EVALUATING QUALITY IN MASS-HOUSING PROJECTS VIA SIX SIGMA: THE CASE OF ODTÜKENT

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

BY

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

SEPTEMBER 2006

Approval of the Graduate School of Natural and Applied Sciences

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ABSTRACT

EVALUATING QUALITY IN MASS-HOUSING PROJECTS VIA SIX SIGMA:
THE CASE OF ODTÜKENT

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September 2006, 123 pages

Quality and quality management have gained importance in the construction industry also due to losses of life and property. For high-quality buildings, the amount of defects during the construction works must be reduced. Thus, it is important to determine the defects which lead to low quality in the construction projects; and architectural, structural and constructional standards to measure some indicators of quality like workmanship, design of components and usage of correct and high-quality materials. Therefore a systematic approach is required to achieve good standards both in design and construction. CONQUAS quality assessment system and Six Sigma quality management system are systems that could provide this systematic approach.

The objective of this research is to evaluate the quality in mass-housing projects via Six Sigma. Thus, level of construction quality of the three houses in ODTÜKENT housing units in Turkey were assessed through Six Sigma with the contribution of CONQUAS quality assessment system. CONQUAS was used for determination of standards, whilst Six Sigma was used for data analysis. After the evaluation of interviews with contractor, site-supervisor, occupants and visual observations, defects and their reasons were determined. Reasons of poor quality in ODTÜKENT housing units were listed as firstly poor workmanship, then improper or of poor-quality material usage and lastly problems in design of detailing.

Despite different construction dates of units studied, the results show that nothing was learned from the previous mistakes and same defects were repeated. This shows the importance of a system providing feedback and evaluation of quality level of a construction project and quality improvement efforts of the contractor, and measuring the progress over time like Six Sigma.

Keywords: Quality, quality in construction industry, housing quality, Six Sigma quality management system, CONQUAS quality assessment system

ÖZ

TOPLU KONUT PROJELERİNDE KALİTENİN ALTI SIGMA İLE DEĞERLENDİRİLMESİ: ODTÜKENT ÖRNEĞİ

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Eylül 2006, 123 sayfa

Kalite ve kalite yönetimi can ve mal kayıplarına bağlı olarak inşaat sektöründe de önem kazandı. Yüksek kalitede binalar için, inşaat sırasında yapılan hatalar azaltılmalıdır. Bu yüzden, inşaat projelerinde düşük kaliteye neden olan hataları; işçilik, bileşenlerin tasarımı ve uygun ve yüksek kalitede malzeme kullanımı gibi kalite göstergelerini ölçmek için temel mimari, yapısal ve yapıma ait standartlar belirlenmesi önemlidir.Hem tasarım hem de inşaat aşamasında iyi bir seviye elde etmek için sistematik bir yaklaşım gerekmektedir. CONQUAS kalite değerlendirme sistemi ve Altı Sigma kalite yönetim sistemi bu sistematik yaklaşımı sağlayabilecek sistemlerden ikisidir.

Bu araştırmanın amacı "toplu konut projelerindeki düşük kalite seviyesi"ne dikkat çekmektir. Bunun için, Türkiye'deki ODTÜKENT lojmanlarındaki üç konutun inşaat kalite seviyeleri Altı Sigma ve CONQUAS kalite değerlendirme sistemini

kullanarak değerlendirilmiştir. CONQUAS standartların belirlenmesi için kullanılırken, Altı Sigma verilerin analizinde kullanılmıştır.Müteahhit, kontrolör ve ev sahipleriyle yapılan söyleşi ve görsel incelemelerin değerlendirilmesinden sonra hatalar ve sebepleri ortaya konmuştur. Buna göre, ODTÜKENT lojmanlarındaki kalite düşüklüğünün nedeni ilk olarak işçilik hatası, sonra uygun olmayan yada düşük kaliteli malzeme kullanımı ve son olarak detayların tasarımdaki hatalardır.

İncelenen binaların yapım tarihleri farklı olmasına rağmen önceki hatalardan ders alınmadığı ve aynı hataların tekrarlandığı görülmektedir. Bu da Altı Sigma gibi geri bildirim ve inşaat projesinde kalite seviyesinin, müteahhidin kalite ilerleme çabalarının değerlendirilmesini sağlayan ve zamanla gerçekleşen ilerlemeyi ölçen bir sistemin önemini ortaya koymaktadır.

Anahtar kelimeler: Kalite, inşaat sektöründe kalite, konut kalitesi, Altı Sigma kalite yönetim sistemi, CONQUAS kalite değerlendirme sistemi

To my family

ACKNOWLEDGEMENTS

I would firstly like to express my sincere appreciation of my supervisor, Mrs. Soofia Tahira Elias-Özkan for her guidance, insight and encouragement throughout the study. It has been a great pleasure and honour to work with her. I am also grateful to all jury members for their invaluable ideas.

I would also like to thank Mrs. İdil Güven for her guidance on the survey of ODTÜKENT housing units and Mrs. Arzu Gönenç Sorguç who allowed me to visit her house for the survey.

I would like to express my thanks and love to my family for their continuous encouragement and patience during my studies and especially to my brother Hasan for his immeasurable assistance and support.

Lastly, special thanks to my faithful friends Neslihan, Gonca and Elvan for their continual support and help.

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ABBREVIATIONS

ACMV	Air-Conditioning and Mechanical Ventilation
AHU	Air Handling Unit
ASCE	American Society of Civil Engineers
BCA	Building and Construction Authority
BQA	Building Quality Assessment
BQIH	Building Quality Index for Houses
CIDB	Construction Industry Development Board
CONQUAS	Construction Quality Assessment System
CSIR	Council for Scientific and Industrial Research
CTRL	Channel Tunnel Rail Link
DFSS	Design for Six Sigma
DMAIC	Define, Measure, Analyze, Improve and Control
DPMO	Defects per Million Opportunities
DQI	Design Quality Indicators
EPC	Engineering, Procurement and Construction
FIDIC	International Federation of Consulting Engineers
HASAS	Health and Safety Assessment System
HDB	Housing and Development Board
HQI	Housing Quality Indicators
ISO	International Organization for Standardization
METU	Middle East Technical University
MOC	Ministry of Construction, China
MPA	Maintenance Period Assessment
NHBRC	National Home Builders Registration Council of South Africa

PASS	Performance Assessment Scoring Scheme
PDCA	Plan, Do, Check and Act
PIP	Process Improvement Programs
QAI	Quality Assessment International
QLASSIC	Quality Assessment System in Construction
TQM	Total Quality Management
YÖK	Higher Education Council of Turkey
6σ	Six Sigma

CHAPTER 1

INTRODUCTION

In this chapter the argument for and the objectives of the study, together with a brief overview of its procedure are presented. The chapter is concluded with a disposition of the subject matter covered in subsequent chapters.

1.1. Argument

Baird *et al*., (1996) stated that "Buildings affect our health, our work, our leisure, our thoughts and emotions, our sense of place and belonging. If buildings work well, they enhance our lives, our communities and our culture." Though, the quality of buildings is of importance, the construction industry is often criticized for its poor performance on quality, cost and safety. There are many reasons for this criticism. Clients continue the usual practice of awarding tenders to the lowest bidder and not rewarding the best designers and contractors who could provide the best service. Also, the industry consists of numerous parties, each of which has a role to play in ensuring the quality of the product. The poor performance of one party will affect the next one and quality is thus difficult to ensure.

Since a home is the most fundamental need for human beings, the housing sector is the mainstay of the construction sector. In developing countries, the rapid urbanization and overwhelming population growth in rural areas resulted in out-migration to urban areas, inevitably leading to the problem of housing shortage. The efforts in housing estate have been directed towards meeting the quantitative shortage of dwellings; cooperatives and mass housing are presented as a solution to this housing problem. Later, qualitative aspects of housing gained importance because of devastating loss of life and property in earthquakes and other natural disasters due to low-quality buildings. Also, users are becoming more conscious of quality issues in housing environments. In accompaniment to economic growth and rising living standards, residents require higher quality of housing.

However, the quality of residential buildings especially mass-housing units has not been significantly improved. The absence of evaluation system and standards in construction industry is one of the key problems because systematic evaluation works to the benefit of all who use buildings or are otherwise involved in their creation and operation. Due to the absence of evaluation system, quality of buildings is not measured and it is not clear that whether occupants are satisfied with their houses or not. Thus, a standard quality level in housing units is not attained.

Different quality assessment systems are being used in the world for the construction industry to increase satisfaction of residents and quality. These systems also determine the standards for construction. In Turkey, housing purchase guide is proposed as a solution, it is designed to help decision of clients whether to buy a house or not. It examines legal, economical, environmental aspects and the existence of some elements but it is not an assessment tool for construction quality. Due to low quality in construction industry especially in mass-housing units and absence of construction quality assessment system to evaluate quality level in projects, this subject was selected as a thesis subject.

In the construction industry, factors such as change, customer demands, competitive pressure and cost affect an organization's ability to understand the client's requirements and meet first time, at minimum cost and high quality. Thus, it is vital to develop a quality management system that avoids any inefficiency that could result in poor quality of products and services being delivered to the customer; and which helps to improve quality and productivity by eliminating the causes of non-conformance to requirements in all activities.

In recent years, due to the success of process-centered quality improvement tools and techniques, especially in the manufacturing industry, their application in the construction industry has received much attention. In their effort to satisfy customers, make profits, gain market leadership and move product/process quality in the construction industry toward higher levels (Thawani, 2004), many organizations have undertaken initiatives to implement various quality management techniques such as business process re-engineering, Kaizen, ISO 9000 and lately Six Sigma quality management system which is a systematic method for process improvement and a product/service development that focuses on eliminating defects at the source instead of trying to manage the defect after it has occurred.

Therefore, in this study Six Sigma quality management system is used with a construction quality assessment system called CONQUAS for evaluation of quality level in mass-housing projects. CONQUAS is selected as the quality assessment tool because it is the only system that gained achievement. Also it states standards and points out the places where the defects occurred.

1.2. Objectives

The main objective of this thesis was to evaluate quality level in ODTÜKENT mass-housing units via Six Sigma criteria to determine the defects and problems originating from workmanship, improper material usage and design of architectural components. The other objectives of this study were:

- to examine applicability of a construction quality assessment system called CONQUAS with Six Sigma quality management system in construction industry for evaluation of quality level in mass-housing projects,
- to bring up the quality concept in construction industry, especially the housing sector, associated with the evaluation of the indicators and guides used for improving the quality level,
- to examine the literature in order to determine which quality assessment systems are available for construction industry,

- to evaluate accumulated knowledge on a quality management system called Six Sigma and its application in the construction industry,
- to make suggestions for improvement in the quality level and to provide a guide for professionals and future research.

1.3. Procedure

The first phase of the study consisted of a literature survey. This was based on an overview of the theses and publications found in Higher Education Council of Turkey (YÖK), Bilkent and Middle East Technical University (METU) libraries. The study was formatted to describe quality in the construction industry. Thereafter, housing quality indicators and quality-related expectations of occupants were compiled from similar studies conducted on this subject.

An evaluation study based on Construction Quality Assessment System (CONQUAS) and Six Sigma was applied to three houses from ODTÜKENT housing units. The survey was conducted on METU-ODTÜKENT because they are the closest housing units and also for determination of the quality level in mass-housing units of a university that consists of Architecture and Civil Engineering Departments. The houses were selected according to their types and their different construction dates to show up similarities and differences related with the level of quality.

The architectural drawings and information about units, their construction materials were acquired from the METU Office of Construction and Technical Works. These were supplemented by photographs taken on site. Also interviews with the occupants of the houses helped to identify problems related with the quality of design and materials used in the houses. Assessment of houses was made to determine quality level according to construction materials, workmanship and design of architectural elements. Social, aesthetical and environmental qualities of housing blocks were disregarded in this research.

A paper published by Low and Hui (2004) on CONQUAS and Six Sigma implementation in the construction industry provided a base case for this research. The information about CONQUAS, together with other construction assessment systems being used in the world and Six Sigma are described in the literature survey. The checklists for the evaluation of houses were taken from the paper mentioned above. The results of checklist analyses were evaluated with Six Sigma to determine the quality level of the houses. Results of these assessments are discussed and finally some suggestions are made for the improvement of quality.

1.4. Disposition

This report is composed of five chapters. The first one given under section titled 'Introduction' covers the subject of study including its argument and objectives together with a general outline of the procedure of data gathered for the study. Conclusively with the disposition, the ongoing of the thesis is presented.

In the literature survey presented in Chapter 2, general aspects of quality and issues related to quality in construction industry and various quality assessment systems being used in the world are investigated. The importance of quality in construction especially in housing is emphasized with the clarification of housing quality indicators. In the last part of the second chapter, principles of six sigma and its application in construction industry were detailed.

In Chapter 3, the case study on quality assessment of construction of the ODTÜKENT housing units is examined in light of the aforementioned studies and analyses. Firstly, the survey material and secondly the survey methodology are described. In Chapter 4, the survey for six sigma quality assessment is revealed for each house. Then the results of the analysis are explained and some suggestions for improvement of construction quality are given.

In the last chapter, the concluding remarks of the survey are presented and wider issues are also discussed.

CHAPTER 2

LITERATURE SURVEY

The literature survey part is comprised of issues related to quality in construction industry, especially in the housing sector and the various quality assessment systems being used in the world. Also, Six Sigma quality management system is explained regarding the implementation in construction industry.

2.1. Quality in the Construction Industry

The concept of quality of goods or services is not new for human being. Throughout history, society has demanded that providers of goods or services should meet their obligations. As cited by Horne (1998), King Hammurabi of Babylon introduced in 1780 B.C. the concept of product quality and liability into the building industry of the time by declaring: "……if a builder build a house for someone, and does not construct it properly, and the house which he built fall in and kill its owner, then that builder shall be put to death. If it kills the son of the owner the son of that builder shall be put to death".

Until the start of World War I, craftsmen assumed responsibility both for the manufacture and inspection of a complete product for the quality of their work. Inspection quality control that was the first formal quality control evolved during World War I when the manufacturing system became more complex (Tenah and Guevara, 1985).

Statistical quality control flourished during World War II when tremendous mass production was necessary. This technique emphasized the sampling of quality of the output but did little to ensure the quality of the production process itself (Tenah and Guevara, 1985).

Finally the fierce international competition for goods and services; and dramatic increase in user quality requirements during the 1980s and 1990s has led the manufacturers to recognize the inadequacy of existing in-plant quality practices and techniques. These problems highlighted the dual quality challenge, providing significant improvement in the quality of products and practices while at the same time, effecting substantial reductions in the overall cost of maintaining quality. A totally new concept was developed based upon the principle that in order to provide genuine effectiveness, control must start with the design of the product and end only when the product has been placed in the hands of the customer who remains satisfied (Tenah and Guevara, 1985). By 1987 the international industry had developed its own generic standards for this concept corresponding to ISO 9000 (International Organization for Standardization) which revised two times later on (ISO, 2006).

According to Low (1993) quality is a multi-faceted concept. This is because there is no absolute definition of quality. A slightly less explicit but nevertheless still all-embracing approach is adopted by the ISO when they define quality as the ``totality of characteristics of a product, process, organization, person, activity or system that bear on its ability to satisfy stated or implied needs" (Low and Wee, 2001). This can be adopted as "conformance to requirements of clients" (Atkins, 1994) or "degree to which a set of inherent characteristics fulfils requirements" (International Towing Tank Conference, 2005).

