Asiedu, Y., and P. Gu. 1998. "Product life cycle cost analysis: State of the art review." *International Journal of Production Research* no. 36 (4):883-908. doi: 10.1080/002075498193444.

Atmaca, Ediz, Fatih Turan, Gözde Kartal, and Emine Sinem Çiğdem. 2012. "Ankara İli Özel Hastanelerinin Veri Zarflama Analizi ile Etkinlik Ölçümü." *Çukurova Üniversitesi İİBF Dergisi* no. 16 (2):135-153.

Banker, Rajiv D., Abraham Charnes, and William Wager Cooper. 1984. "Some models for estimating technical and scale inefficiencies in data envelopment analysis." *Management Science* no. 30 (9):1078-1092.

Barima, O. K. B. 2010. "Examination of the Best, Analogous, Competing Terms to Describe Value in Construction Projects." *International Journal of Project Management* no. 28 (3):195-200.

Beydilli, Esma. 2010. "*Çevreye Duyarlı Bina Değerlendirme Sistemlerinin "Yaşam Kalitesi" Kavramı Çerçevesinde Yeterliliği*." Master of Science dissertation, Architecture, Mimar Sinan Fine Arts University.

Bishop, Jeff. 1978. *The Appraisal of Buildings: A Case-study and Critique of Approaches.* University of Bristol: School for Advanced Urban Studies.

Burt, Maurice Edward. 1978. *A survey of quality and value in building*. Watford: Department of the Environment, Building Research Establishment.

CABE. 2001. *The value of urban design: a research project commissioned by CABE and DETR to examine the value added by good urban design.* London: Thomas Telford.

Cariaga, Ignacio, Tamer El-Diraby, and Hesham Osman. 2007. "Integrating Value Analysis and Quality Function Deployment for Evaluating Design Alternatives." *Journal of Construction Engineering and Management* no. 133 (10):761-770. doi:10.1061/(ASCE)0733-9364(2007)133:10(761).

Charnes, Abraham, Arie Y. Lewin, and Lawrence M. Seiford. 1994. *Data Envelopment Analysis: Theory, Methodology and Applications*. The Netherlands: Kluwer Academic Publishers Group.

Charnes, Abraham, William W. Cooper, and Edwardo Rhodes. 1978. "Measuring the efficiency of decision making units." *European Journal of Operational Research* no. 2 (6):429-444. doi: http://dx.doi.org/10.1016/0377-2217(78)90138-8.

Chen, Zhen, Derek Clements-Croome, Ju Hong, Heng Li, and Qian Xu. 2006. "A multicriteria lifespan energy efficiency approach to intelligent building assessment." *Energy and Buildings* no. 38 (5):393-409. doi: http://dx.doi.org/10.1016/j.enbuild.2005.08.001.

CIPS. 2013. *Whole Life Costing (WLC) - The CIPS position and what the buyer needs to know*. CIPS Knowledge.

Cook, Wade D., and Larry M. Seiford. 2009. "Data envelopment analysis (DEA) – Thirty years on." *European Journal of Operational Research* no. 192 (1):1-17. doi: http://dx.doi.org/10.1016/j.ejor.2008.01.032.

Cooper, Rachel, Margaret Bruce, Andrew Wootton, David Hands, and Lucy Daly. 2003. "Managing design in the extended enterprise." *Building Research & Information* no. 31 (5):367-378. doi: 10.1080/0961321032000107555.

Cooper, William W, Lawrence M Seiford, and Kaoru Tone. 2007. "Data envelopment analysis: A comprehensive text with models, applications, references and DEA-Solver Software. Second editions." *Springer, ISBN* no. 387452818:490.

CRISP Commission 04/13. 2005. *Report of the Be/nCRISP Value Task Group.* London: RIBA.

Dell'Isola, Alphonse J. 1982. *Value Engineering in the Construction Industry*. New York: Van Nostrand Reinhold.

Dell'Isola, Alphonse J. 1997. *Value engineering: practical applications... for design, construction, maintenance & operations*. Kingston, Mass: R.S. Means Company.

Dell'Isola, Alphonse J. 1998. *Value engineering: Practical applications for design, maintenance, and operations*. Van Nostrand Reinhold, New York: R. S. Means Co.

Deng, Fei, and Hedley Smyth. 2013. "Nature of Firm Performance in Construction." *Journal of Construction Engineering and Management* no. 140 (2):04013040. doi:10.1061/(ASCE)CO.1943-7862.0000778.

Dent, N. 1995. "Value." In *The Oxford Companion to Philosophy*, edited by T. Honderich, Oxford: Oxford University Press.

Devine-Wright, Hannah, Derek S. Thomson, and Simon A. Austin. 2003. "Matching values and value in construction and design." Paper read at *Crossing Boundaries: the Value of Interdisciplinary Research: Proceedings of the Third Conference of the EPUK (Environmental Psychology in the UK) Network*, at the Robert Gordon University, June 23-24.

Dewulf, Geert, and Juriaan van Meel. 2004. "Sense and nonsense of measuring design quality." *Building Research & Information* no. 32 (3):247-250. doi: 10.1080/0961321042000189662.

DGNB. 2013. *DGNB System brochure: Excellence defined.Sustainable building with a systems approach*. Stuttgart: DGNB.

Dhillon, B.S. 2010. *Life Cycle Costing for Engineers*. London: Taylor & Francis.

Egan, John. 1998. *Rethinking Construction: Report of the Construction Task Force*. Norwich: HMSO.

El-Gohary, Nora. 2010. "Model-based automated value analysis of building projects." Paper read at Proceedings of the CIB W78: 27th International Conference, Cairo, Egypt.

El-Mashaleh, Mohammad S. 2010. "Decision to bid or not to bid: a data envelopment analysis approach." *Canadian Journal of Civil Engineering* no. 37 (1):37-44. doi: 10.1139/L09-119.

El-Mashaleh, Mohammad S. 2013. "Empirical Framework for Making the Bid/No-Bid Decision." *Journal of Management in Engineering* no. 29 (3):200-205.

El-Mashaleh, Mohammad S, R. Edward Minchin Jr., and William J. O'Brien. 2007. "Management of construction firm performance using benchmarking." *Journal of Management in Engineering* no. 23 (1):10-17.

El-Mashaleh, Mohammad S, and R. Edward Minchin Jr. 2014. "Concessionaire Selection Model Based on Data Envelopment Analysis." *Journal of Management in Engineering* no. 30 (4):04014013. doi:10.1061/(ASCE)ME.1943-5479.0000262.

El-Mashaleh, Mohammad S., Shaher M. Rababeh, and Khalied H. Hyari. 2010. "Utilizing data envelopment analysis to benchmark safety performance of construction contractors." *International Journal of Project Management* no. 28 (1):61-67. doi: http://dx.doi.org/10.1016/j.ijproman.2009.04.002.

Fasal, John H. 1972. *Practical value analysis methods.* New York: Hayden Book Co.

Fowler, Theodore C. 1990. *Value Analysis in Design*. New York: Van Nostrand Reinhold.

Fuller, Sieglinde. 2010. "Life-cycle cost analysis (LCCA)." *National Institute of Building Sciences, An Authoritative Source of Innovative Solutions for the Built Environment* no. 1090.

Fuller, Sieglinde K., and Stephen R. Petersen. 1996. "Life-cycle costing manual for the federal energy management program, 1995 Edition." *NIST handbook* no. 135.

Gale, Bradley, and Robert Chapman Wood. 1994. *Managing customer value: Creating quality and service that customers can see.* New York: Simon and Schuster.

Gambatese, John A., and Phillip S. Dunston. 2003. "Designer Consideration of Project Lifecycle Performance." Paper read at Construction Research Congress 2003, Honolulu, Hawaii, 1-8.

Gann, David M., Ammon J. Salter, and Jennifer K. Whyte. 2003. "Design Quality Indicator as a tool for thinking." *Building Research and Information* no. 31 (5):318-333. doi: 10.1080/0961321032000107564.

Gluch, Pernilla, and Henrikke Baumann. 2004. "The life cycle costing (LCC) approach: a conceptual discussion of its usefulness for environmental decision-making." *Building and Environment* no. 39 (5):571-580.