On the other hand, ISO describes quality management as coordinated activities to direct and control an organization with regard to quality. It uses a systematic set of activities to ensure that processes create products with maximum quality at minimum cost (International Towing Tank Conference, 2005).

There is increased concern for construction quality because the construction industry is often criticized for its poor performance on quality, cost, safety and speed (Low and Tan, 1996). A survey conducted on quality of construction by the International Federation of Consulting Engineers (FIDIC) within member associations confirmed that failure to achieve appropriate quality of construction is a problem worldwide and is evident in both developed and developing countries (FIDIC, 2004).

According to Atkinson (1995), quality of a building derives not only from the quality of its design and of the process through which the design was developed, from the quality of the construction process and the care taken in translating the design into practical shape, and from the quality of materials used and equipment installed, but also from the way it is used, and the quality of building management and maintenance. The main factors that influenced quality were attributed to design (e.g., lack of coordination of design, unclear and missing documentation) and poor workmanship (e.g., lack of care and knowledge) (BRE 1981; Chew *et al*., 2004).

Chung (1999) defined construction quality as the satisfaction of requirements of all parties with the construction project (Low and Wee, 2001). Quality is characterized by Arditi and Günaydın (1999) as follows:

- Meeting the requirements of the owner/client as to functional adequacy with qualified design; completion on time and within budget; life-cycle costs; operation and maintenance, better workmanship, better aesthetic/appearance, application of high quality materials/technology.
- Meeting the requirements of the design professional as to provision of well-defined scope of work; budget to assemble and use a qualified, trained and experienced staff; budget to obtain adequate field information prior to design; provisions for timely decisions by owner and design professional; and contract for performance of work on a reasonable schedule.
- Meeting the requirements of the constructor as to provision of contract plans, specifications, and other documents prepared in sufficient detail to permit the constructor to prepare priced proposal or competitive bid; timely decisions by

the owner and design professional on authorization and processing of change orders; fair and timely interpretation of contract requirements from field design and inspection staff; and contract for performance of work on a reasonable schedule which permits a reasonable profit.

- Meeting the requirements of regulatory agencies (the public) as to public safety and health; environmental considerations; protection of public property including utilities; and conformance with applicable laws, regulations, codes and policies.

2.1.1. Characteristics of the Construction Industry Affecting Quality Management

The early development work on quality management took place in a manufacturing environment and most of the literature on the subject is related to factory productions. This creates a mistaken impression in minds of those engaged in activities other than manufacturing that the tenets of quality management hold no benefits for them. Any organization whose livelihood depends on successful performance in the market place can benefit from quality management (Kökçüoğlu, 1997).

However, the manufacturing-oriented quality concepts cannot be applied to the construction industry, since design and other processes of civil engineering projects are more complex, expensive, immovable and long-lived which needs a high order of management skills and an understanding of human behaviour (Al-Momani, 2000; Kazaz and Birgönül, 2005).

Construction has many characteristics that differentiate it from other industries and affecting quality management implementations. The characteristics obtained from different researches and papers are as follows (Kanji and Wong, 1998, McIntyre, 2002, Serpell *et al.,* 2002):

1. Almost all construction projects are unique;
2. Unlike manufacturing industries, which have a fixed factory site, construction sites are unique in terms of environment and condition;
3. There is no clear, uniform evaluation standard in overall construction quality as there is in manufactured items and materials; thus, construction projects usually are evaluated subjectively;
4. Since construction projects are a single-order design product, the owner usually directly influences the production. Moreover, excessive changes to the details of the design of a project are typical throughout the construction process;
5. The participants in both the design and construction stages are likely to change from project to project;
6. Lack of education and training of people especially the construction workers' that do not have a favourable attitude with respect to active participation in quality improvement ;
7. Many of its workers are transient and self-employed, thus making it difficult to generate long-term cultural perspectives;
8. Virtual lack of research and development;
9. Various parties are involved in the same area at the same time;
10. If not designed or built correctly, there is usually little that can be done to put things right at a later stage. The reworks at site cost much higher than in factory.

These characteristics substantially differentiate the construction industry from others and they indicate that quality management systems that work effectively in a mass production industry have not been considered suitable for the construction industry. Unfortunately, the construction industry's uniqueness is all too frequently used as an excuse for not adopting new technologies and management techniques that have been successfully implemented elsewhere. As a result, the construction industry has lagged behind other industries such as manufacturing and automotive industries in the adoption of new technologies and management techniques for performance improvement (Marosszeky and Karim, 1997).

2.1.2. Reasons of Poor Quality in Construction

Poor quality has been an endemic problem in construction industry due to lack of improvement and dominance of the traditional project management approaches. Researches show that poor quality can waste incredible amounts of money either directly or indirectly.

The reasons of insufficient quality in construction are given by Low (1996) and Madenli (2002) as:

- Unconformity of projects and construction materials to technical regulations and standards;
- Insufficient number of quality control engineers and trained technical staff;
- Poor management of unqualified contractors in construction site;
- Insufficient tests (quality control tests, construction tests, etc.) and tests performed by inexperienced, unqualified technical staff ;
- Poor workmanship because of unqualified and untrained workers in construction-site;
- Insufficiency of standards and technical specifications that do not match the current developments in construction techniques and systems;
- Engineering/design errors;
- Unconformity of construction materials to the quality standards;
- Paying more attention to completing the works on schedule and within budget than to achieving quality in construction;
- Poor communication between parties;
- Improper definition of client requirements, work descriptions;
- Unfavourable site conditions.

From the above, it would appear that the quality of construction work is dependent to a large extent on the attitudes of the contractors and consultants. Failure of any of the parties seriously affects the quality of the final project. Therefore, adopting a quality management approach towards projects and construction is of importance for the construction industry and its parties.

2.1.3. Advantages and Disadvantages of Quality Management

In recent years, participants in the construction industry have become aware of rising construction costs and perceptions of increased quality problems. Great expenditures of time, money and resources both human and material are wasted because of inefficient or nonexistent quality management system.

The companies try to achieve the management of quality to gain marketing advantage in the homeland or global area. Also quality management systems are becoming a prerequisite for tendering in multinational projects funded by international investment organizations. Moreover, in some developed countries it is also a must for public construction projects whose clients are the government agencies.

In addition to all the above-mentioned reasons, there are some other reasons for implementing quality management given by Madenli (2002) as follows:

- To improve management ability;
- To increase profitability, productivity;
- Requisition of strategic partners;
- To enhance sales;
- To enhance product and service quality;
- To increase customer satisfaction.

As long as the quality management system has been appropriately designed to accommodate the particular requirements of the project and client, numerous examples of advantages have been presented.

Chew and Chai (1996) determined some of the advantages of implementing quality management to a construction company as follows:

- Optimization of resources usage in the organization;
- Improvement of communication between parties;

- Improvement of tractability of quality problems;
- Reduction of material wastage;
- Provision of useful documented reference;
- Improvement of work quality with fewer rejects and less repeated work;
- Rectification of errors at early stage;
- Improvement of corporate quality image;
- Increment of competitive advantage in national and international markets;
- Increment of management power;
- Improvement of the ability of evaluation of delays and change;
- Decrease in the cost of reworks due to errors and shortcomings;
- Improvement of productivity;
- Increase in customer satisfaction.

The implementation of a certified quality management system in construction is criticized as costly and time consuming, which has also discouraged particularly small companies from choosing this route. Some of the underlined disadvantages are (Dissanayaka *et al.,* 2001):

- More paperwork;
- Unnecessary bureaucracy;
- Additional cost;
- Less flexibility.

2.2. Housing Quality

The rapid population growth and high rate of urbanization has made the need for adequate housing a very important concern especially in developing countries (Djebarni and Al-Abed, 1998). According to the Turkish Construction Sector Report 2005 published by Yapı Endüstri Merkezi (2006), the need for housing can be defined as "the number and quality of dwellings needed to secure the accommodation of people at minimum level independently of their ability to pay and their individual preferences and the difference between the available number of homes and their qualities at any given time".

Under the influence of industrialisation and changing policies, when migration to the big cities began, the problem of shanty towns and illegal building, which has been continuously on the agenda, has reached the stage where it has virtually become legal. The reason behind the illegal and unregulated building of substandard housing which has been taking place is an attempt to close the gap in housing (Yapı Endüstri Merkezi, 2006).

Housing shortage and illegal buildings have forced the government to solve the housing problem by rapid housing production systems in several ways (Altas and Özsoy, 1998). Mass housing and cooperative housing schemes were perceived by the government as the way for especially low income groups to own their houses and to live under better housing conditions by providing minimum acceptable standards, amenities, and facilities within and outside the dwelling units, thereby contributing to an improvement in the quality of life of the residents (Djebarni and Al-Abed, 1998). Dwelling units in both systems are designed for standard average users. Neither the differences of occupants' characteristics, nor the changing needs of residents, in time, are considered in design (Altas and Özsoy, 1998).

On the other hand, quality-related issues in mass housing projects are completely ignored due to utilization of low-cost construction techniques and poorly designed projects (Kazaz and Birgönül, 2005). The rush to respond to the needs seems to result in low quality housing that does not adequately match the needs of people (Djebarni and Al-Abed, 1998).

As a natural response to the poor-quality problem frequently observed, dwellers are not fully satisfied with the quality of products or services delivered within their housing units. Therefore, residents are compelled to make extensive modification and addition immediately after moving into their housing units. This brings an extra financial burden on their already limited budgets.

It has been observed that these processes even start before the delivery of the house, and continue throughout the life cycle of the housing unit. Due to financial limitations, occupants - who can not afford such a modification process within their houses - are forced to adopt cheap, primitive, provisional, and inconvenient measures creating an unfavourable living environment for themselves (Kazaz and Birgönül, 2005).

2.2.1. Definition of Housing Quality

Housing quality is a complex concept because it is neither absolute, nor static. Rather, it is a relative concept that may vary between countries and also between specific groups of people in each country both at one point in time and over long periods. In principle, because housing quality is context dependent and variable over time, there are no 'objective' static standards or prescriptions that can provide a comprehensive account of this subject. Hence, the presence of inadequate housing conditions should not only be considered as an architectural or a technical problem, but also as an economic and a political one (Lawrence, 1995).

Housing quality can be interpreted in many ways and definitions of "housing quality" have been dependent on the approach of the researcher. (Lawrence, 1995) Each definition attempts to be comprehensive. However, each one has its own problems and is inadequate in some respects, as each one views quality from a certain angle (Djebarni and Al-Abed, 1998). Diverse approaches reflect the rationale and objectives of those who conduct or sponsor research and policy formulation. For example, studies on housing quality may be intended for the formulation and implementation of government housing policies, or academic research, or the dissemination of information to professional groups (such as architects or building contractors) and to the public.

The purpose of defining housing quality may concern one or more of the following goals (Lawrence, 1995):

1. the assessment of aesthetic and/or use values of residential buildings;
2. the identification of targets for upgrading or replacing the existing housing stock;

3. the allocation of housing loans and subsidies by consideration of effective occupancy conditions, household income and expenditure;
4. concern about the health and well-being of residents in relation to the internal and external conditions of housing neighbourhoods.

Given that there is a wide range of contributions on the subject, there is no consensus neither on the definition nor on the operationalisation used to define and measure housing quality (Lawrence, 1995).

Lawrence (1995) summarized different approaches to quality as follows:

1. Those approaches that focus on the point-of-view of the individual, be it that of an architect, a building contractor, a housing administrator, or a resident. By this approach, people are meant to evaluate a specific residential environment using one or more sociological and/or psychological research methods.
2. Research about the material/quantifiable characteristics of housing, especially in terms of the external appearance of residential buildings and their functional, technical and construction components. Calculations of net habitable floor area per person, and of acoustic and thermal insulation provided by internal and external walls, are commonly included. These approaches often ignore the fact that ergonomic, technical and physical standards of housing are dependent on cultural values, social conventions and individual preferences which may vary over time.
3. Studies of the supply of housing (annual construction output), of the cost of new residential buildings, of the rationale and outcomes of housing construction grants to public authorities and private firms, and of housing subsidies and allowances to households.

Each of these approaches address a number of factors, but none of them define a broad, integrated definition of housing quality, one that integrates these three sets of approaches simultaneously (Tiwari, 2002).

Many researchers noted that it is best to use multiple criteria to measure "quality" (Djebarni and Al-Abed, 1998). Lawrence (1995) calls for an integrated definition of housing quality in which "sets of architectural, demographic, economic, ecological and political factors are explicitly interrelated". As Harrison (2004) pointed out, housing is usually evaluated from an economic perspective, a social perspective, or a physical condition perspective.

Attempts to measure housing quality are complicated by socioeconomic and political characteristics of communities. Most of the housing evaluation studies concern neighbourhood scale and social variables such as management, maintenance, friendly neighbours and other residents and urban context (Altaş and Özsoy, 1998).

The predictors of housing quality are defined in terms of the physical structure of the dwelling and other facilities offered by the house, including amenities like availability of kitchen, bath and toilet facilities, area, number and arrangement of rooms, room spaces (size, shape, level of enclosure, etc.), other physical characteristics such as material type and detailing; and the physical environment including the locational features (distance from central business district, etc.) (Sengendo and Shuaib, 1999).

Morris (1972); identified three areas of housing quality:

1. structural quality, which refers primarily to durability of the shell;
2. service quality, which is concerned with the kinds of equipment, facilities, and conveniences which the dwelling provides; and
3. the state of maintenance and care taking (Djebarni and Al-Abed, 1998).

Housing quality is a multi-dimensional issue, and the parametric standardization of housing quality is very difficult. The enhanced physical standards for dwellings do not automatically equate straight-forwardly with improved housing quality from user perspectives (Harrison, 2004). For example, a 100 m² house may satisfy a household, but another household may report its dissatisfaction (Tiwari, 2002). However, the basic way to guide the performance-oriented concept and high quality houses is establishing a practicable building performance of housing evaluation system. It offers qualitative and quantitative indicating standard to raise the housing quality. There are assessment systems and indicators to try to solve the low-quality housing problem.

2.2.2. Housing Quality Indicators and Assessment Guides

The British set about solving the problems of low-quality housing, starting with the government sponsored Egan report, which set concrete goals for improvements in the housing industry (Topping, Lawrence and Spencer, 2004). A number of different indicators are being used for trying to capture the values and quality. Notable examples among these are Housing Quality Indicator (HQI) and Design Quality Indicator (DQI) which are explained in more detail below.

a) *Housing Quality Indicators (HQI)*

The Housing Quality Indicators (HQI) system is a measurement and assessment tool designed in 1996 to allow potential or existing housing schemes in UK to be evaluated on the basis of quality. The quality rating derived by using the system does not provide a direct correlation with financial value, nor does it set out minimum standards. The HQI allows an assessment of quality of key features of a housing project in three main categories (Housing Corporation, 2006):

- location
- design
- performance

These three categories produce the ten 'Quality Indicators' that make up the HQI system. The ten indicators are:

1. Location
2. Site - visual impact, layout and landscaping

3. Site - open space
4. Site - routes and movement
5. Unit - size
6. Unit - layout
7. Unit - noise, light and services
8. Unit - accessibility
9. Unit - energy, green and sustainability issues
10. Performance in use

The HQI system consists of two parts: the "HQI form" and a "scoring spreadsheet". The "HQI form" is a booklet containing information on the project and the ten indicators. The first page of the HQI form contains the project description. The main body of the HQI form contains information on the ten indicators that measure quality. In general, each Indicator in the HQI form takes up a double page spread with the text guidance and scoring instructions on the left and the Indicators on the right. Each indicator contains a series of yes/no questions that are completed by the developer or client. When an item is genuinely 'not applicable' (n/a), this can be indicated so that its score is removed from the total available.

It is important to relate dwelling design to the way in which people wish to live and the context in which their home is placed. For this reason, the Indicators look not only at the unit and its design in detail (5-9), but also the context and surroundings (1-4), and aspects of performance in use (10). Schemes that contain a very large number of individual units, irrespective of number of unit types, may require sampling techniques.

The second part of the HQI system is a "scoring spreadsheet". The information from the HQI form is transferred to this spreadsheet. The spreadsheet, with its computer-based score calculation, turns the answers to the HQI form into a standardized score. This score is expressed as a series of scores showing how well the scheme performed on each indicator as well as an aggregated score. The most current version of the HQI is available online on Housing Corporation web-site (www.housingcorp-online.org/HC/HELP/Acrobat/HQIFormv3.pdf, 2006). A representative example is given in Appendix A.

b) *Design Quality Indicators (DQI)*

DQI was developed by UK's Construction Industry Council in 2001 with research input from the authors and the architects in practice for evaluating design quality of buildings. It can be used through strategic briefing stages to set priorities and answer questions till the completeness of the post-occupancy evaluations in order to receive feedback from the project team and everyone involved in the development process to contribute to improving the quality of built environment. The DQI is divided into three categories: *"Functionality, Impact, and Build Quality "*. These three categories introduce the quality indicators of the DQI system (www.dqi.org.uk, 2006).

DQI Online is an interactive tool that includes a simple and non-technical questionnaire. The scores range from 0 to 5 where 0 means not applicable, 1 - strongly agree to 5 - strongly disagree. The results can be obtained instantly and displayed in different ways to help facilitate discussion among project participants. The online application of the DQI system is obtainable on DQI Online web-site (www.dqi.org.uk, 2006).

c) *Building Evaluation Checklist*

This checklist was developed by Düzgüneş (2003) in the eighties and published as "Case-Study Report Form: A Handbook for Architects" in 2003. The report form consists of three parts. The first part is called introductory information, which includes background information on the project and the graphics and drawings of the design if available. The second and the main part titled Analysis, involves eight sections, each evaluating a building sub-system for the most part defined in line with the author's personal understanding.

These are supplemented by sections on site planning and overall design efficiency. The sub-systems analysed in this part are:

- The structural system
- The enclosure system
- The fenestration system
- The cladding system
- The conduit/flow system
- The environment- and comfort-control system
- The transportation system
- The amenities system

Scores ranging from 1 to 6 are used for the evaluation of items where ‘1’ is ascribed as “neglected” or “irrelevant” while ‘6’ as “very good”. The last part, titled Evaluation, is the part where the surveyor expresses his/her observations about the subject as a whole (Düzgüneş, 2003).

d) *Housing Purchase Guide*

“Housing Purchase Guide”, an evaluation system on the residential buildings, is prepared and published by Yapı Endüstri Merkezi with the contribution of instructors of Istanbul Technical University in Turkey in 2005. The guide consists of 165 questions evaluating the housing from technical, economical and legal aspects.

The guide is designed for apartments with reinforced concrete structural system with regards to the conditions of Turkey. The guide aims to provide conscious preferences of clients when buying a house. The 13 main categories of the guide consisting of questions are as follows:

- Legal assessment
- Economical assessment
- Architectural assessment
- Building environment
- Structural system and earthquake resistance
- Kitchen and bathrooms

- Walls, ceilings and suspended floors
- Doors and windows
- Roofs and ongrade floors
- Electrical, telephone and lighting systems
- HVAC system
- Sanitary plumbing
- Fire safety (protection)

The questions are answered by ‘yes’, ‘no’ or ‘not related with assessment’ (not applicable). The answers are evaluated as positive (+) or negative (-) properties of the house. If number of positive (+) answers is more, then the house is adequate to meet the requirements of the client. The “Housing Purchase Guide” is available on Yapı Endüstri Merkezi web-site (www.yapi.com.tr/VI_images/arastirma/YEM_KONUT_REHBERI.pdf, 2006). An example is given in Appendix B.

2.3. Quality Assessment Systems in the Construction Industry

Ho (1999) defined building evaluation as ‘the systematic assessment of building performance relative to defined objectives and requirements.’ An effective quality assessment system should be able to detect and measure all types of defects and capture all aspects of construction quality that affect the performance of buildings. The quality assessment can be carried out by measuring the constructed works against workmanship standards and specifications. Such measurements have to be comprehensive, straight-forward, consistent and effective. Furthermore, the assessments have to be carried out systematically and within reasonable cost and time frame (Council for Scientific and Industrial Research, 2005).

Comprehensive quality standards alone do not assure the effectiveness of the quality assessment system. The integrity of the tests and inspection methods are as important as the quality standards. Such measurements without proper and accurate tests and detection methods, defects cannot be detected. (Low, 2001)

Each building material, component, and assembly should be examined with regards to its quality, compatibility, and interactions with its adjacent materials and components. Thus to effectively ensure conformance of quality of the entire system, quality assessment tools should be employed. In the next section, the quality assessment systems being used in the world are analyzed. The systems evaluating workmanship and design quality of buildings are explained in detail in the following section.

2.3.1. CONQUAS

To enhance and promote quality construction in Singapore, the Building and Construction Authority (BCA) introduced the Construction Quality Assessment System (CONQUAS) in 1989 to evaluate the quality performance of building contractors in the public sector (Low,Kee and Leng, 1999). It is now regarded as the *de facto* quality yardstick for the construction industry in Singapore.

CONQUAS was essentially developed to meet three objectives (Singapore Building Construction Authority, 2005):

1) To have a standard quality assessment system for construction projects.
2) To make quality assessment objective by:
    - measuring constructed works against workmanship standards and specification.
    - using a sampling approach to suitably represent the whole project.
3) To enable quality assessment to be carried out systematically within reasonable cost and time.

A tendering advantage, called Premium Scheme, was introduced in 1990 to give an incentive to contractors with high CONQUAS scores. According to the scheme, a contractor would have a 0.2 per cent premium for every point scored above a CONQUAS score of 65 if the average CONQUAS score of his three most recent projects is at least 65. Local contractors who consistently produce good quality work therefore are entitled to enjoy a preferential advantage of up to 5 percent (or S$5 million, whichever is the lowest) of the contract sum over their competitors when tendering for government projects. In this manner, there is an attractive incentive for contractors to deliver good quality buildings (Low, Kee and Leng, 1999).

The CONQUAS covers most aspects of the general building works. The assessment consists of three components (Singapore Building Construction Authority, 2005):

a) Structural works,
b) Architectural works and
c) Mechanical and electrical works.

Each component is further divided into different items for assessment. However, the assessment excludes works such as piling, heavy foundation and sub-structure works which are heavily equipment-based and called under separate contracts or sub-contracts.

a) Structural works

The structural integrity of the building is of paramount importance as the costs of failure and repairs are very significant. The assessment of structural works comprises:

i. Site inspection of formwork, steel reinforcement, prefabricated components, etc during construction. The assessment shall include structural steel and pre-stressed concrete if each constitutes more than 20% of the total structural cost. Precast elements are assessed if the precast concrete volume exceeds 20% of total structural concrete volume.
ii. Laboratory testing of compressive strength of concrete and tensile strength of steel reinforcement.
iii. Non-destructive testing of the uniformity and the cover of hardened concrete.

b) Architectural works

Architectural works deal mainly with the finishes and components. This is the part where the quality and standard of workmanship are most visible. The assessment covers:

i. Site inspection of internal finishes, roofs, external walls and external works at the completion stage of the building. Internal finishes include floors, internal walls, ceiling, doors, windows and components.
ii. Material and functional tests such as on window watertightness, wet area water-tightness test and adhesion of internal wall tiles. There is also in-process assessment on installation of waterproofing for internal wet areas.

c) Mechanical and electrical works

The quality of mechanical and electrical works is important in view of its increasingly high cost proportion and its impact on the performance of a building. The assessment covers electrical works, air-conditioning and mechanical ventilation works (ACMV), fire protection works, sanitary and plumbing works and the basic mechanical and electrical fittings. The stages of the assessment include:

i. Site inspection of installed works before embedded/concealed. Such items include ACMV ductworks, electrical conduits, concealed pipes, etc.
ii. Site inspection of final installed works such as the air handling unit (AHU), cooling tower, fire alarm control panel, etc.
iii. Performance tests on selected works such as the water pressure test, earthing test, dry riser test, etc.

The building is assessed primarily on workmanship standards by the assessors from the BCA on site using standard score sheets. The assessment is done throughout the construction process for structural, mechanical and electrical works and on the completed building for architectural works. The Figure 2.1 illustrates the scoring process starting at the quality standards.

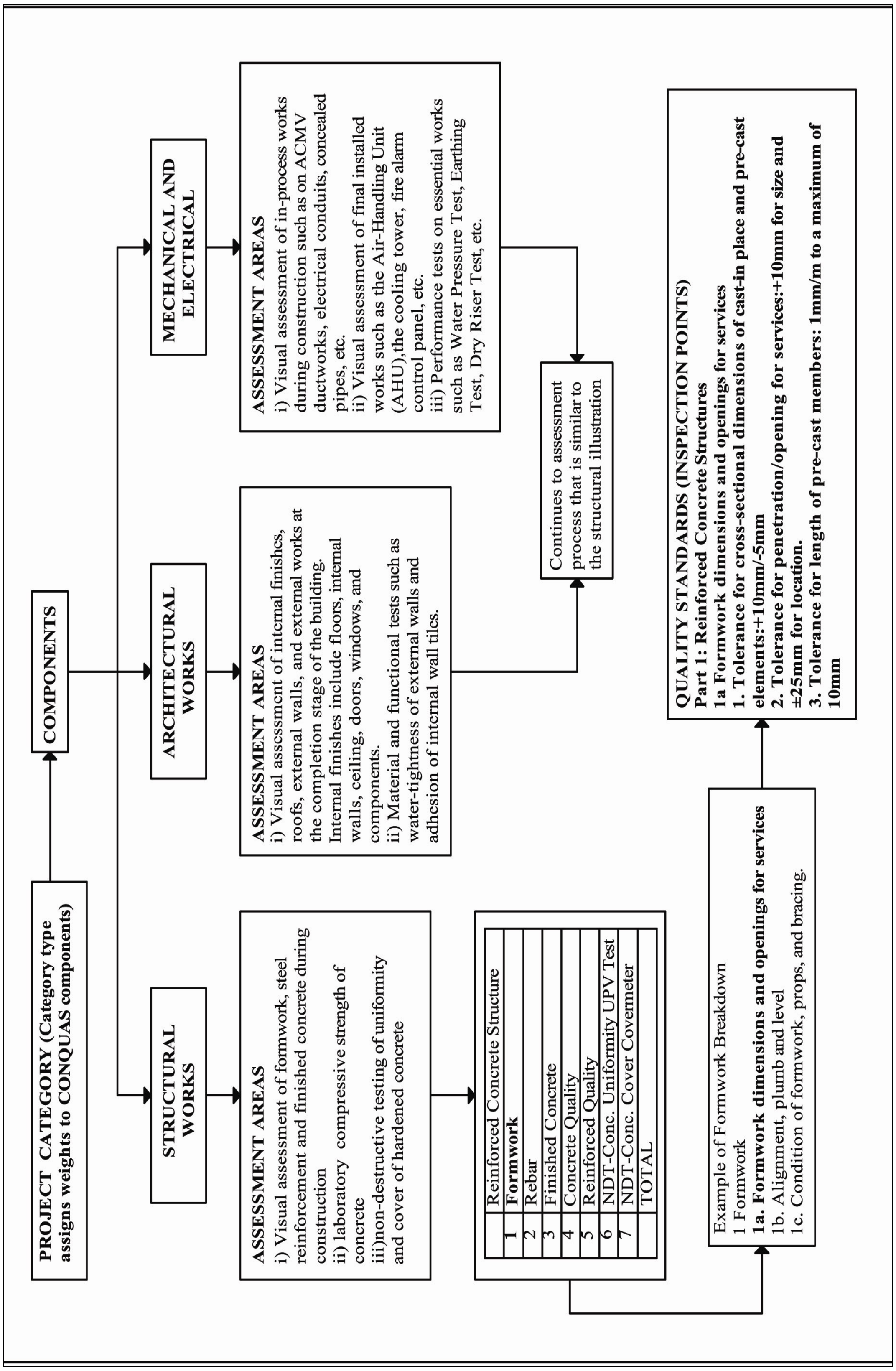


Figure 2.1 CONQUAS scoring process
(Source: Minchin and Smith, 2001)

Apart from site inspection, the assessment also includes tests on the materials and the functional performance of selected services and installations. These tests help to safeguard the interest of building occupants in relation to safety, comfort and aesthetic defects which surface only after sometime (Singapore Building Construction Authority, 2005).

The scores from the assessments are then summed to provide the total CONQUAS score for the building being evaluated. The weightages for structural, architectural and mechanical-electrical works are allocated according to four categories of buildings as in Table 2.1:

Table 2.1 CONQUAS Building Categories and Weight Scheme
(Source: Minchin and Smith, 2001)

Components	CATEGORY A Offices, shopping malls, industrial buildings, airports, hospitals, etc.	CATEGORY B Condominiums, institutional buildings (schools etc)	CATEGORY C Public Housing	CATEGORY D Landed properties
Structural Works	30%	35%	45%	40%
Architectural Works	50%	55%	50%	55%
M&E Works	20%	10%	5%	5%
CONQUAS SCORE	100%	100%	100%	100%

The weightage system is a compromise between the cost proportions of the three components in the various buildings and their aesthetic value.

It must, however, be noted that CONQUAS does not attempt to measure the quality of building design nor the level of maintenance found in a building. It only assesses the extent to which the contractor has met the specifications and requirements of the designers (Low, 1993).

Furthermore, as it is impossible to inspect every single component of a building because of time constraints; CONQUAS uses a sampling system for the assessment. The sampling system, which is mainly based on the gross floor area of the building, ensures that the assessment adequately represents the entire building. Selection of samples is based on drawings and location plans.

The scoring is done on the works that are inspected for the first time. Rectification and correction carried out after the assessment are not re-scored. The objective of this practice is to encourage contractors to do things right the first time.
When an assessed item does not comply with the corresponding CONQUAS standards, it is considered failed and “X" is noted in the assessment form. Likewise “√" is given for an item meeting the standards. "-" indicates that the item is not applicable. The score is computed based on the number of "√" over the total number of items assessed.

Buildings that are eligible for CONQUAS assessment must be between one to three years of completion. While the lower limit of one year helps to ensure that faults, if any, can be detected, the upper limit of three years ensures that the building concerned can still be regarded as a relatively new development (Singapore Building Construction Authority, 2005).