Gransberg, D. D., and M. A. Ellicott. 1997. "Best-value contracting criteria." *Cost Engineering (Morgantown, West Virginia)* no. 39 (6):31-34.

Grösche, Peter. 2009. "Measuring residential energy efficiency improvements with DEA." *Journal of Productivity Analysis* no. 31 (2):87-94.

Hartkopf, Volker, and Vivian Loftness. 1999. "Global relevance of total building performance." *Automation in Construction* no. 8 (4):377-393.

Hartman, Robert S. 1967. "Formal axiology and the measurement of values." *The Journal Of Value Inquiry* 1, no. 1: 38.

Hirofumi, Fukuyama. 2014. "Radial Efficiency Measures in Data Envelopment Analysis." In *Encyclopedia of Business Analytics and Optimization*, edited by Wang John, 1967-1976. Hershey, PA, USA: IGI Global.

Horta, Isabel M, Ana S. Camanho, and Jorge Moreira Da Costa. 2010. "Performance assessment of construction companies integrating key performance indicators and data envelopment analysis." *Journal of Construction Engineering and Management* no. 136 (5):581-594.

International Standardisation Organisation (ISO). 2006. *ISO 15686-5: Building and Constructed Assets – Service Life Planning: Part 5 - Whole-Life Costing (Draft)*. Geneva: ISO.

Jahani, H., and N. El-Gohary. 2012. "Value-Sensitive Construction: Value Discovery in Building Projects." Paper read at Construction Research Congress 2012, India, 797-807.

Juan, Yi-Kai. 2009. "A hybrid approach using data envelopment analysis and case-based reasoning for housing refurbishment contractors selection and performance improvement." *Expert Systems with Applications* no. 36 (3):5702-5710.

Kale, S., İlal, M. E. and Ülkeryıldız, E. 2012. "An entropy-based model for evaluating the housing design performance." Paper read at IAHS World Congress on Housing Sciences, İstanbul, 226-234.

Kelly, John, Steven Male, and Drummond Graham. 2004. *Value management of construction projects*. United Kingdom: Blackwell Science Ltd.

Kenley, Russell. 2003. *Financing Construction: Cash Flows and Cash Farming*. London: Spon Press.

Kluckhohn, C. 1951. "Values and value-orientations." In *Toward a general theory of action*, edited by Talcott Parsons and Edward Albert Shils. MA: Harvard University Press.

Kim, Sun-Sook, In-Ho Yang, Myoung-Souk Yeo, and Kwang-Woo Kim. 2005. "Development of a housing performance evaluation model for multi-family residential buildings in Korea." *Building and Environment* no. 40 (8):1103-1116.

Lee, Wen-Shing, and Kuei-Peng Lee. 2009. "Benchmarking the performance of building energy management using data envelopment analysis." *Applied Thermal Engineering* no. 29 (16):3269-3273.

Levitt, Raymond E. 2007. "CEM Research for the Next 50 Years: Maximizing Economic, Environmental, and Societal Value of the Built Environment 1." *Journal of Construction Engineering and Management* no. 133 (9):619-628.

Lin, Chien-Liang, and Hong-Ming Huang. 2009. "Improved baseline productivity analysis technique." *Journal of Construction Engineering and Management* no. 136 (3):367-376.

Lin, Chien-Liang, and Hai-Lin Tan. 2014. "Performance Measurement in the Public Sector: Example of the Building Administration Authorities in Taiwan." *Journal of Management in Engineering* no. 30 (1):97-107.

Loe, Eric. 2000. *The Value of Architecture: Context and current thinking*. London: RIBA.

Lu, Jian, Baabak Ashuri, and Mohsen Shahandashti. 2014. "A Data Envelopment Analysis Model for Building Energy Efficiency Benchmarking." In *Construction Research Congress 2014*, 1073-1082.

Lu, Y., Q. Cui, and Y. Le. 2012. "Modeling Green Value Creation in a Construction Company." In *ICSDEC 2012*, 617-625.

Macmillan, Sebastian. 2006a. "Added value of good design." *Building Research & Information* no. 34 (3):257-271.

Macmillan, S. 2006b. *The value handbook: getting the most from your buildings and spaces.* London: Commission for Architecture and the Built Environment (CABE).

Martić, Milan, Marina Novaković, and Alenka Baggia. 2009. "Data envelopment analysis-basic models and their Utilization." *Organizacija* no. 42 (2):37-43.

Marzouk, M. M. 2011. "ELECTRE III model for value engineering applications." *Automation in Construction* no. 20 (5):596-600. doi: http://dx.doi.org/10.1016/j.autcon.2010.11.026.

McCabe, Brenda, Viet Tran, and Joseph Ramani. 2005. "Construction prequalification using data envelopment analysis." *Canadian Journal of Civil Engineering* no. 32 (1):183-193.

Mearig, Tim, Nathan Coffee, and Michael Morgan. 1999. *Life cycle cost analysis handbook.* State of Alaska: Department of Education and Early Development, Education Support Services/Facilities.

Moon, Sungwoo, Chideok Ha, and Jinkook Yang. 2011. "Structured idea creation for improving the value of construction design." *Journal of Construction Engineering and Management* no. 138 (7):841-853.

Neely, Andy. 1999. "The performance measurement revolution: why now and what next?" *International Journal of Operations & Production Management* no. 19 (2):205-228. doi:10.1108/01443579910247437.

Oyedele, Lukumon O, Kwok Wai Tham, Moshood O Fadeyi, and Babatunde E Jaiyeoba. 2012. "Total Building Performance Approach in Building Evaluation: Case Study of an Office Building in Singapore." *Journal of Energy Engineering* no. 138 (1):25-30.

Ozbek, Mehmet Egemen, Jesús M de la Garza, and Konstantinos Triantis. 2009. "Data envelopment analysis as a decision-making tool for transportation professionals." *Journal of Transportation Engineering* no. 135 (11):822-831.

Ozbek, Mehmet Egemen, Jesús M de la Garza, and Konstantinos Triantis. 2010a. "Data and modeling issues faced during the efficiency measurement of road maintenance using data envelopment analysis." *Journal of Infrastructure Systems* no. 16 (1):21-30.

Ozbek, Mehmet Egemen, Jesús M de la Garza, and Konstantinos Triantis. 2010b. "Efficiency measurement of bridge maintenance using data envelopment analysis." *Journal of Infrastructure Systems* no. 16 (1):31-39.

Ozbek, Mehmet Egemen, Jesus M de la Garza, and Konstantinos Triantis. 2012. "Efficiency measurement of the maintenance of paved lanes using data envelopment analysis." *Construction Management and Economics* no. 30 (11):995-1009.

Özden, Ünal H. 2008. "Veri zarflama analizi (VZA) ile Türkiye'deki vakıf üniversitelerinin etkinliğinin ölçülmesi." *Journal of the School of Business Administration, Istanbul University* no. 37 (2):167-185.

Pilateris, Peter, and Brenda McCabe. 2003. "Contractor financial evaluation model (CFEM)." *Canadian Journal of Civil Engineering* no. 30 (3):487-499.

Potts, Keith, and Nii Ankrah. 2013. *Construction cost management: learning from case studies*. New York: Routledge.

Preiser, Wolfgang F.E. 1995. "Post-occupancy evaluation: How to make buildings work better."*Facilities* no. 13(11):19-28.

Preiser, Wolfgang F. E. 2002. "The evolution of post-occupancy evaluation: Toward building performance and universal design evaluation." In *Learning From Our Buildings A State-of-the Practice Summary of Post-Occupancy Evaluation*, edited by Federal Facilities Council,Board on Infrastructure and the Constructed Environment, National Research Council, 9-22. Washingthon: National Academy Press.

Pulaski, Michael H., and Michael J. Horman. 2005. "Continuous value enhancement process." *Journal of Construction Engineering and Management* no. 131 (12):1274-1282.

Ramanathan, Ramu. 2003. *An introduction to data envelopment analysis: a tool for performance measurement*. London: Sage.

Ristimäki, Miro, Antti Säynäjoki, Jukka Heinonen, and Seppo Junnila. 2013. "Combining life cycle costing and life cycle assessment for an analysis of a new residential district energy system design." *Energy* no. 63:168-179.

Rokeach, M. 1973. *Nature of Human Values*. NY: Free Press.