The CONQUAS model provides several clear advantages (Minchin and Smith, 2001):

1. A well-defined measurement scheme that permits measurements among various projects to be compared on an equal basis.
2. The independent third party is involved in the project and views quality and test results without knowledge of interacting factors.
3. By modifying the bid amount rather than the prequalification, the contractor is being rewarded for consistently providing above the targeted level of quality. The target level of 65 would represent a project that meets the minimum acceptable level of quality.

Disadvantages of the CONQUAS approach are (Minchin and Smith, 2001):

1. Does not consider the effectiveness of the contractor's safety or management systems.
2. The cost of supporting a third party process must be considered in weighting the total costs.

More of a concern than disadvantage is the use of cost as the basis of structuring the matrix of weights for the various buildings. However, this permit distribution of quality items on a rationalized objective basis rather than a subjective basis (Minchin and Smith, 2001).

2.3.2. PASS

In an attempt to improve the quality management of public housing construction in Hong Kong, the Hong Kong Housing Authority initiated to implement a quality assessment system named "Performance Assessment Scoring Scheme (PASS)" in 1991 (Kwok and Tang, 1999).

PASS has been developed to measure performance output directly against defined standards and to provide a fair means of comparing the performance of individual contractors. The assessment is a simple yes/no exercise. To give a fair assessment, several locations are sampled to give an even measure of the overall standard. The sampling spots are selected randomly by computers from all possible spots defined in the PASS manual. PASS is divided into three types of measurement: output, input and maintenance period assessments. The input assessment mainly deals with the management capability, organization and communication issues. The output assessment is to assess the quality of the final output of building works (Tam *et al.*, 2000). The maintenance assessment is carried out during the maintenance period, which is aimed at checking how the building functions after occupation (Kam and Tang 1997; Tam *et al.,* 2000).

a) Output assessment
   - Structural Works Assessment
   - Architectural Works Assessment
   - External Works Assessment
   - General Obligations
b) Input Assessment
   - Management Input Assessment
   - Programme and Progress Assessment
c) Maintenance Period Assessment

Structural Works Assessment comprises on-site inspection of various key trades and site inspection records. This aspect of output is allotted 35 per cent of the total output score. It is composed of four factors:

1. Reinforcement
2. Formwork and falsework
3. Finished concrete
4. Construction quality and practice

Architectural Works Assessment comprises on-site inspection of workmanship of components, finishing and inspection of regular test results required under the contract to be conducted on critical items susceptible to latent defects. The 35 per cent allotted to architectural work are distributed among several factors. It is composed of 13 factors:

1. Floor
2. Internal wall finishes
3. External wall finishes
4. Ceiling
5. Windows
6. Plumbing / drainage
7. Components
8. Precast components

9. Waterproofing
10. Shop front and cladding
11. External works
12. External plumbing / drainage
13. Builders' work and test (Record checking)

External Works Assessment is allotted 10 per cent of the total output assessment. Factors covered by this aspect include roads, emergency access, footpaths, pedestrian areas, drainage, and covered walkways with specific quality standards and tolerances.

General Obligations Assessment is concerned with the contractor's duties and responsibilities under the contract. The 20 per cent allotted for this aspect are assessed with respect to factors like safety and other obligations with specific quality standards (Tam *et al*., 2000).

The Other Obligations Assessment is composed of two factors:

1. Site Security, Access and Building Materials
2. Environmental, Health and Other Provisions

The Safety Assessment is composed of four factors:

1. Score for Safety and Health Management System
2. Score for Implementation of the Safety and Health Plan
3. General Site Safety
4. Block Related Safety

Management Input Assessment measures the Contractor's site management capabilities directly against defined standards and provides a fair means of comparing the performance of individual contractors. It is composed of four factors:

1. Management and organization of works
2. Resources
3. Co-ordination and control
4. Documentation

Programme and Progress Assessment is conducted mainly by referring to adequacy (i.e. the comprehensiveness and updateness) of the contractor's programme. Progress performance is assessed by using two basic complementary "tools" to guide the actual progress achievement in the period under assessment in a more complete and wider perspective. It is composed of three factors:

1. Programming
2. Progress against programme
3. Milestone dates

Maintenance Period Assessment (MPA) is used to assess the contractor's performance on a project during the 12-month Maintenance Period following certified completion. It is composed of three factors (Hong Kong Housing Authority web-site, 2006):

1. Outstanding works
2. Execution of works of repair
3. Management, response and documentation

The combined input and output assessments gives a composite score, which is used for consideration of tender opportunities while the weighting of the output and input assessments is 75 per cent and 25 per cent, respectively. Maintenance assessment is used as a supplementary tool for decisions to penalize contractors (Tam *et al.,* 2000).

This was seen in Hong Kong as an effective assessment and incentive system for promoting continuous quality improvement. However, the analysis of PASS scores has indicated that the general level of quality has not been significantly improved. Only a few large contractors can achieve the acceptable quality levels (Tam *et al*., 2000).

2.3.3. QLASSIC

Quality Assessment System in Construction (QLASSIC) was developed by Construction Industry Development Board of Malaysia (CIDB) in co-operation with construction related professional bodies, associations and certification bodies in 1999. It is a method used to measure construction quality and to benchmark the level of quality achieved in the construction process. It is intended to compliment the normal contractual drawings and specifications in a project. It was developed to achieve the following objectives: to evaluate the quality of workmanship in the construction project based on the approved standards and specification, to have a standard quality assessment system for the construction industry, to compare quality between projects, to evaluate a contractor's performance and, finally to be used for data compilation for statistical analysis in estimating the quality of workmanship and the productivity level of the construction industry (Takim, Akintoye and Kelly, 2003).

QLASSIC assessment covers 3 major components in building construction:

- Structural works
- Architectural works
- External works

Assessments of workmanship are done, based on some standards that are set out, and points are awarded if the workmanship complies with the standards. Forty percent of the classic points are allocated to the standard of structural works, fifty percent for the standard of architectural works and ten per cent for the standard of external works.

a) *Structural work* covers the structural aspects of a building. Quality assessment includes the quality of:

- workmanship
- construction material for both concrete and steel structure works

The concrete structure standards encompass the:

- framework
- reinforcement
- concrete works

The quality of material is based on standards of:

- aggregates
- cement
- properties of the finished concrete
- steel reinforcement

b) *Architectural works* deal mainly with the finishes and fittings of the building. The QLASSIC assessment elements that are covered by architectural activities include internal and external:

- Wall
- Floor
- Ceiling
- Roof
- Plumbing and sanitary fittings
- Door and window
- Building components
- Quality of material

c) *External works* cover the general external work elements in building construction such as the:

- aprons
- drains
- roads and footpaths
- turfings
- fences and gates

QLASSIC is primarily based on workmanship standards and specifications achieved and it does not cover design specifications. For example QLASSIC does not assess any design inadequacies like poor ventilation or narrow corridor.

Assessments are conducted on the three components and points are summed up to give a total score, called the *QLASSIC score* for the building. The assessment of structural work is done during the construction process, while both the architectural and external works are conducted after the completion of the project, before handing over to the client. A team of assessors from Construction Industry Development Board of Malaysia (CIDB) carries out the assessments. *QLASSIC evaluations* are done for superstructure components of a building and do not cover substructure works, mechanical works and electrical services. Assessment samples are determined at random and represent the entire project. The strength of this model is that it is very simple to implement. However, a major weakness is that assessment of architectural and external work is not conducted until the project is completed (Construction Industry Development Board Malaysia, 2006).

2.3.4. BQA

The Building Quality Assessment (BQA) programme is another quality tool which originated in New Zealand and was introduced in Europe in 1985 (Clements-Croome, 2003). BQA is a computerized system of building appraisal tool for scoring the performance of a building, relating actual performance to identified requirements for user groups in that type of building. It was developed by Ryder Hunt in Australia in conjunction with Victoria University of Wellington under the umbrella company, Quality Assessment International (QAI) in Australia (Clift, 1996).

The BQA system is based on a weighted evaluation of 137 factors of building design parameters. These factors are ascribed among the nine categories and these are described in Table 2.2 (Clements-Croome, 2003). It can be used as an aid for portfolio or asset management, rent reviews, investment appraisals, purchasing or selling properties, defining quality at briefing stage for new build and refurbishment, and judging alternative design proposals. It is possible to compare and score the quality of buildings of the same type (e.g. offices) (Clift, 1996).

Table 2.2 The BQA categories
(Source: Clements-Croome, 2003)

BQA Category	Description
Presentation	Appearance of the building & impression created
Space Functionality	Factors that determine operation of spaces
Access & Circulation	Matters concerned with access of people & goods
Amenities	Facilities or spaces for people
Business services	Electrical services & information technology
Working Environment	Working conditions of people in their work spaces
Health & Safety	Mandatory & other health or safety requirements
Structural Considerations	Building structure, construction & condition
Building Operations	Short & long term management of the building

BQA developed a detailed comparable grading system for each factor. Neither the categories nor the factors are all of equal importance. The score for each factor (0-10) is multiplied by a factor weight (0-100) to reflect its importance in the view of the user. The weighted scores are summed for each category and normalized by the sum of the weights for that category. The category score is also weighted to reflect its importance and when added to the other category scores gives an overall BQA score for the particular building (Clift, 1996).

In practice BQA is carried out by trained assessors who visit the building as well as examine drawings and specifications. They enter scores on a computer for the software to carry out the calculations and produce reports (Clift, 1996).

2.3.5. Other Quality Assessment Systems

China' first regulation on commercial housing quality assessment, the current *Ministry of Construction (MOC) housing quality assessment system*, started on a trial basis in 1999 aiming at promoting housing reform. The MOC housing quality assessment system includes more than 380 items concerning five major features on housing quality, granting all qualified housing programs the rating of "A", "AA", or "AAA" (People's daily online, 2006).

A quality assessment system called *Building Quality Index for Houses (BQIH)* for assessing the structural performance of housing in South Africa is currently under development in conjunction with the Division of Building and Construction Technology, Council of Scientific and Industrial Research (CSIR) and the National Home Builders Registration Council (NHBRC). The basic principles of the BQIH system follow those adopted in CONQUAS (Council for Scientific and Industrial Research, 2005).

2.3.6. Evaluation of Construction Quality Assessment Systems

The quality assessment systems mentioned above are generally based on workmanship standards; they measure constructed works against these standards. They do not attempt to measure the quality of building design nor the level of maintenance in a building. Only BQA evaluates building design parameters and only in PASS, maintenance assessment is carried out. General level of quality has not been significantly improved by these systems except CONQUAS. CONQUAS is the only system that gained achievement. It determines the standards, evaluates buildings' quality, points out defects and gives scores to the contractors according to these results. Thus, contractors participate in a tender according to the scores obtained from previous works.

From the above, it has been shown that some countries already practice quality assessment systems in guiding developments toward improved quality. Main causes of building defects can be classified into a few areas: design detailing, materials, construction quality, microenvironment, and maintenance practices (Chew *et al*., 2004). Thus to effectively resolve building defects, it is imperative to implement quality management. Six Sigma is one of these quality management systems that can be used to improve the quality of constructions. This system is explained in detail in the following section.

2.4. The Six Sigma Quality Management System

Six Sigma that was started in Motorola in the early 1980s and became well-known with the implementation in General Electric is a highly disciplined process that focuses on developing and delivering near-perfect products and services.

Sigma (σ), Greek letter that is the statistical representation of Standard Deviation, measures how far a given process deviates from perfection (Pande *et al*., 2000; Low and Hui, 2004). The central idea behind Six Sigma is that if the number of “defects” can be measured in a process, then they can be eliminated by systematically figuring out how to get as close to "zero defects" as possible.

Six Sigma is developed as a rigorous and disciplined methodology that uses data and statistical analysis to measure and improve a product/service quality by identifying and eliminating "defects" that are caused by product and/or process variability in manufacturing and service-related processes (iSix Sigma, 2004).

The European Construction Institute (2004); defined Six Sigma as (Ferng and Price, 2005):

> “A powerful management tool that assists companies to achieve breakthrough improvements in quality, eliminate defects, streamline operations, and thus dramatically improve profits. By redesigning and improving these processes, errors and waste are minimised leading to dramatic reductions in variability.”

A sigma quality level offers an indicator of how often defects are likely to occur, whereby higher sigma quality levels indicate a process that is less likely to create defects. A process with less variation is able to fit more standard deviations or sigmas between the process centre and the nearest specification limit than a process that is highly variable. A Six Sigma level of performance means six standard deviations or sigmas can fit between the process centre and the nearest specification limit (Wang *et al*., 2004).

Table 2.3 Simplified Sigma conversion table
(Source: Low and Hui, 2004)

Yield=percentage of items without defects	Defects per million opportunities (DPMO)	Sigma level
30.9	690,000	1
69.2	308,000	2
93.3	66,800	3
99.4	6,210	4
99.98	320	5
99.9997	3.4	6

For Example, as seen in Table 2.3 a company running at One Sigma have 690,000 defects per million opportunities. An "opportunity" is defined as a chance for non-conformance or not meeting the required specifications of customers (General Electric, 2005). In other words only 31% of their product would be free from defects. Traditionally companies accepted three or four sigma performance levels as the norm, despite the fact that these processes created between 6,200 and 67,000 problems per million opportunities which means 93%-99% defect-free products/services. A 99% level of perfection sounds well for the first time but 1% margin of error can add up to a lot of mistakes (Pyzdek, 2000). Chowdhury (2001) estimates it to be 20000 lost articles of mail every hour, and four accidents per day at airports (Low and Hui, 2004). The number of defects for 1% margin of error (3.8σ) and 6σ can be seen in Figure 2.2.

Activity	Defects @ 99% (3.8 Sigma)	Defects @ 99.9997% (6 Sigma)
Drinking Water	Unsafe drinking water for 15 mins per day	Unsafe drinking water for 2 mins per year
Mail Delivery	20,000 lost articles of mail per hour	7 lost articles of mail per hour
Hospital Surgery	5000 incorrect procedures per week	2 incorrect procedures per week
Air Travel	2 abnormal landings at most airports each day	1 abnormal landing every 5 years

Figure 2.2 The number of defects for 3.8σ and 6σ
(Source: Construction Industry Institute, 2006)

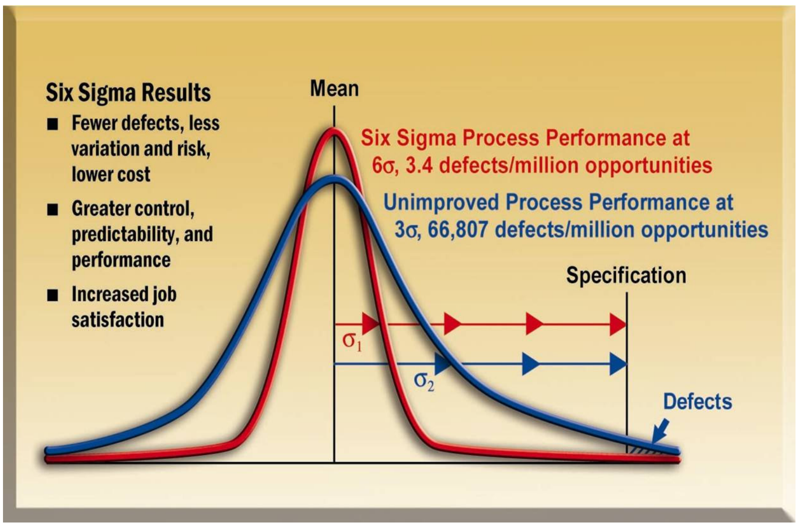


Figure 2.3 Six Sigma concept
(Source: Construction Industry Institute, 2006)

Six-Sigma was named as “level of perfection” because the process mean produce 3.4 defects per million opportunities (DPMO) as seen in Figure 2.3. To achieve Six Sigma quality, a process must produce no more than 3.4 defects per million opportunities to give a response to the increasing expectations of customers and the increased complexity of modern products and processes.