Sanoff, H. 2001. *School Building Assessment Methods*. Washington: National Clearinghouse for Educational Facilities.

Santoyo-Castelazo, Edgar, and Adisa Azapagic. 2014. "Sustainability assessment of energy systems: integrating environmental, economic and social aspects." *Journal of Cleaner Production* no. 80 (0):119-138. doi: http://dx.doi.org/10.1016/j.jclepro.2014.05.061.

Saxon, Richard. 2005. *Be Valuable: A guide to creating value in the built environment*. London: Constructing Excellence.

Schwartz, S. H. 2012. An Overview of the Schwartz Theory of Basic Values. *Online Readings in Psychology and Culture, 2*(1).

Scott, Sidney, Nancy C. Smith, Douglas D. Gransberg, Keith R. Molenaar. 2006. *NCHRP Report 561:Best-value procurement methods for highway construction projects:* Transportation Research Board, Washington, DC: The National Academies Press.

Sklair, Leslie. 2010. "Iconic architecture and the culture-ideology of consumerism." *Theory, Culture & Society* no. 27 (5):135-159.

Slater, Stanley F. and John C. Narver. 2000. "Intelligence generation and superior customer value." *Journal of the Academy of Marketing Science* no. 28 (1):120-127.

Soetanto, R., A. R. J. Dainty, J. Glass, and A. D. F. Price. 2006. "Towards an explicit design decision process: the case of the structural frame." *Construction Management and Economics* no. 24 (6):603-614.

Spencer, N. C., and Winch, G. M. 2002. *How buildings add value for clients*. London: published for Construction Industry Council by Thomas Telford.

Stringer, Allan, Jack Dunne, and Halim Boussabaine. 2012. "Schools design quality: A user perspective." *Architectural Engineering and Design Management* no. 8 (4):257-272.

Sowlati, T. 2001. *Establishing the practical frontier in data envelopment analysis*. Ph.D. thesis, Department of Mechanical and Industrial Engineering, University of Toronto, Ont.

Tatari, Omer, and Murat Kucukvar. 2011. "Eco-Efficiency of Construction Materials: Data Envelopment Analysis." *Journal of Construction Engineering and Management* no. 138 (6):733-741.

Thomson, Derek S., Simon A. Austin, Hannah Devine-Wright, and Grant R. Mills. 2003. "Managing value and quality in design." *Building Research & Information* no. 31 (5):334-345.

Tsolas, Ioannis E. 2013. "Modeling profitability and stock market performance of listed construction firms on the Athens Exchange: Two-Stage DEA Approach." *Journal of Construction Engineering and Management* no. 139 (1):111-119.

Vitruvius, P. 1960. *Vitruvius: The ten books on architecture*. (Morgan, M. H Translation), New York: Dover Publications.

Waggoner, Daniel B., Andy D. Neely, and Mike P. Kennerley. 1999. "The forces that shape organisational performance measurement systems: An interdisciplinary review." *International Journal of Production Economics* no. 60–61 (0):53-60. doi: http://dx.doi.org/10.1016/S0925-5273(98)00201-1.

Wang, E., Z. Shen, L. Wang, and N. Barry. 2014. "Benchmarking Building Energy Performance Using Data Envelopment Analysis with Normalized Metrics—A Residential Case Study." Paper read at Computing in Civil and Building Engineering, 1994-2000.

Watts, J, and Robert E Chapman. 2008. "Engineering economics." In Section 5, Chapter 7, *SFPE Handbook of Fire Protection Engineering*. edited by Philip J. DiNenno, Dougal Drysdale, L. Beyler, 5–104. Quincy, MA: SFPE.

Winch, Graham, Roger Courtney, and Stephen Allen. 2003. "Re-valuing construction." *Building Research & Information* no. 31 (2):82-84.

Womack, J.P. and Jones, D.T. 1996. *Lean Thinking*. London: Simon & Schuster.

Wong, Franky W. H., Patrick T. I. Lam, and Edwin H. W. Chan. 2009. "Optimising design objectives using the Balanced Scorecard approach." *Design studies* no. 30 (4):369-392.

Wong, Nyuk Hien, and Wy Leng Seow Jan. 2003. "Total building performance evaluation of academic institution in Singapore." *Building and Environment* no. 38 (1):161-176.

Xue, Xiaolong, Qiping Shen, Yaowu Wang, and Jinfeng Lu. 2008. "Measuring the productivity of the construction industry in China by using DEA-based Malmquist productivity indices." *Journal of Construction Engineering and Management* no. 134 (1):64-71.

Yaffey, Michael. 1989. "Variants of the cash flow statement." *Project Appraisal* no. 4 (1):17-28.

Yavuz, Mina, Sevgi Zeynep Doğan, and Serdar Kale. 2014. "Veri Zarflama Analiziyle Tasarım Başarım Değerlendirmesi." In *PYYK*. Antalya, 317-330.

Yu, Wen-der, Kwo-Wuu Wang, and Ming-Teh Wang. 2012. "Pricing Strategy for Best Value Tender." *Journal of Construction Engineering and Management* no. 139 (6):675-684.

Zemke, Dina Marie V., and Madeleine Pullman. 2008. "Assessing the value of good design in hotels." *Building Research & Information* no. 36 (6):543-556.

Zengin, Yasemin, and Erhan Ada. 2010. "Cost management through product design: target costing approach." *International Journal of production research* no. 48 (19):5593-5611.

Zhang, L., and N. El-Gohary. 2014. "Discovering Stakeholder Values for Axiology-based Sustainability-oriented Value Analysis of Educational Building Projects." In *Construction Research Congress 2014*, 623-632.

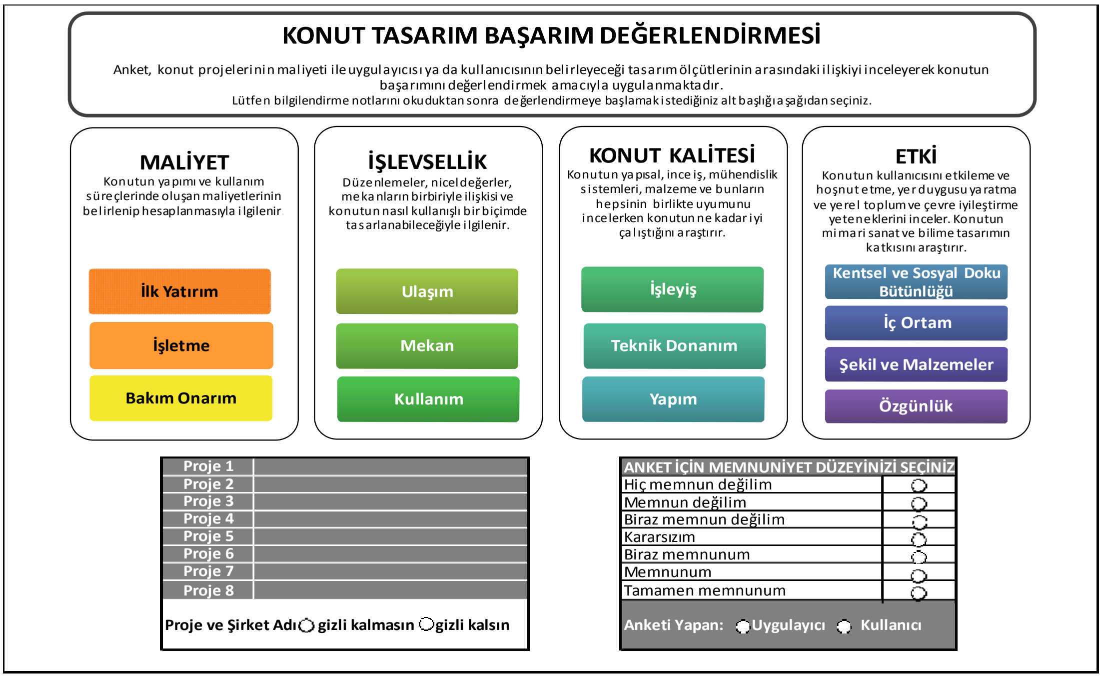
Zhang, Xueqing. 2006. "Public clients' best value perspectives of public private partnerships in infrastructure development." *Journal of Construction Engineering and Management* no. 132 (2):107-114.