Six Sigma methodologies can be applied to any industry, from telecommunications and manufacturing to financial services, healthcare, and entertainment. In addition to the material and labour savings, other benefits of Six Sigma implementation are as follows (Low and Hui, 2004):

- Improvement of customer satisfaction and process flow
- Provision of a better understanding of customer requirements
- Improvement of delivery and quality performance
- Increment of productivity
- Reduction in cycle times
- Improvement of capacity and output
- Increment of product reliability
- Decrease of work-in-progress
- Reduction in total defects or errors — or cost of poor quality
- Reduction of the waste chain
- Increment of market share,
- Increment of profits by improving revenue and reducing costs
- Improvement of morale, teamwork and career potential.

In short, the goal of Six Sigma is to increase profits by eliminating variability, defects and waste that undermine customer loyalty (Kashiwagi, 2004).

Harry and Schroeder (2000) stated that in contrast to Total Quality Management (TQM) programmes, which tend to focus on improving individual operations with unrelated processes, Six Sigma focuses on making improvements in all operations within a process (Low and Hui, 2004).

While many traditional quality programmes have focused on detecting and correcting mistakes, Six Sigma provides specific methods to recreate the process itself so that the defects are never produced in the first place. Some of the following features make Six Sigma different (Thawani, 2004):

- Customer and process focus
- Driven by top leadership
- Disciplined approach-DMAIC
- Involvement of people-from top to bottom
- Well defined roles and infrastructure
- Mandatory training
- Statistical and data based decisions

2.4.1. Six Sigma Implementation

The implementation of Six-Sigma is not a short-term, quick improvement process. A committed leadership is essential in coaching and guiding the adoption of this holistic, long-term, and continuous improvement methodology. The steps to an ideal roadmap for establishing the Six Sigma system and launching improvements are to (Pande *et al.*, 2000; Low and Hui, 2004):

1. Create and agree on strategic business objectives
2. Identify key customers, core, key sub- and enabling processes, and owners of these processes
3. Define customer requirements
4. Measure current performance
5. Prioritize, analyze and implement improvements
6. Expand and integrate the Six Sigma system

The prerequisites for successful implementation of Six Sigma, obtained from different researches, include the following attributes (Low and Hui, 2004; Ferng and Price, 2005):

1. Top management-driven six sigma implementation is needed. Hoerl (1998) also cited continued to management support and enthusiasm as essential ingredients for success.
2. Six Sigma works best when everybody is involved.
3. The value that companies place on understanding and satisfying customer needs
4. The manner that combines the right projects with the right people and tools
5. Six-Sigma efforts must be integrated with existing business strategies and key performance measures. Tools which are familiar to the organisations must be selected.
6. Adequate training must be provided
7. An adequate data collection system for measurement must be established.

2.4.2. Six Sigma Tools

There are several models that can be used in the implementation of Six Sigma in an organization.

a) DMAIC

DMAIC, an integral part of the Six Sigma Quality Initiative, refers to a data-driven quality strategy for improving processes. DMAIC is an acronym for five interconnected phases: Define, Measure, Analyze, Improve, and Control (iSix Sigma, 2004). Its roots stem from the Deming model of PDCA (Plan, Do, Check, and Act) which describes the basic logic of data based improvement programs (Pande et. al., 2000).

The steps involved are:

i. Define Phase

Define who the customers are, what their requirements are for products and services, and what their expectations are; the project boundaries and the timeline and define the process to be improved by mapping the process flow (Kashiwagi, 2004). Identify, evaluate and select projects for improvement and select teams (Thawani, 2004).

ii. Measure Phase

Identify the key measures, the data collection plan or the plan for measurement for the process in question and execute the plan for data collection. (Pande *et al.*, 2000; Low and Hui, 2004) and collect data from many sources to identify expectations. (Kashiwagi, 2004)

iii. Analyse Phase

Analyze data using statistical quality control tools, the production or business process associated with the problem to identify the root causes and vital few' determinants of the performance (Low and Hui, 2004)

iv. Improve Phase

Improve target process by designing creative solutions to fix and prevent problems, create innovative solutions using technology and discipline and develop and deploy implementation plan (Kashiwagi, 2004).

v. Control Phase

Control and monitor the process using statistical process control to sustain the gains and improvements (Low and Hui, 2004).

b) DFSS

Another model called Design for Six Sigma (DFSS) is used when a product or a process does not exist (radical product or process design) or when incremental changes need to be incorporated into existing products or processes (Ferng and Price, 2005).

The employees must be capable of choosing the most appropriate tools and techniques for their situations. There are three major sets of tools/techniques that are required within the Six Sigma problem solving framework. These are outlined below (Henderson and Evans, 2000):

- Team tools – responsibility grid, threat versus opportunity matrix, action workouts, etc.

- Process improvement tools/techniques – brainstorming, Pareto analysis, process mapping, cause and effect analysis,
- Statistical Tools – Hypothesis tests (t-test, F-test, Chi squared, test), ANOVA, scatter plots, capability analysis, control charts, regression analysis, etc.

In addition to the tools and techniques, it is also need to have a clear understanding of the common metrics used within Six Sigma business strategy. Examples of these metrics include: costs of poor quality, number of customer complaints, defect rate, throughput yield to mention a few.

2.4.3. Six Sigma Organization

One of the most important elements of Six Sigma is the role everyone plays. Every player must have clearly defined roles and responsibilities. The roles and responsibilities of Six Sigma team members are categorized as champions, master black belts, black belts and green belts (titles created by Motorola).

Champions select projects, identify Black and Green Belt candidates, set improvement targets, review the projects on a regular basis and remove any roadblocks to the programme's success (Thawani, 2004). A Champion is a quality leader in the organization and is responsible for developing and implementing strategy, setting objectives, allocating resources, and monitoring progress (Ferng and Price, 2005).

Master Black Belts are the project managers of Six Sigma projects and are people most responsible for creating lasting, fundamental changes in the way the company operates from top to bottom. They serve as instructors for both Black and Green Belts, teach the core points of Six Sigma and provide ongoing coaching and support to project teams to ensure the appropriate application of statistics. They provide strategic and operational assistance to the project (Ferng and Price, 2005).

Black Belts are the backbone of Six Sigma deployment and continuous improvements. They build teams and attack problems by managing projects and then driving the teams for solutions that work, resulting in delivery of bottom line results (Thawani, 2004).They are the key to whole project, the true leaders of Six Sigma (Low and Hui, 2004).

Green Belts provide internal team support to Black Belts and work part-time on Six Sigma projects. They assist in data collection, computer input analysis of data using the software, and preparation of reports for management (Thawani, 2004).

2.4.4. Six Sigma in the Construction Industry

Literature review showed the application of six sigma in various domains. Some of these domains, which the authors came across, were finance, healthcare, automobile, aerospace etc. However, a literature search did not identify many six sigma implementations in the construction industry. (Kashiwagi, 2004)

One obstacle to achieving the required improvement has been the construction industry's reluctance to learn from other industries, hence causing time lags between the development of new technologies and management techniques, and their implementation within construction.

Since it is still a relatively new concept in the building industry, some construction companies started to use this quality initiative in their organizations. In 2000 Bechtel which is one of the world's engineering, construction, and project management companies with 40,000 employees decided to implement a Six Sigma program. Bechtel was the first major engineering and construction company to embrace Six Sigma. According to Eckhouse (2004), the company embarked on a US$30 million Six Sigma programme aimed at "*identifying and preventing rework and defects in everything from design to construction to on-time delivery of employee payroll*".

In 2002 Bechtel's Six Sigma Program initiated 300 Process Improvement Programs (PIP) and managed to save the company over $200 million dollars. Tenant (2001) stated that:

> "The greatest challenge for Six Sigma in practice is to be found in non-manufacturing environment where the difficulties lie in bridging the gap between subjective issues such as what actually constitute a defect and subsequently defining measurable and actionable variables for improvements."

Bechtel brought Six Sigma in to streamline and strengthen its engineering, procurement, and construction (EPC) processes but not to improve the workmanship quality of its construction products. For example, on the Channel Tunnel Rail Link (CTRL) project in the UK, a high-speed rail connection between London and Paris. The project includes more than a hundred kilometres of new track and many new bridges and tunnels. Bechtel which is a partner in the group responsible for the design, construction and project management of CTRL, has brought Six Sigma into many aspects of the project and the project team uncovered a way to save hundreds of job hours on one of the tunnelling jobs. Also, by applying Six Sigma's rigorous statistical measurement and analytical tools, the project team discovered that repeated problems with the delivery of ballast, the stone that form the rail foundation, were caused at the loading area that receives the ballast from Scotland. Elimination of problem produced substantial savings by avoiding cost overruns associated with construction delays (Bechtel Corporation, 2005).

When productivity declined on a section of the West Coast Route Modernization project in the United Kingdom, Six Sigma was used to identify the cause, using data to improve the process and at a nationwide telecommunications project, Six Sigma helped optimize the management of costs and schedules(Bechtel Corporation, 2005). Six Sigma has been utilized by many other construction companies in some way. Raytheon, an electronics, space, information technology, technical services company, implemented it company wide beginning in 1999, however they recently closed their construction division and did not announce any gains for that division.

The main barriers to the development and application of Six Sigma in construction are identified as (Ferng and Price, 2005):

- lack of resources
- difficulty in data collection
- difficulty in accurately translating client's needs
- implementation is at the expense of day-to-day business
- general perception that small organisation do not benefit significantly
- complexity
- human factors such as resistance to change
- lack of general information pertaining to Six Sigma in construction
- general perception that it is more for production industry
- projects are unique and one off with different clients
- needs to be tailored for each project-inflexibility.

How Six Sigma is Applied to Construction Industry?

The case study, published in the paper written by Low and Hui (2004), highlights how Six Sigma is applied for improving the quality of internal finishes for public housing projects that are provided by Housing and Development Board (HDB) in Singapore. HDB projects have been assessed, through CONQUAS. CONQUAS assessment consists of three components as described in literature survey related with CONQUAS on page 24:

- Structural Works (45%)
- Architectural Works (50%)
- Mechanical and Electrical (M&E) Works (5%)

Low and Hui (2004) stated that architectural works are likely to be a major source of complaints by flat-dwellers. Unlike structural works and mechanical-electrical works which are predominantly concealed, architectural works deal mainly with the finishes and components. This is also the part where the quality and standard of workmanship achieved through site inspection are most visible, thus giving rise to the possibility of more complaints by flat-dwellers.

The breakdown of the architectural works assessment according to percent weightages, sum up to 100%, is as follows:

- Internal finishes: floors (16%), internal walls (16%), ceilings (6%), doors (6%), windows (6%), and components (6%)
- Roofs (6%)
- External walls (12%)
- External works (6%)
- Materials and functional tests: plastering sand silt content (2%), external wall paint warranty (1%), water-tightness tests for windows and external wall joints (6%), wet area water-tightness test (3%), flat roof waterproofing warranty (2%), flat roof ponding test (2%), and pull-off test for internal wall tiles (4%)

As the architectural elements associated with internal finishes are the most visible to the naked eye, it is necessary to reduce the incidence of defects associated with internal finishes in order to eliminate the number of complaints relating to poor quality for internal finishes (Low and Hui, 2004).

For this purpose, a defect grouping guide used for assessing internal finishes, as part of the CONQUAS assessment system, is as follows (Low and Hui, 2004):

- *Floors and walls*: finishing, alignment and evenness, cracks and damages, hollowness, and jointing;
- *Ceilings*: finishing, alignment and evenness, cracks and damages, roughness, and jointing; and
- *Doors, windows, and components*: Joints and gaps, alignment and evenness, materials and damages, functionality, and accessories defects.

The related defects which CONQUAS assessors look for include stains, patchiness, roughness, unevenness, cracks, chips, dents, scratches, inconsistent joints, warping, corrosion, damages, missing items, etc.

When an assessed item does not comply with the corresponding standards specified in CONQUAS Manual, it is considered failed and a “X” is noted in the assessment, A “√” is indicated for an item meeting the standards, and a “-“ indicates that the item is not applicable. The score is computed based on the number of “√” over the total number of items assessed.

In Six Sigma, measuring current performance is necessary before initiatives can be taken for Six Sigma improvement projects. To do so, the CONQUAS scores relating to internal finishes of a project completed by contractors were reviewed. The CONQUAS score sheets of contractors (checklists) relating to the completed project were then subject to Six Sigma analysis. An example of such a “Six Sigma Data Collection Sheet for Internal Finishes” is shown in Table 2.4 for one flat unit in the project completed by contractors.

Table 2.4 Six sigma data collection sheet for internal finishes-checklist
(Source: Low and Hui, 2004)

Locations		Floors					Walls					Ceilings					Doors					Windows					Components				
		Finishing	Alignment&Evenness	Cracks&Damages	Hollowness	Jointing	Finishing	Alignment&Evenness	Cracks&Damages	Hollowness	Jointing	Finishing	Alignment&Evenness	Cracks&Damages	Roughness	Jointing	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Accessories Defects	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Acccessories Defects	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Accessories Defects
Bedrooms	Wall 1	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
	Wall 2	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
	Wall 3						√	√	√	√	√																				
	Wall 4						√	√	√	√	√																				
Hall	Wall 1	√	√	√	√	√	√	√	√	√	X	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√					
	Wall 2						√	√	√	√	√																				
	Wall 3						√	√	√	√	√																				
	Wall 4						√	√	√	√	√																				
Kitchen	Wall 1	X	√	√	√	√	√	√	√	√	√	√	√	√	√	√											√	√	√	√	√
	Wall 2	√	√	√	√	√																									
	Wall 3																														
	Wall 4																														
Toilets	Wall 1	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
	Wall 2	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
	Wall 3						√	√	√	√	√																√	√	√	√	√
	Wall 4						√	√	√	√	√																√	√	√	√	√
No. of Defects		1					1					0					0					0					0				
No. of Checks		35					65					30					25					25					35				
Total Number of Defects																											2				
Total Number of Checks/Opportunities for Defects																											215				

The discrete method of data collection is used in CONQUAS. To calculate sigma for the processes, the DPMO (or defects per million opportunities) formula is used:

$$\text{DPMO} = \frac{\text{No. of defects}}{\text{No. of opportunities} \times \text{No. of units}} \times 1{,}000{,}000$$

The DPMO relating to the internal finishes of one flat unit recently completed by contractors was then calculated based on the collected data.

$$\text{DPMO} = \frac{\text{No. of ``}\times\text{'' in the data collection sheet}}{\text{No. of opportunities of defects} \times \text{No. of units}} \times 1{,}000{,}000$$

Based on the sigma conversion table in Table 2.3, the equivalent sigma for calculated DPMO and percentage of the time got right by contractors was specified. For example, DPMO calculated according to the information obtained from Table 2.4 was:

$$\text{DPMO} = \frac{32}{215 \times 1} \times 1{,}000{,}000 = 148{,}837.21$$

The equivalent sigma for 148837.21 DPMO was approximately 2,66σ and (77.39%) according to Table 2.3. The quality of internal finishes was not applicable because it was under the minimum acceptable sigma level of 3.8σ (right 99% of the time). Contractors were encouraged to get at least 3.8σ and supervise their on-going building projects more closely to ensure that the level of workmanship for internal finishes complies with the quality standards specified in CONQUAS. For example cracks in screed finish should not be wider than 0.3 mm, surface evenness of plaster finish should not be more than 4 mm/1.2 m, cracks in skim coats for ceiling should not be more than 0.3 mm wide and not more than 200 mm long, etc. (Low and Hui, 2004).

Following the completion of the on-going projects, the internal finishes were assessed for their CONQUAS points. The assessment exercise also provided the data for computing the sigma of completed works to ascertain if the improvement measures taken by contractors have indeed helped to raise the sigma to at least 3.8σ. With improvements in sigma score, the probability of flat-dwellers to complain about defects relating to internal finishes was further eliminated (Low and Hui, 2004).

CHAPTER3

MATERIAL AND METHOD

In this chapter the details of the materials and methodology that are used to conduct the study are presented. ODTÜKENT and case housing units are ‘The Survey Material'. Then, the method of the study and analysis consisting of sample survey used for the quality assessment of dwellings are presented as ‘The Survey Methodology'.

3.1. Survey Materials

A survey was carried out on quality assessment of housing units through Six Sigma. A case study was conducted on the three houses of ODTÜKENT housing units in Ankara. In this regard, information about ODTÜKENT, housing types and general characteristics of houses are presented.

ODTÜKENT, which accommodate residences for academic staff and administrative staff, is located in Middle East Technical University (M.E.T.U.) Campus in Ankara. It is on the west of the campus site (Figure 3.1).

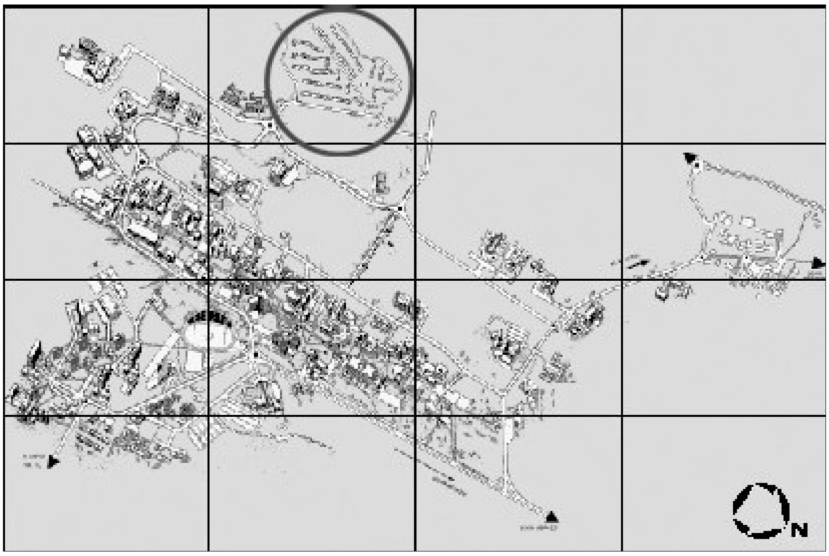


Figure 3.1 Schematic map of existing METU Campus
(Source: Middle East Technical University, 2006)

ODTÜKENT project aimed to answer the increasing housing needs of academic staff with a satisfying level of spatial quality and comfort both in the levels of architectural and urban design. Baykan Günay designed the site layout of the first stage of the project, which was changed depending on the final project. Gönül Evyapan and Erhan Acar developed the preliminary architectural design while Erhan Acar supervised the production drawings and Atabaş Mimarlık sub-contracted the job. ODTÜKENT is a project, realized with the participation of members and students of METU Faculty of Architecture (Güzer, 2001).

The housing units in ODTÜKENT were constructed between 1996 and 1998, whereas the ones in KONUKEVİ 3 and 4 were constructed between 2003 and 2005 by EBİ A.Ş. The satellite image of the ODTÜKENT – KONUKEVİ area is shown in Figure 3.2. The site is situated on a north-facing slope, which creates a height difference of roughly 22m in 380m (5.8%).

Figure 3.2 Satellite image of ODTÜKENT
(Source: Middle East Technical University, 2006)

Mainly ODTÜKENT site is organized on two different grid orientations. These are 60º and 15º deflected from north-south line. On the 60º grids there are only row houses having very similar dimensions. On the 15º grids there are similarly oriented row houses and apartment blocks. Housing units are organized in mainly two types of buildings; 2 or 3 storey row houses and 3 or 4 storey row apartments that consist of duplex flats at the uppermost storey. There are 141 row houses and 72 apartment housing units in all (Atabaş Mimarlık, 2006). The housing units with 38.000 m² closed area in ODTÜKENT are composed of 213 houses with six different types of plans.

The types and their characteristics are specified as follows:

- KOD 10 – 13 row house with 150 m² (basement + 3 rooms + living room)
- KOD 11 – 106 row house with 140 m² (basement + 2 rooms + living room)
- KOD 12 – 11 duplex row house with 102 m² (3 rooms + living room)
- KOD 13 – 11 ground flat in row house with 75 m² (2 rooms + living room)
- KOD 14 – 20 duplex house in apartment with 110 m² (3 rooms + living room)
- KOD 15 – 52 flat in apartment with 65 m² (room + living room)

The row houses are gathered in blocks including 2 to 6 attached row houses. The apartment blocks that are also seemed to be in the row character, this is perceived as an attempt of standardization. General layout of building types in ODTÜKENT is shown in Figure 3.3.

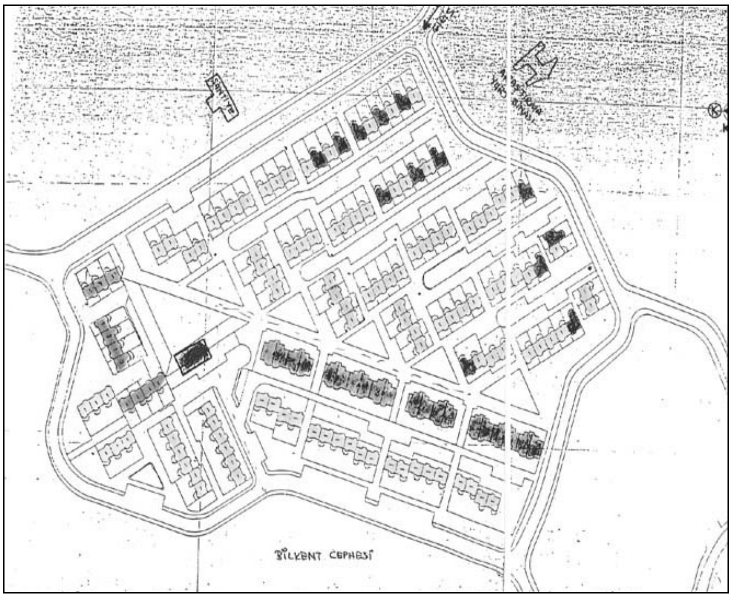


Figure 3.3 General layout of building types
(Source: Middle East Technical University, 2006)

There is also a market, children's playground and facility management office that takes care of the maintenance and repair works of the housing units in ODTÜKENT.

Table 3.1 Types and characteristics of dwellings in KONUKEVİ area.

KONUKEVİ 2	**KONUKEVİ 3-4**
4 flat with 55 m² (room + living room)	8 flat with 88 m² (2 rooms + living room)
3 flat with 65 m² (room + living room)	16 flat with 91 m² (2 rooms + living room)
2 flat with 75 m² (2 rooms + living room)	8 flat with 98 m² (2 rooms + living room)
9 flat with 90 m² (2 rooms + living room)	
9 flat with 100 m² (2 rooms + living room)	
3 flat with 108 m² (2 rooms + living room)	
4 flat with 120 m² (3 rooms + living room)	
2 flat with 150 m² (3 rooms + living room)	
Total: 36 flats	**Total: 32 flats**

As seen from Table 3.1, the buildings in KONUKEVİ 3 and 4 consist of 32 flats, KONUKEVİ 2 has 36 units as seen in Table 3.1 and there are also 48 houses on the west of ODTÜKENT. Total number of housing units in ODTÜKENT area is 329.

Three houses were selected for the quality assessment through Six Sigma: Unit A and Unit B are from ODTÜKENT area and Unit C is from KONUKEVİ area. Plan of ODTÜKENT area indicating Unit A and Unit B is shown in Figure 3.4.

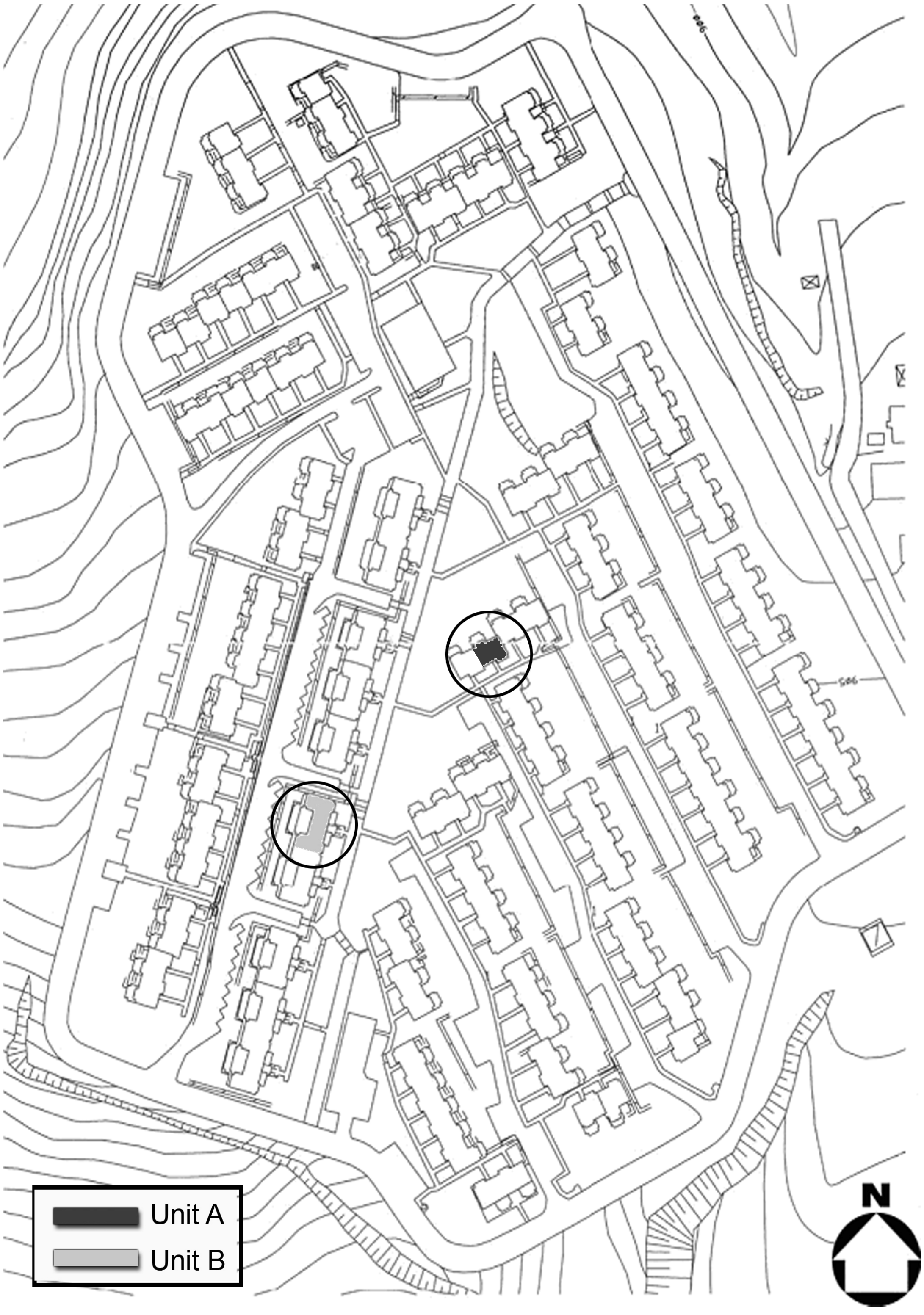


Figure 3.4 Plan of ODTÜKENT area indicating Unit A and Unit B.
(Source: METU Directorate of construction and technical works)

Unit A - It is an example of row house in ODTÜKENT (KOD 11). It is a 3-storey structure– basement floor, ground floor and 1st floor. The exterior view of the unit is shown in Figure 3.5. The covered area is approximately 140 m². There are two store rooms and a boiler room in the basement. The rooms in the ground floor are arranged as living room, dining room and kitchen that are interconnected with each other. Also there is a WC, an entrance hall and a terrace. The 1st floor contains two rooms, a hall and a bathroom. The floor plans are shown in Figure 3.6-3.8.