Zhu, Joe. 2003. *Quantitative models for performance evaluation and benchmarking: data envelopment analysis with spreadsheets and DEA excel solver*. New York: Springer.

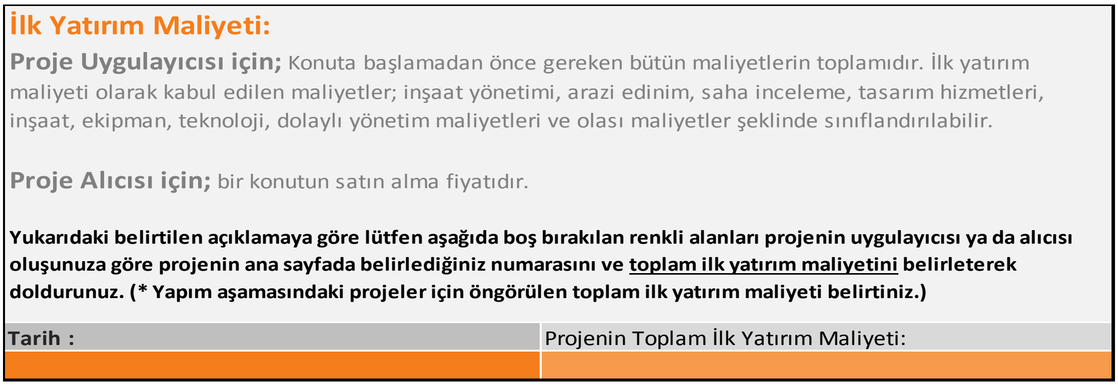
Zhu, Joe, and Wade D. Cook. 2007. *Modeling data irregularities and structural complexities in data envelopment analysis.* Newyork: Springer.

APPENDIX A

QUESTIONNAIRE



(a)



İlk Yatırım Maliyeti:

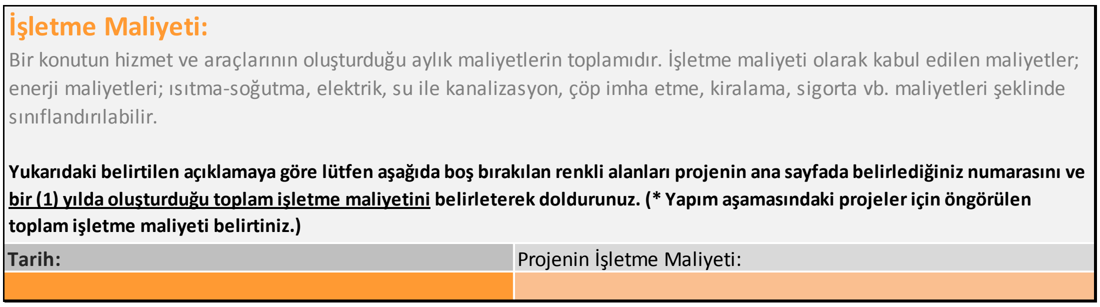
Proje Uygulayıcısı için; Konuta başlamadan önce gereken bütün maliyetlerin toplamıdır. İlk yatırım maliyeti olarak kabul edilen maliyetler; inşaat yönetimi, arazi edinim, saha inceleme, tasarım hizmetleri, inşaat, ekipman, teknoloji, dolaylı yönetim maliyetleri ve olası maliyetler şeklinde sınıflandırılabilir.

Proje Alıcısı için; bir konutun satın alma fiyatıdır.

Yukarıdaki belirtilen açıklamaya göre lütfen aşağıda boş bırakılan renkli alanları projenin uygulayıcısı ya da alıcısı oluşunuza göre projenin ana sayfada belirlediğiniz numarasını ve toplam ilk yatırım maliyetini belirleterek doldurunuz. (* Yapım aşamasındaki projeler için öngörülen toplam ilk yatırım maliyeti belirtiniz.)

Tarih :	Projenin Toplam İlk Yatırım Maliyeti:

(b)



İşletme Maliyeti:

Bir konutun hizmet ve araçlarının oluşturduğu aylık maliyetlerin toplamıdır. İşletme maliyeti olarak kabul edilen maliyetler; enerji maliyetleri; ısıtma-soğutma, elektrik, su ile kanalizasyon, çöp imha etme, kiralama, sigorta vb. maliyetleri şeklinde sınıflandırılabilir.

Yukarıdaki belirtilen açıklamaya göre lütfen aşağıda boş bırakılan renkli alanları projenin ana sayfada belirlediğiniz numarasını ve bir (1) yılda oluşturduğu toplam işletme maliyetini belirleterek doldurunuz. (* Yapım aşamasındaki projeler için öngörülen toplam işletme maliyeti belirtiniz.)

Tarih:	Projenin İşletme Maliyeti:

(c)

Bakım Onarım Maliyeti:

Bakım maliyeti, bir konutun bakımıyla ilgili tüm harcamaları belirtirken; onarım maliyeti, binanın sahip olduğu sistemleri değiştirmeden ömrünü uzatmak amacıyla yapılan beklenmeyen harcamaları ifade etmektedir. Bakım onarım maliyeti olarak kabul edilen maliyetler; bina çevresi iyileştirme, altyapı ve üstyapı (dış duvar sistemleri, pencere, kapı, iç bölme, döşeme, tavan, iç özellikler, iletim sistemleri; sıhhi tesisat boru ve armatürleri, yangın koruma sistemleri, HVAC dağıtım, ekipman ve kontrolleri, elektrik servisi/üretimi, elektrik dağıtım, elektrik aydınlatma ve özel elektrik sistemleri ile ekipman vb.) maliyetleri şeklinde sınıflandırılabilir.

Yukarıdaki belirtilen açıklamaya göre lütfen aşağıda boş bırakılan renkli alanları projenin ana sayfada belirlediğiniz numarasını ve on (10) yılda oluşturacağı toplam bakım onarım maliyetini belirleterek doldurunuz. (* Yapım aşamasındaki projeler için öngörülen toplam bakım onarım maliyeti belirtiniz.)

Tarih:	Projenin Bakım Onarım Maliyeti:

(d)

Ulaşım:

Konuta herkes rahatlıkla ulaşabilir.

Aşağıda yer alan ifadelere projenizin hangi oranda katıldığını (Hiç Katılmıyorum ile Tamamen Katılıyorum arasında) belirtecek şekilde işaretleyiniz.

		Hiç Katılmıyorum	Katılmıyorum	Biraz Katılmıyorum	Kararsızım	Biraz Katılıyorum	Katılıyorum	Tamamen Katılıyorum
1	Konuttan toplu taşıma araçlarına kolaylıkla ulaşılabilir	○	○	○	○	○	○	○
2	Parkyeri kolaylıkla bulunabilir	○	○	○	○	○	○	○
3	Genel olarak ulaşım rahattır	○	○	○	○	○	○	○
4	Çevre ve yerleşim bakımından güvenlidir	○	○	○	○	○	○	○
5	Yemek siparişi, kargo vb. teslimatlar güvenli bir şekilde konuta ulaşabilir	○	○	○	○	○	○	○
6	Gelen ziyaretçi konutun alana yerleşimini kolaylıkla kavrayabilir	○	○	○	○	○	○	○
7	Konut ve çevresindeki tabelalar anlaşılır ve yeterlidir	○	○	○	○	○	○	○
8	Görme engelliler kolaylıkla konuta ulaşabilir	○	○	○	○	○	○	○
9	İşitme engelliler kolaylıkla konuta ulaşabilir	○	○	○	○	○	○	○
10	Tekerlekli sandalye kullananlar konuta kolaylıkla ulaşabilir	○	○	○	○	○	○	○
11	Konutun giriş ve çıkışı kolaylıkla bulunabilir	○	○	○	○	○	○	○
12	Konutun çevresindeki yollar konuta ulaşım için yeterlidir	○	○	○	○	○	○	○
13	Konutun çevresindeki yollar konutla bağlantılıdır	○	○	○	○	○	○	○
14	Konutun çevresindeki yollar trafik yoğunluğuna, trafik akışına ve trafik ışıklarına göre düzenlenmiştir	○	○	○	○	○	○	○

(e)

Mekan: Konutu oluşturan mekanlar işlevlerine, kullanım amaçlarına uygun boyutlarda tasarlanmıştır. **Aşağıda yer alan ifadelere projenizin hangi oranda katıldığını (Hiç Katılmıyorum ile Tamamen Katılıyorum arasında) belirtecek şekilde işaretleyiniz.**		Hiç Katılmıyorum	Katılmıyorum	Biraz Katılmıyorum	Kararsızım	Biraz Katılıyorum	Katılıyorum	Tamamen Katılıyorum
1	Konut doğru büyüklükte kurgulanmıştır							
2	Odalar arasındaki ilişkiler uygundur							
3	Dolaşım alanları (yürüme ve geçiş alanları) iyi tasarlanmıştır							
4	Konut büyüklüğü ve mekan büyüklüklerinin oranı doğrudur							
5	Genel ve özel kullanım mekanları dengeli dağılmıştır							
6	Yeterli depolama alanı mevcuttur							
7	Mekanlar kullanıcı gereksinimlerine uygun biçimde tasarlanmıştır							
8	Mekan tasarımı esnektir. Mekanın kullanım şekli kolayca değiştirilebilir							
9	Dışarıdan bakıldığında konut kütlesinin her bölümü birbiriyle bir bütünlük içindedir ve hoş bir görünüm oluşturur							
10	Konutun dış görünümü konutun kullanım amacı hakkında bilgi verir							
11	Konuttaki açıklıklar (pencere, balkon, kapı vb.) iç mekan kalitesini arttıracak şekilde tasarlanmıştır (ışığın içeriye süzülmesi, manzara, iç mekan gizliliği, gürültü, sıcaklık, yansıma vb.)							

(f)

Kullanım: Konut, kullanıcısının aktivitelerini iyileştirir ve değişen ihtiyaçlarına cevap verebilir. **Aşağıda yer alan ifadelere projenizin hangi oranda katıldığını (Hiç Katılmıyorum ile Tamamen Katılıyorum arasında) belirtecek şekilde işaretleyiniz.**		Hiç Katılmıyorum	Katılmıyorum	Biraz Katılmıyorum	Kararsızım	Biraz Katılıyorum	Katılıyorum	Tamamen Katılıyorum
1	Kullanıcısının ihtiyaçlarını karşılar							
2	Konut kullanım amacını verimli kılacak şekilde tasarlanmıştır							
3	Kullanıcısının faliyetlerini iyileştirir, güzelleştirir							
4	Kullanıcının faliyetleri için güvenlidir							
5	Kullanıcısının değişen ihtiyaçlarına uygun şekilde düzenlenebilir							
6	Aydınlatması farklı kullanıcıların ihtiyaçlarına cevap verebilecek şekilde çok amaçlı kurgulanmıştır							
7	Tasarımı değişen kullanıma cevap verebilir							
8	Isıtma, havalandırma ve teknolojik sistem donanımları değişen kullanıcı ihtiyaçlarını karşılayabilecek niteliktedir							
9	Binanın strüktürel sistemi kullanım değişikliğine olanak sağlar							
10	Yasal önlemler konuta izinsiz girişi ve ihlali engeller							
11	Güvenlik hem konut kullanıcıları hem de genel kullanıcılar açısından düşünülmüştür (Yangın güvenliği, trafik güvenliği, kimyasal güvenlik vb. sağlanmıştır)							
12	Konut çıkışlarının görüş açısı güvenlik açısından uygundur							
13	Konutun ana girişinden dışarıdan içeriye doğru girildiğinde hoş bir deneyim yaşanır							

(g)

İşleyiş: Konutun bakımı kolaylıkla yapılabilir. Konutun iç mekanları ilgili standartları karşılamaktadır. **Aşağıda yer alan ifadelere projenizin hangi oranda katıldığını (Hiç Katılmıyorum ile Tamamen Katılıyorum arasında) belirtecek şekilde işaretleyiniz.**		Hiç Katılmıyorum	Katılmıyorum	Biraz Katılmıyorum	Kararsızım	Biraz Katılıyorum	Katılıyorum	Tamamen Katılıyorum
1	Kolay temizlenebilir	○	○	○	○	○	○	○
2	Kullanıcı kaynaklı yıpranma ve aşınmalara karşı dayanıklıdır	○	○	○	○	○	○	○
3	Bakımı kolay yapılabilir	○	○	○	○	○	○	○
4	Bulunduğu bölgenin iklim koşullarına uygun tasarlanmıştır	○	○	○	○	○	○	○
5	Zamana karşı dayanıklı olacak şekilde inşa edilmiştir	○	○	○	○	○	○	○
6	Konutun yapısal sistemi rasyonel/mantıklı bir şekilde kurgulanmıştır	○	○	○	○	○	○	○
7	Konutun ince işlerinde (boya, sıva, süpürgelik, çerçeve vb.) dayanıklı malzemeler kullanılmıştır	○	○	○	○	○	○	○
8	Yeterli günışığı almaktadır	○	○	○	○	○	○	○
9	Yapay aydınlatma düzeyi yeterlidir	○	○	○	○	○	○	○
10	Kullanıma uygun yeterli ısıtma soğutma sağlanmaktadır	○	○	○	○	○	○	○
11	Akustik kalitesi konutun kullanım amacı için yeterli ve uygundur	○	○	○	○	○	○	○
12	Hava kalitesi yeterli ve konutun kullanım amacına uygundur	○	○	○	○	○	○	○
13	Konutun işletimi (mekanik sistemlerin işletilmesi vb.) kolaydır	○	○	○	○	○	○	○
14	Konuta ilişkin hata ve şikayet bildirimi düşük seviyedir	○	○	○	○	○	○	○
15	Yıkım ve geri dönüşüme (recycle) uygun tasarlanmıştır	○	○	○	○	○	○	○

(h)

Teknik Donanım: Konutun işletimi kolaydır ve verimli şekilde enerji, su vb. kullanımı sağlar. **Aşağıda yer alan ifadelere projenizin hangi oranda katıldığını (Hiç Katılmıyorum ile Tamamen Katılıyorum arasında) belirtecek şekilde işaretleyiniz.**		Hiç Katılmıyorum	Katılmıyorum	Biraz Katılmıyorum	Kararsızım	Biraz Katılıyorum	Katılıyorum	Tamamen Katılıyorum
1	Teknik donanım kolaylıkla yenisiyle değiştirilebilir	○	○	○	○	○	○	○
2	Teknik donanım düzgün, iyi çalışmaktadır	○	○	○	○	○	○	○
3	Teknik donanım kolayca çalıştırılabilmektedir	○	○	○	○	○	○	○
4	Teknik donanım sessiz çalışmaktadır	○	○	○	○	○	○	○
5	Teknik donanım sistem gereksinimlerini kontrol altında tutmaktadır	○	○	○	○	○	○	○
6	Konutun yangın önleme planı vardır	○	○	○	○	○	○	○
7	Teknik donanımlar arasında koordinasyon vardır, eşgüdümlü çalışır	○	○	○	○	○	○	○
8	Teknik donanım insan sağlığına uygundur	○	○	○	○	○	○	○
9	Teknik donanım için gerekli güvenlik önlemleri alınmıştır	○	○	○	○	○	○	○
10	Bakım ekibi iş bitimi sonrası güvenlik ve temizliği taahhüt eder	○	○	○	○	○	○	○
11	Acil tamir durumlarında hızlı ve yeterli geri dönüş sağlanır	○	○	○	○	○	○	○
12	Planlanan bakım ve tamir şartları sağlanır	○	○	○	○	○	○	○
13	Konuta ulaşım noktalarının bakımı yapılır	○	○	○	○	○	○	○

(i)