Figure 3.5 An exterior view of Unit A

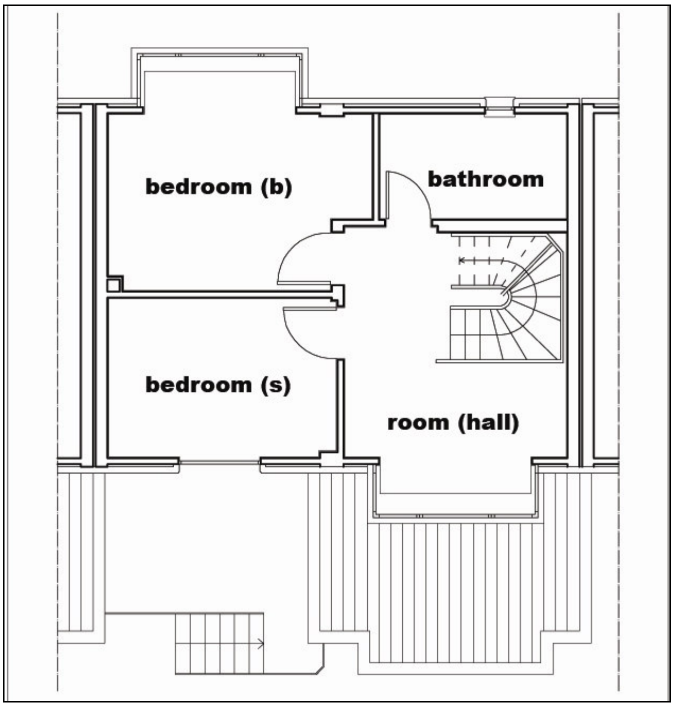


Figure 3.6 First floor plan of Unit A

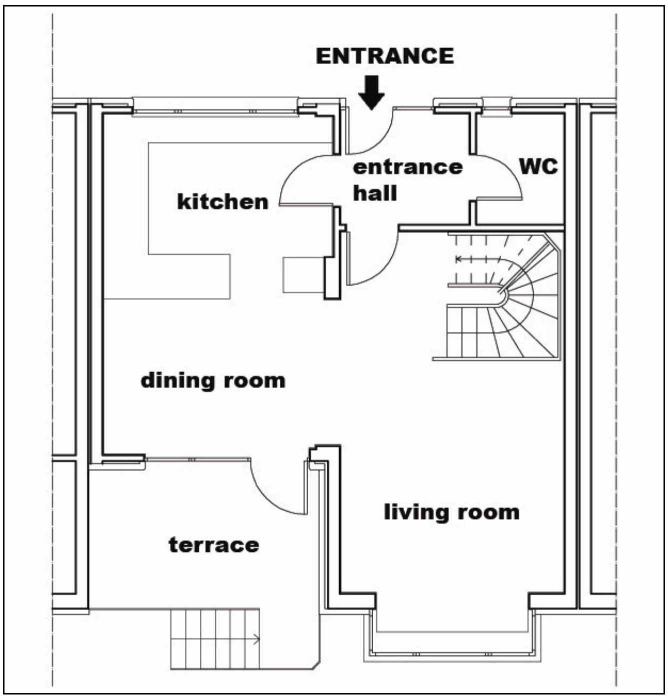


Figure 3.7 Ground floor plan of Unit A

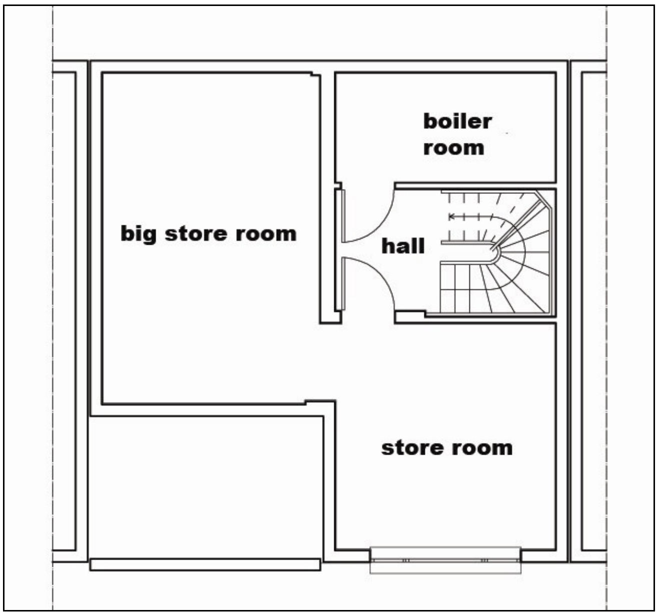


Figure 3.8 Basement plan of Unit A

Unit B - It is an example of a duplex house in the apartment blocks in ODTÜKENT (KOD 14). It covers an area of about 110 m². A photo of the apartment blocks is shown in Figure 3.9. The unit includes an entrance hall, kitchen, a small room, WC, living room, dining room and a balcony on the first floor and on the second floor there are three rooms and a bathroom. The floor plans of the unit are shown in Figure 3.10-3.11.

Figure 3.9 Photo of the apartment blocks

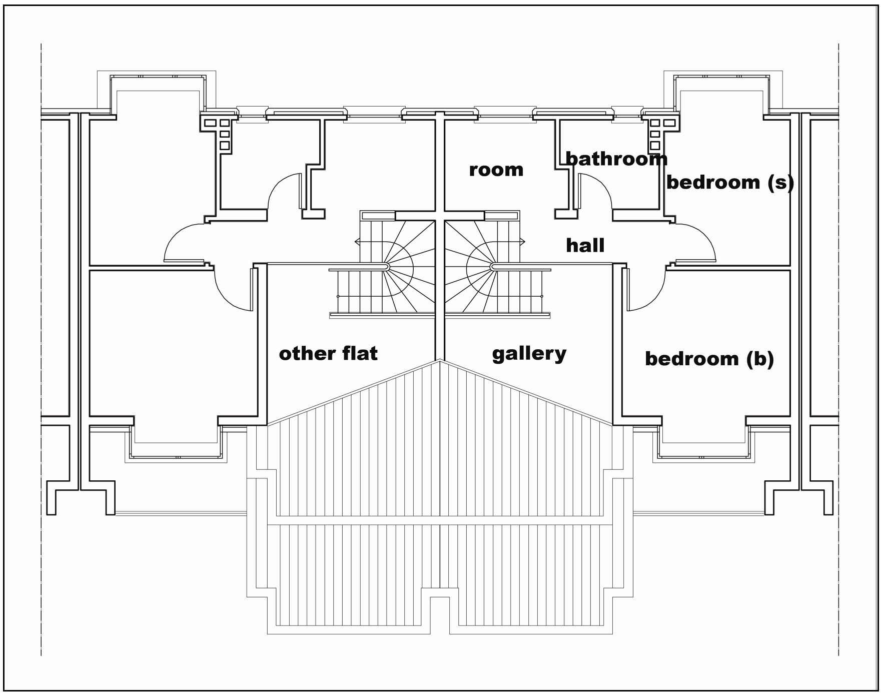


Figure 3.10 First floor plan of Unit B

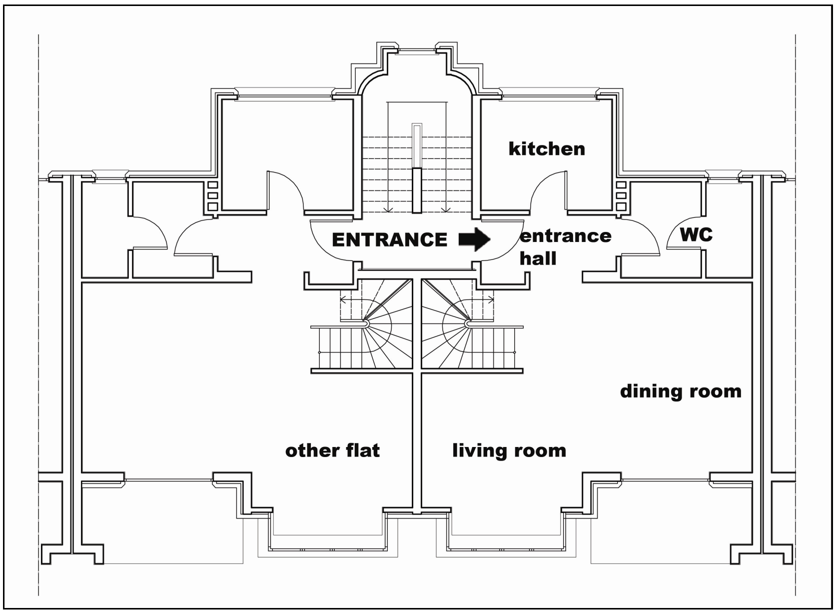


Figure 3.11 Ground floor plan of Unit B

Unit C - It is a flat with an area of 110 m² in the KONUKEVİ area. It is planned with an entrance hall, kitchen, living room, two rooms and a bathroom. The picture of the house is shown in Figure 3.12; the floor plan is in Figure 3.13.

Figure 3.12 An exterior view of the flats in KONUKEVİ

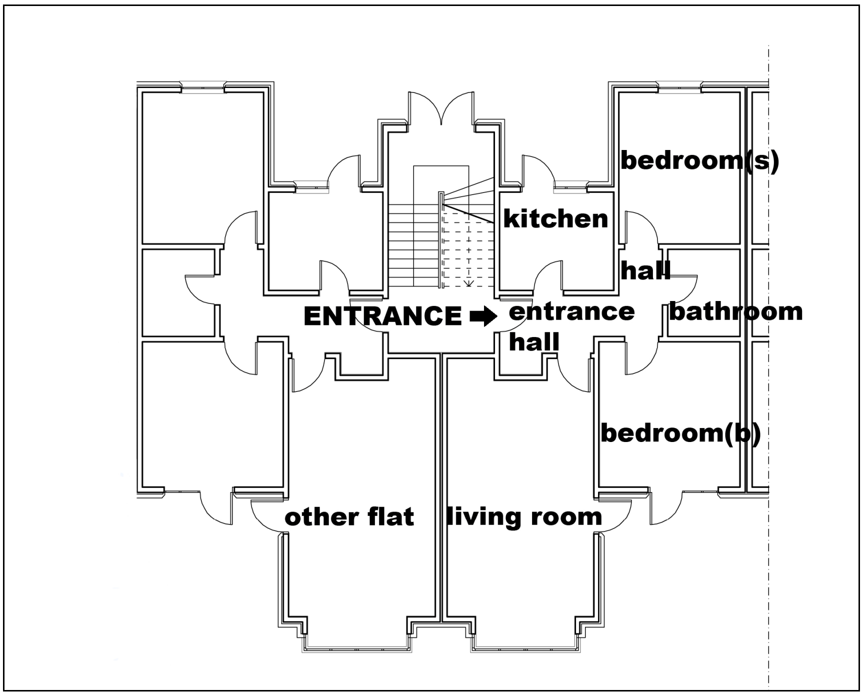


Figure 3.13 Plan of Unit C

3.2. Survey Methodology

For the quality assessment survey of ODTÜKENT housing units, a sample case in the article of *'Implementing and Applying Six Sigma in Construction'* (Low and Hui, 2004), explained in detail in literature survey, is used.

For the survey, three of dwellings from ODTÜKENT were chosen as case studies. The selection is done according to their construction dates and types. Houses with different construction dates were selected for assessment to show whether there is an improvement in quality levels or not.

The survey focused on the workmanship quality of houses because the problems in workmanship quality are the most visible ones. The material and design quality of the houses are also assessed. Other quality aspects defined in housing quality are neglected such as social, aesthetical and environmental quality etc.

All related data about ODTÜKENT, technical data and architectural drawings of houses were taken from Directorate of Construction and Technical Works and EBİ Construction Company. The photos of the buildings, materials and components were taken by the author.

The CONQUAS assessment system was applied to the case study in ODTÜKENT as described in the literature survey. There are two variable groups in the research, internal finishes and locations:

- *Internal Finishes*: These elements are the main elements of the buildings' design and tenancy, including *floors, walls, ceilings, doors, windows and components.*

Quality assessment of finishes and components are done according to defect groups as shown in Table 3.2.

Table 3.2 Defects grouping guide for assessment of internal finishes
(Source: Singapore Building Construction Authority, 2005)

Components	Defects Grouping	Defects Description
Floor	Finishing	Stains, Painting / Coating Defects, Tonality, Patchy & Roughness
Wall	Alignment & Evenness	Alignment, Uneveness, Squareness
	Crack & Damages	Crack, Chipping, Dent, Scratches
	Hollowness / Delamination	
	Jointing	Joints, Pointing
Ceiling	Finishing	Stains, Painting / Coating Defects, Patchy & Roughness
	Alignment & Evenness	
	Crack & Damages	Crack, Chipping, Dent, Scratches
	Roughness	
	Jointing	Joints, Pointing
Door	Joints & Gap	Joints, Gap etc too big, Inconsistent, Improper Seal
Window	Alignment & Evenness	
Component	Material & Damages	Crack, Chipping, Dent, Scratches, Defects, Finishing, Tonality
M&E Fittings	Functionality	Movement, Functionality, cannot be opened or closed properly,
	Accessories Defects	Missing items, Improper Fixing, Stains, Corrosion, Other damages

The internal finishes of each room in the houses were examined on the basis of these standards. These standards compromised of two parts; general requirements and standards for different types of finishing materials as described below:

1. General Requirements: These are the standards that are categorized according to the defect groups and valid for all materials. An example of this kind of standards is shown in Table 3.3.

Table 3.3 Standards (general requirements) of floors for all types of finishing materials (Source: Singapore Building Construction Authority, 2005)

	Item*	**Standards**
1	**Floors**	
1a	**General Requirements**	1) **Finishing** • No stain marks • Consistent colour tone 2) **Alignment & Evenness** • Evenness of surface (not more than 3mm per 1.2 m) • Falls in wet areas should be in right direction • No ponding in falls for wet area • For staircases, the variance in lengths of threads and risers must not exceed 5 mm; nosing must be straight 3) **Crack & Damages** • No visible damage / defects 4) **Hollowness / Delamination** • No hollow sound when tapped with a hard object • No sign of delamination 5) **Jointing** • Consistent skirting thickness and no visible gap between wall & skirting

2. Standards for different types of finishing materials. Table 3.4 expresses the floor standards according to different types of finishing materials.

Table 3.4 Standards of floor according to different types of finishing materials (Source: Singapore Building Construction Authority, 2005)

	Item*	Standards
1b	**Screed finish**	1) Surfaces should not be unduly rough or patchy
		2) Expansion joints should be provided at interval as stated by architect
1c	**Tiled finish**	1) Consistent and neat pointing
		2) No hollow sound when tapped with a hard object
		3) Joints are aligned and with consistent with skirting and wall tiles
		4) Consistent joint size
		5) Lippage between 2 tiles should not be more than 1mm
		6) Expansion joints should be provided at interval as stated by architect
1d	**Timber floor**	1) No warpage
		2) Timber strips to rest firmly on joists or screed
		3) No visible gap between timber strips
		4) Edges of the floor to be properly sealed
1e	**Carpet**	1) Stretched or even surface
		2) Joint should not be visible
		3) Proper anchoring at all edges
1f	**Raised floor**	1) No loose floor panels or rocking
		2) No protrusion / potential of stripping over floor panels

The first step was to compile a list of the construction materials used in projects, according to the information gathered from architectural drawings of houses, information acquired from EBİ Construction Company and on-site visual inspections by the author. These materials were used to determine the standards which are used for assessment of the units (Table 3.4). The standards are taken from 'CONQUAS 21 Manual' on the web-site: http://www.bca.gov.sg. All standards used are shown in Appendix C.

- *Locations*: These finishes are assessed with the spaces they are involved in, like living room, dining room, rooms, kitchen, bathroom, WC, etc.

These variables (internal finishes with their defect groups and locations according to the walls) were stated in checklists. The checklists used to assess the houses were obtained from the sample case. An example of checklist used for survey is expressed on Table 2.4. Assessment related with floors and ceilings of location are shown on the row marked as 'Wall1', related with walls on rows of 'Wall1, Wall2, Wall3, Wall4' and related with doors, windows and components on rows that they exist on. As it is indicated in literature survey, when an assessed item does not comply with the corresponding standards, it is considered failed and marked as "X" on the checklist and while the mark "√" is indicated for an item meeting the standards.

The occupants of the buildings were interviewed to obtain their views related with material and workmanship quality; as well as the design problems of the houses. The results obtained from the assessment are analyzed through the Six Sigma to define the quality level of the housing units studied. During the evaluation phase of information, the results are defined as sigma values and these values are compared with the acceptable sigma values to determine whether the values are acceptable or not. The results of the assessment are presented in Chapter 4.

Apart from the sample case described in the literature survey, the "control phase" following the completion of the on-going projects was not taken into consideration in the survey of ODTÜKENT housing units since it is impossible to control whether there is an improvement in the quality levels according to the recommendations or not as there is no new construction. During executing of this study, AutoCAD 2005 and Adobe Photoshop CS2 softwares were used to draw the plan of houses.