Yapım: Konutta kullanılan yapı malzemeleri ve yapım yöntemi yeterince iyidir ve sürdürülebilirlik ilkeleri gözönünde bulundurulmuştur. **Aşağıda yer alan ifadelere projenizin hangi oranda katıldığını (Hiç Katılmıyorum ile Tamamen Katılıyorum arasında) belirtecek şekilde işaretleyiniz.**		Hiç Katılmıyorum	Katılmıyorum	Biraz Katılmıyorum	Kararsızım	Biraz Katılıyorum	Katılıyorum	Tamamen Katılıyorum
1	Uygun malzemeler kullanılmıştır	○	○	○	○	○	○	○
2	Yapım (inşaat) detaylı ve iyi düşünülmüştür	○	○	○	○	○	○	○
3	Tasarımında güvenlik unsurları göz önünde bulundurulmuştur	○	○	○	○	○	○	○
4	Yapı bileşenlerinin bütünlüğü, birleşimi sağlanmıştır	○	○	○	○	○	○	○
5	Mobilyalar, demirbaşlar, bitiş malzemeleri bütünlük içindedir	○	○	○	○	○	○	○
6	Yapım sistemi etkili ve verimli tasarlanmıştır	○	○	○	○	○	○	○
7	Yapım sistemi hızlı bir şekilde inşaa edilebilir	○	○	○	○	○	○	○
8	Döşeme sisteminin çözümü iyi düşünülmüştür	○	○	○	○	○	○	○
9	Cephe sisteminin çözümü iyi düşünülmüştür	○	○	○	○	○	○	○
10	Çatı sisteminin çözümü iyi düşünülmüştür	○	○	○	○	○	○	○
11	İç duvar sisteminin çözümü iyi düşünülmüştür	○	○	○	○	○	○	○
12	İnce işlerin işçiliği iyidir	○	○	○	○	○	○	○
13	Servis sistemleri iyi tasarlanmıştır	○	○	○	○	○	○	○
14	Standart mekan tasarımı kullanılmıştır	○	○	○	○	○	○	○

(j)

Kentsel ve Sosyal Doku Bütünlüğü: Konut yakın çevresini iyileştirir ve güzelleştirir. **Aşağıda yer alan ifadelere projenizin hangi oranda katıldığını (Hiç Katılmıyorum ile Tamamen Katılıyorum arasında) belirtecek şekilde işaretleyiniz.**		Hiç Katılmıyorum	Katılmıyorum	Biraz Katılmıyorum	Kararsızım	Biraz Katılıyorum	Katılıyorum	Tamamen Katılıyorum
1	Konutun bulunduğu yapılı çevre iyi tasarlanmıştır	○	○	○	○	○	○	○
2	Keyifli bir yapılı çevre içinde konumlanmıştır	○	○	○	○	○	○	○
3	Konut bulunduğu semtin çevre ve bahçe düzenlemesine katkı sağlamıştır	○	○	○	○	○	○	○
4	Konumlanması iyidir	○	○	○	○	○	○	○
5	Semt/çevre sakinleri konuttan memnundur	○	○	○	○	○	○	○
6	Konut bulunduğu semtin yapısal bütünlüğüne katkı sağlamıştır	○	○	○	○	○	○	○
7	Yerel etkinliklerde teşvik edici, canlandırıcı rol üstlenir	○	○	○	○	○	○	○
8	Bulunduğu yapılı çevrede görsel olarak bir odak noktası oluşturur	○	○	○	○	○	○	○
9	Bulunduğu yapılı çevrenin bir kimlik kazanmasına katkı sağlar	○	○	○	○	○	○	○
10	Konut en doğru, iyi yönlenmeden ve en güzel manzaralardan yararlanır	○	○	○	○	○	○	○
11	Konutun ölçeği inşa edildiği arazinin ölçeğine uygundur	○	○	○	○	○	○	○
12	Konutun ölçeği içinde bulunduğu yapılı çevrenin ölçeğine uygundur	○	○	○	○	○	○	○
13	Kullanım amacı çevre binaların kullanım amaç ve işlevleriyle uyum içindedir	○	○	○	○	○	○	○

(k)

İç Ortam: Konutu kullanmak bir zevktir. Konutun kaliteli bir iç ortamı vardır. Konutun iç ortamı kişisel kontrole uygundur. **Aşağıda yer alan ifadelere projenizin hangi oranda katıldığını (Hiç Katılmıyorum ile Tamamen Katılıyorum arasında) belirtecek şekilde işaretleyiniz.**		Hiç Katılmıyorum	Katılmıyorum	Biraz Katılmıyorum	Kararsızım	Biraz Katılıyorum	Katılıyorum	Tamamen Katılıyorum
1	İç kullanımı memnuniyet vericidir	○	○	○	○	○	○	○
2	Konut içi insan yoğunluğu uygundur	○	○	○	○	○	○	○
3	İç ortamın stres azaltıcı etkisi vardır	○	○	○	○	○	○	○
4	Konut içi genel kullanım mekanları eğlenceli olacak şekilde düzenlenmiştir	○	○	○	○	○	○	○
5	İç ortam doğal ışık kalitesi yüksektir	○	○	○	○	○	○	○
6	İç ortam yapay ışık kalitesi yüksektir	○	○	○	○	○	○	○
7	İç ısı konfor koşullarına uygundur	○	○	○	○	○	○	○
8	İç mekan hava kalitesi sağlık koşullarına uygundur	○	○	○	○	○	○	○
9	İç mekan akustik kalitesi yüksektir	○	○	○	○	○	○	○
10	İç mekan görüntüleri zengindir	○	○	○	○	○	○	○
11	İç kullanımı kullanıcının kontrolü altındadır	○	○	○	○	○	○	○
12	İç ortamları konforludur	○	○	○	○	○	○	○
13	İç ortamdaki sıcaklık bireyin rahat edebileceği düzeydedir	○	○	○	○	○	○	○

(l)

Şekil ve Malzemeler: Konut şeklinin ve malzemelerinin iyi bir birleşimidir. **Aşağıda yer alan ifadelere projenizin hangi oranda katıldığını (Hiç Katılmıyorum ile Tamamen Katılıyorum arasında) belirtecek şekilde işaretleyiniz.**		Hiç Katılmıyorum	Katılmıyorum	Biraz Katılmıyorum	Kararsızım	Biraz Katılıyorum	Katılıyorum	Tamamen Katılıyorum
1	Şekli göze hoş görünmektedir	○	○	○	○	○	○	○
2	Şekil kompozisyonu, düzenlenmesi göze hoş görünmektedir	○	○	○	○	○	○	○
3	Arazi üzerindeki yönlenmesi, konumlanması iyidir	○	○	○	○	○	○	○
4	Şekil ve kullanılan malzemeler uyumludur	○	○	○	○	○	○	○
5	Kullanılan malzemeler kaliteyi arttırmaktadır	○	○	○	○	○	○	○
6	Konutun renk ve dokusu keyif vericidir	○	○	○	○	○	○	○
7	Şekil iyi düşünülmüştür	○	○	○	○	○	○	○
8	Konutun bölümlerinin kolay farkedilebilir, tanımlanabilir işlevleri vardır	○	○	○	○	○	○	○

(m)

Karakter ve Özgünlük:

Konut canlandırır, neşelendirir, kendine bağlar.

Aşağıda yer alan ifadelere projenizin hangi oranda katıldığını (Hiç Katılmıyorum ile Tamamen Katılıyorum arasında) belirtecek şekilde işaretleyiniz.

		Hiç Katılmıyorum	Katılmıyorum	Biraz Katılmıyorum	Kararsızım	Biraz Katılıyorum	Katılıyorum	Tamamen Katılıyorum
1	Güvenlik duygusu sağlar	○	○	○	○	○	○	○
2	Moral verir, neşelendirir	○	○	○	○	○	○	○
3	Ziyaretçiler konuta gelmekten mutlu olurlar	○	○	○	○	○	○	○
4	Kullanıcının aktivitesine uygun olan imajı güçlendirir	○	○	○	○	○	○	○
5	Kalitesinden ötürü kitleler tarafından tanınması muhtemeldir	○	○	○	○	○	○	○
6	Özgünlük sahibidir	○	○	○	○	○	○	○
7	Düşünmeye sevkeder	○	○	○	○	○	○	○
8	Belirgin bir tasarım görüşünü, vizyonunu vurgular	○	○	○	○	○	○	○
9	Konutun tasarımının ve yapımının yeni bilginin gelişimine katkı sağlaması muhtemeldir	○	○	○	○	○	○	○
10	Konut kütlesinde varolan değişiklikler, konuta olan ilgiyi ve kütledeki çeşitliliği arttırır	○	○	○	○	○	○	○
11	Kullanıcısının statüsünü, itibarını, sosyal durumunu yansıtır	○	○	○	○	○	○	○
12	Tasarımcıların, uzmanların tespit ettiği tüm ihtiyaçlara cevap verir	○	○	○	○	○	○	○
13	Konut en iyi değeri sunar. Konutun bedeli, sahip olduğu niteliklerle en iyi dengededir	○	○	○	○	○	○	○
14	Müşteri sonuç üründen memnundur	○	○	○	○	○	○	○

(n)

Figure A.1. Original Questionaire in Turkish

APPENDIX B

PROJECTS

(a)

(b)

(c)

Figure B. 1. Project 1

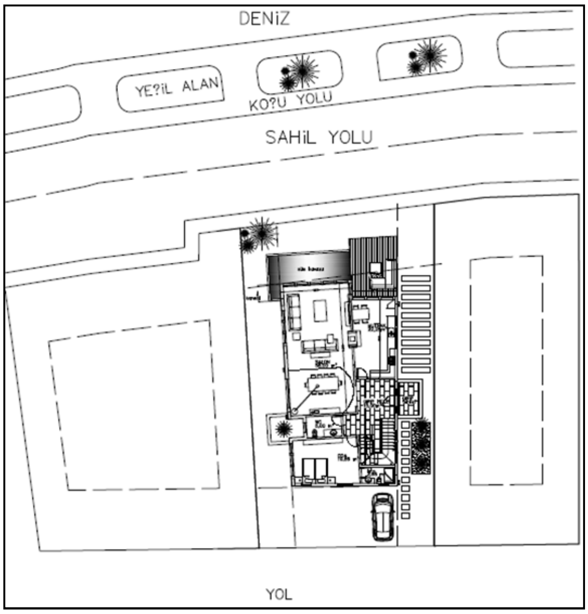
(a)

(b)

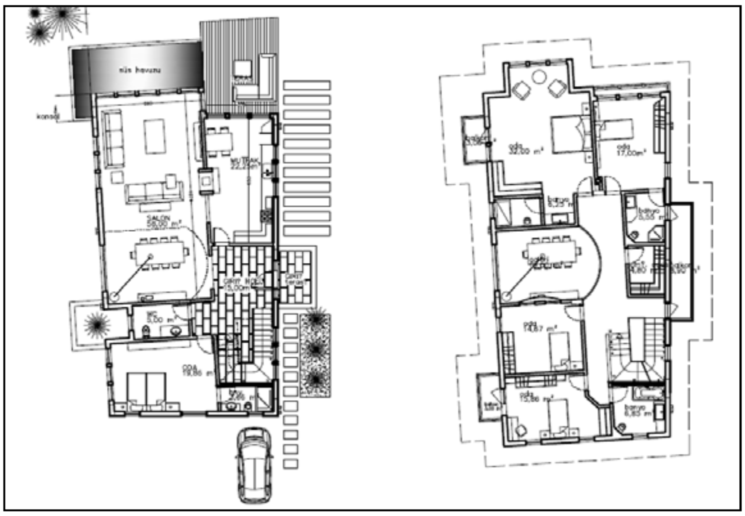
(c)

Figure B. 2. Project 2

(a)



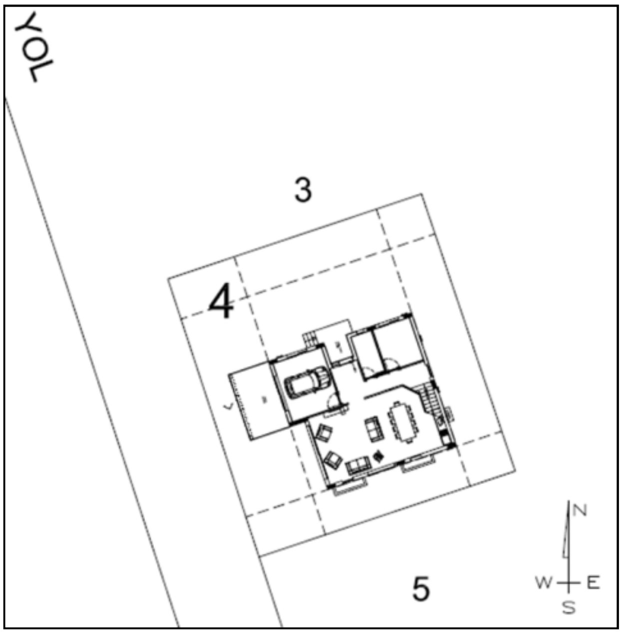
(b)



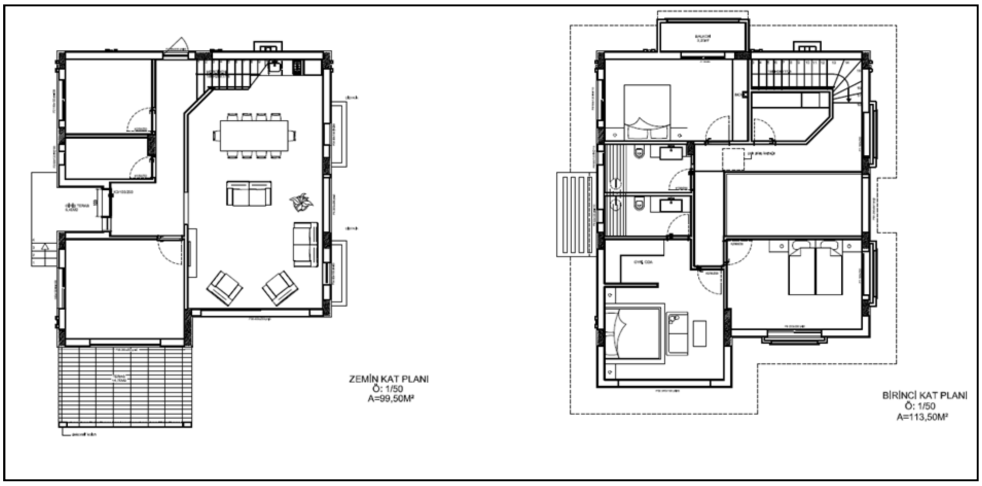
(c)

Figure B. 3. Project 3

(a)



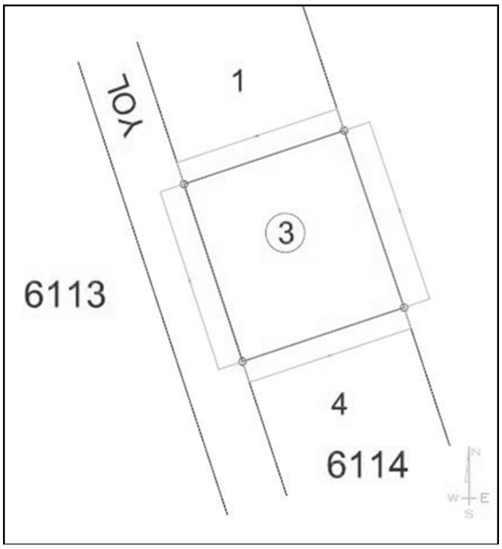
(b)



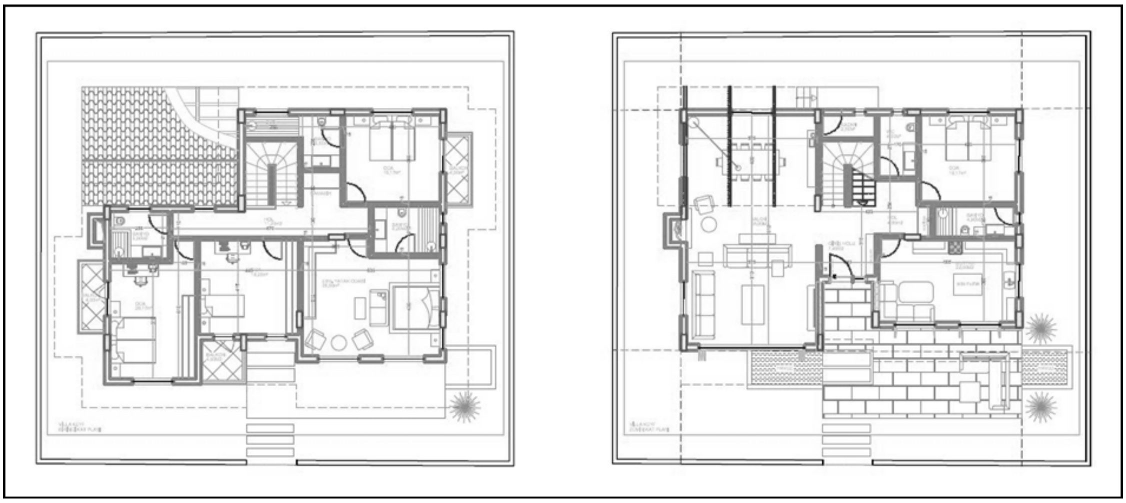
(c)

Figure B. 4. Project 4.

(a)



(b)



(c)

Figure B. 5. Project 5.

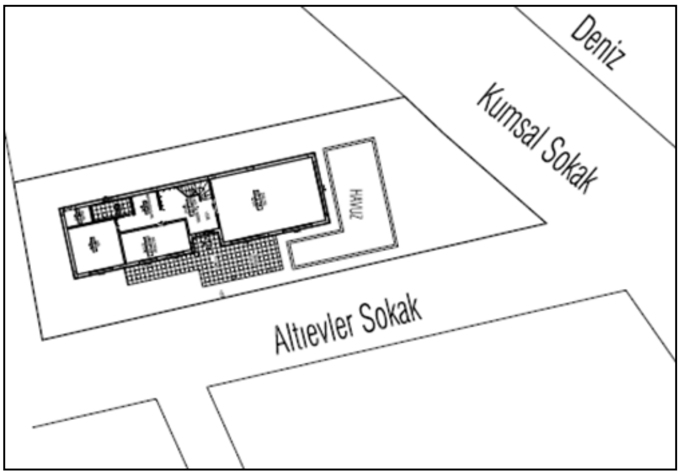
(a)

(b)

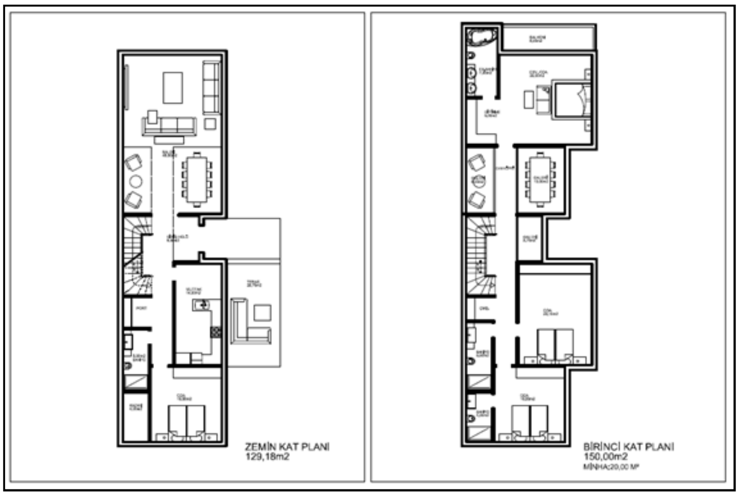
(c)

Figure B. 6. Project 6.

(a)



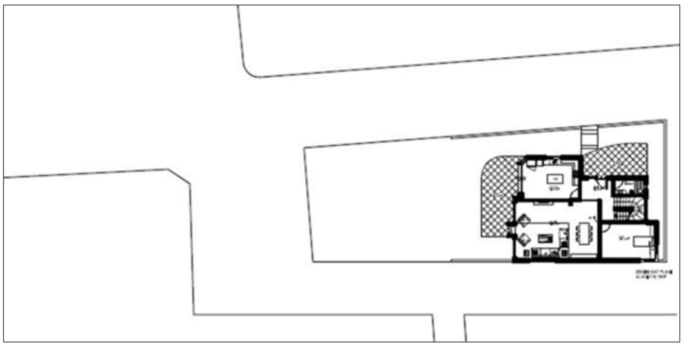
(b)



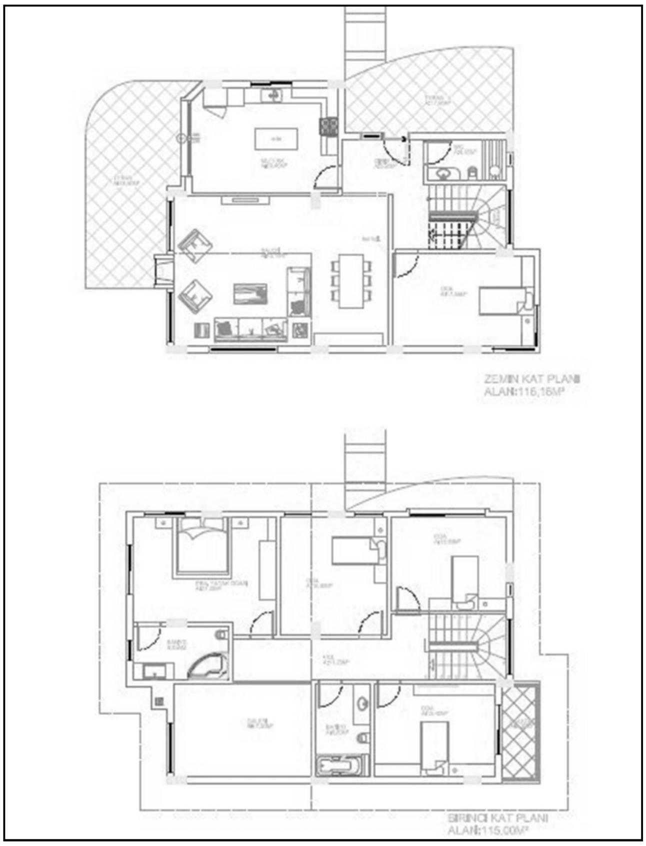
(c)

Figure B. 7. Project 7.

(a)



(b)



(c)

Figure B. 8. Project 8.

APPENDIX C

INTEREST RATES

Date	(1+imontly)
01-08-2008	1,0162
05-09-2008	1,0159
03-10-2008	1,0155
07-11-2008	1,0186
05-12-2008	1,0192
02-01-2009	1,0172
06-02-2009	1,0153
06-03-2009	1,0152
03-04-2009	1,0146
01-05-2009	1,0142
05-06-2009	1,0137
03-07-2009	1,0135
07-08-2009	1,013
04-09-2009	1,0109
02-10-2009	1,0108
06-11-2009	1,0102
04-12-2009	1,0102
01-01-2010	1,0101
05-02-2010	1,01
05-03-2010	1,0098
02-04-2010	1,0096
07-05-2010	1,0094
04-06-2010	1,0096
02-07-2010	1,0092
06-08-2010	1,009
03-09-2010	1,0089
01-10-2010	1,0087
05-11-2010	1,0084
03-12-2010	1,0082
07-01-2011	1,0079
04-02-2011	1,008
04-03-2011	1,0081
01-04-2011	1,0082
06-05-2011	1,0086
03-06-2011	1,0087
01-07-2011	1,0097
05-08-2011	1,0105
02-09-2011	1,0103
07-10-2011	1,0104

Date	(1+imontly)
04-11-2011	1,0112
02-12-2011	1,0121
06-01-2012	1,012
03-02-2012	1,0121
02-03-2012	1,0112
06-04-2012	1,011
04-05-2012	1,0108
01-06-2012	1,0106
06-07-2012	1,0104
03-08-2012	1,0102
07-09-2012	1,01
05-10-2012	1,0097
02-11-2012	1,0092
07-12-2012	1,0086
04-01-2013	1,0083
01-02-2013	1,008
01-03-2013	1,0079
05-04-2013	1,0076
03-05-2013	1,0075
07-06-2013	1,0069
05-07-2013	1,0071
02-08-2013	1,0079
06-09-2013	1,0087
04-10-2013	1,0092
01-11-2013	1,009
06-12-2013	1,0088
03-01-2014	1,0089
07-02-2014	1,0104
07-03-2014	1,0112
04-04-2014	1,0114
02-05-2014	1,011
06-06-2014	1,0105
04-07-2014	1,0098
01-08-2014	1,0092
05-09-2014	1,0092
03-10-2014	1,0089
07-11-2014	1,0091
05-12-2014	1,0092
02-01-2015	1,0091

Figure C. 1. $(1+i_{monthly})$ values between 01.08.2008 and 02.01.2015.