CHAPTER 4

QUALITY ASSESSMENT OF ODTÜKENT HOUSING UNITS THROUGH SIX SIGMA

In this chapter are presented the results and discussions of quality assessment of three of ODTÜKENT housing units according to six sigma criteria. This survey aims to evaluate the quality level of finishes and components of houses. The houses are assessed according to the aspects of workmanship quality, material quality and design quality through visual observations and interviews with occupants under 'Survey for Six Sigma'. In the last part, namely 'Discussions' are presented evaluation of the results and recommendations for improvement of quality levels of construction.

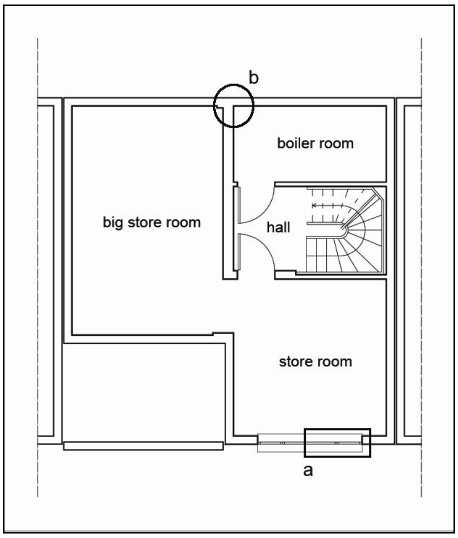
3.3. Survey for Six Sigma

Quality Assessment of Unit A

Construction Materials: Construction materials used for floors, walls, ceilings, doors and windows in Unit A are listed in Table 4.1. There is no skirting in bedrooms and entrance hall. Timber skirting is used with timber floor in living room, dining room and room on the 1st floor. In store rooms, boiler room and hall in basement; material of floor is used as skirting material also. Railings, radiator, sink, mirror, closet, bathtub, basin, cupboards are the items assessed in the components part.

Table 4.1 Construction materials of Unit A

	Floors	Walls	Ceilings	Doors	Windows
Living Room	Wooden parquet	Plaster and paint	Plaster and paint	metal framed wood veneer	PVC + double glazed
Dining room	Wooden parquet	Plaster and paint	Plaster and paint	PVC + double glazed	PVC + double glazed
Kitchen	30x30 cm coloured ceramic tile	50 cm ceramic tile over countertop, other surfaces are plaster and paint	Plaster and paint	metal framed wood veneer	PVC + double glazed
WC	30x30 cm white ceramic tile	20x25 cm white ceramic tile up to ceiling level	Plaster and paint	metal framed wood veneer	PVC + glass
Entrance Hall	30x30 cm coloured ceramic tile	Plaster and paint	Plaster and paint	Wooden door with glass	
Room (hall)	Wooden parquet	Plaster and paint	Wooden ceiling boards		PVC + double glazed
Bedroom(b)	Carpet on screed floor	Plaster and paint	Wooden ceiling boards	metal framed wood veneer	PVC + double glazed
Bedroom(s)	Carpet on screed floor	Plaster and paint	Wooden ceiling boards	metal framed wood veneer	PVC + double glazed
Bathroom	30x30 cm white ceramic tile	20x25 cm white ceramic tile up to ceiling level	Plaster and paint	metal framed wood veneer	PVC + single glazed
Store rooms	Mosaic tile	Plaster and paint	Plaster and paint	metal framed wood veneer	PVC + double glazed
Hall	Mosaic tile	Plaster and paint	Plaster and paint		
Boiler room	Mosaic tile	Plaster and paint	Plaster and paint	metal framed wood veneer	



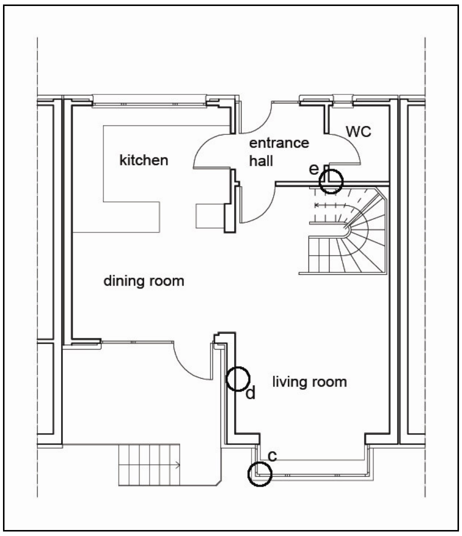
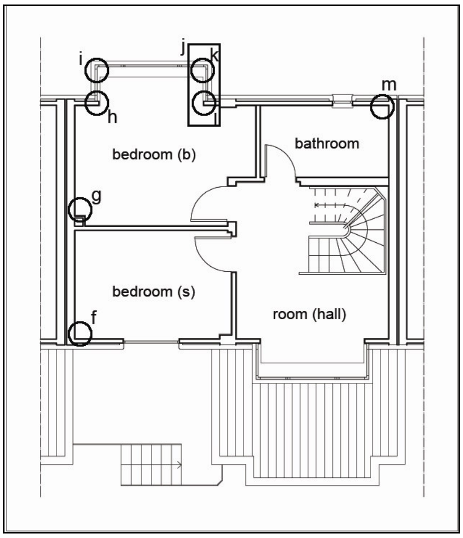


Figure 4.1 Basement floor (left) and ground floor (right) plans of Unit A indicating the points of defects.



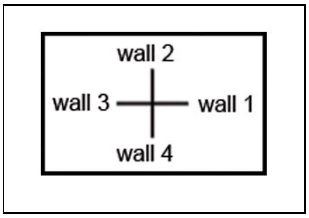


Figure 4.2 First floor plan of Unit A indicating the points of defects (left) and key for direction of walls (right)

a. Workmanship quality

- Stain marks and mortar splashes are seen on bathroom floor. This has been evaluated under "floor-finishing" of bathroom in checklist.
- There are visible gaps between the parquets.

Figure 4.3 Gap between timber strips

Figure 4.4 Tiles around pipes are not properly trimmed and filled

- Tiles around pipes are not properly trimmed and filled as seen in Figure 4.4.
- Floor screed under the carpet of bedroom (b) is not even, it is unduly rough. This has been evaluated under "floor-finishing" of bedroom (b) in checklist.
- The entrance hall floor is visibly deformed and depressed.
- Figure 4.5 indicates visible crack on the surface of Bedroom (b) floor.

Figure 4.5 Crack on the floor surface

Figure 4.6 Gap between wall and skirting (defect 'd')

- As the wall surfaces are not even, there is visible gap between wall and skirting in living room, dining room and hall. Figure 4.6 indicates the defect 'd' shown on floor plan in Figure 4.1.
- In living room and bedroom (b) water leaks between wall and the sill. Discolouration occurs on the surfaces of these walls 3 and 4 of living room and wall-2 of bedroom (b). It is seen as defect 'i' shown on floor plan in Figure 4.1.
- There is drainage problem in these houses. According to first project there is no concrete pavement around the building. It is added later but there is a gap between pavement and wall. Water leaking through this gap caused colour change on the store room wall-4 as there is no damp insulation for walls in basement. Figure 4.7 indicates defect 'a' shown on floor plan in Figure 4.2.

Figure 4.7 Water leakage on wall (defect 'a')

Figure 4.8 Crack near the sill of window (defect 'h')

- Cracks are seen on walls (bedrooms wall-3) that are shared by two houses and near the sills of windows. Figure 4.8 shows defect 'h' seen on floor plan in Figure 4.1.
- Surfaces of walls are rough especially above the skirting (living room wall-3) or at the lower parts of walls (bedroom wall-3).
- Blistered plaster is observed on wall-1 of bedroom (s).
- Walls do not meet at right angles because of unevenness and alignment problem. Point 'f' shows the defect on the corner of bedroom (s) wall 3 and 4.
- Tiled surface is not plumb and true, and deviation is more than the allowable limit which should not exceed 3mm in 1.2m height. Figure 4.9 shows that edge is also not straight in bathroom. The photo shows defect 'm' shown on floor plan in Figure 4.1.
- Corners and joints are not straight as seen in Figure 4.10. The photo shows defect 'g' and has been evaluated under 'wall-jointing' of bedroom (b) wall-3 on checklist.

Figure 4.9 Tiled surface is not plumb and true (defect ‘m’)

Figure 4.10 Corners and joints are not straight (defect ‘g’)

Figure 4.11 Alignment problem on wall (defect ‘j’)

Figure 4.12 Uneven wall and corner (defect ‘b’)

- There is alignment/evenness problem on all wall surfaces. Figure 4.11 of defect ‘j’ shows the alignment problem on bedroom (b) wall-1, left side of the wall above the window upper level is longer than the right side. This problem is valid for nearly all walls above the windows. The height difference reaches to 2.5 cm on wall-4 of living room. Thus, the edges of walls above the window do not appear straight and aligned.
- On wall-3 of the boiler room seen in Figure 4.12 showing defect ‘b’, there are two different levels which are not aligned and straight.
- The height of wall from the bottom level of window to floor level differs. Wall-4 of living room is an example.
- Floor joints in bathroom and WC are not aligned with the wall tiles because of the different dimensions of floor and wall tiles.
- Tiles are not with consistent joint widths in bathroom and WC.
- Lippage between two tiles are more than 1 mm for tiles.
- Paint splashed on tiles’ surfaces is seen in bathroom and WC especially near the edges of ceiling.
- Because of water leakage on ceiling of bathroom and WC, discolouration appears on surface. Figure 4.13 shows the leaks on ceiling of WC. It is the photo of defect ‘e’ shown on floor plan in Figure 4.1.

Figure 4.13 Water leakage on ceiling (defect ‘e’)

Figure 4.14 Uneven ceiling

- Uneven surface of bathroom ceiling is shown in Figure 4.14. Same problem is seen on the WC ceiling.
- Corners of ceiling are not straight. This problem is seen in bathroom and WC where the corners are the meeting points of two different materials.
- There is visible gap between the door leaf and frame more than 5 mm in dining room door opening to terrace.
- As the walls are uneven, alignment/level of doors with walls is not possible.
- Door and frame corners are not at right angles in bedrooms.
- Doors made of PVC are not evenly sealed with gasket.
- There is a problem in opening and closing for the entrance door. Without lifting the door upwards it is impossible to close the door. Living room and bedroom(s) door do not close easily.
- As the walls are not aligned, uneven, alignment/level of windows with wall openings is not possible, there are gaps between window frame and wall as seen in Figure 4.15 showing defect 'l'. To close these gaps metal strips in rooms and ceramic pieces in bathroom and WC have been used. The metal pieces corroded as a result of rainwater leakage in bedroom (b) wall-2. Also the kitchen window on wall-2 is not aligned.

Figure 4.15 Gap between window frame and wall (defect 'l')

Figure 4.16 Window frames do not meet at right angle

- As seen in Figure 4.16, window frame corners do not meet at right angle in living room. Thus, opening of the window on wall-3 of living room is hindered by the window frame on wall-4 and the window does not open completely. It is seen in Figure 4.17 that is a photo of defect ‘c’. In bedroom (b), shutter on wall-1 opens by scraping the window on wall-2 that causes damage on the surface of the shutter as seen Figure 4.18. The photo shows defect ‘k’.

Figure 4.17 Window does not open completely (defect ‘c’)

Figure 4.18 Damage on surface of shutter (defect ‘k’)

- All the windows are not sealed with gasket evenly. Gaskets of windows are missing or do not meet properly at corners.
- Sign of corrosion is seen in pipes of the bathroom and WC radiators.
- Most of the radiators are not level and aligned. For example radiators on wall-4 of living room and on wall-4 of bedroom (s) are lopsided.

b. Design of components quality

- Edges of carpet floor are not properly sealed. There is no skirting to fit carpet in bedrooms.
- Surface drainage is used around the houses but there is drainage problem on the basements.

- Plinth protection around the buildings were not provided initially but was a later addition. Therefore, there is a gap between the plinth protection and the building which allows water to seep through to the basement walls.
- Non-existence of damp insulation material for basement is a design problem.
- Windows cannot be opened because of inappropriate detailing.

c. Material quality

- The carpet used in bedrooms is thin and of poor-quality. It has been evaluated as "floor-finishing" defect of bedrooms.
- Floor tile is used as skirting material in basement and shown as "floor-jointing" defect for all rooms of basement on the checklist.

Although it is not evaluated in internal finish checklists, other problems related with the house is efflorescence and spalling of plaster seen on wall of terrace because of not using high quality material. Also there is level difference on the landing. Figure 4.19 shows the terrace wall.

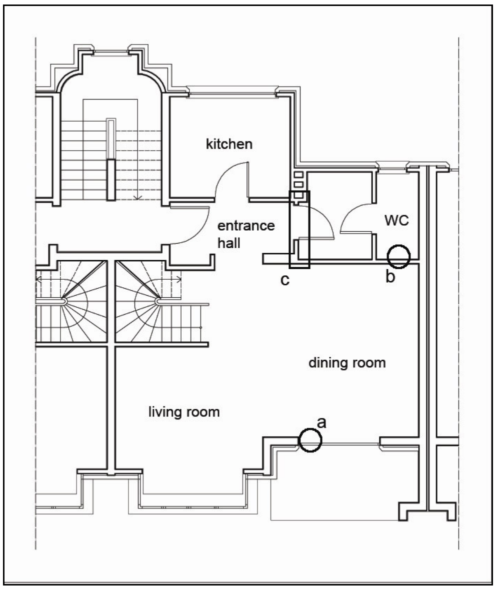
Figure 4.19 Spalling of plaster on terrace wall

Quality Assessment of Unit B.

Construction Materials: Construction materials used for floors, walls, ceilings, doors and windows in Unit B is expressed in Table 4.2. There is no skirting in bedrooms, room and entrance hall. Timber skirting is used with timber floor in living room and dining room.

Table 4.2 Construction materials of Unit B

	Floors	Walls	Ceilings	Doors	Windows
Living Room	Wooden parquet	Plaster and paint	Plaster and paint		PVC + double glazed
Dining room	Wooden parquet	Plaster and paint	Plaster and paint	PVC + double glazed	PVC + double glazed
Kitchen	30x30 cm coloured ceramic tile	60 cm ceramic tile over countertop, other surfaces are plaster and paint	Plaster and paint	metal framed wood veneer	PVC + double glazed
WC	30x30 cm white ceramic tile	20x25 cm white ceramic tile up to ceiling level	Plaster and paint	metal framed wood veneer	PVC + single glazed
Entrance Hall	30x30 cm coloured ceramic tile	Plaster and paint	Plaster and paint	metal framed wood veneer	
Room	Carpet on screed floor	Plaster and paint	Plaster and paint		PVC + double glazed
Bedroom(b)	Carpet on screed floor	Plaster and paint	Plaster and paint	metal framed wood veneer	PVC + double glazed
Bedroom(s)	Carpet on screed floor	Plaster and paint	Plaster and paint	metal framed wood veneer	PVC + double glazed
Bathroom	30x30 cm white ceramic tile	20x25 cm white ceramic tile up to ceiling level	Plaster and paint	metal framed wood veneer	PVC + single glazed
Hall	Carpet on screed floor	Plaster and paint	Plaster and paint		



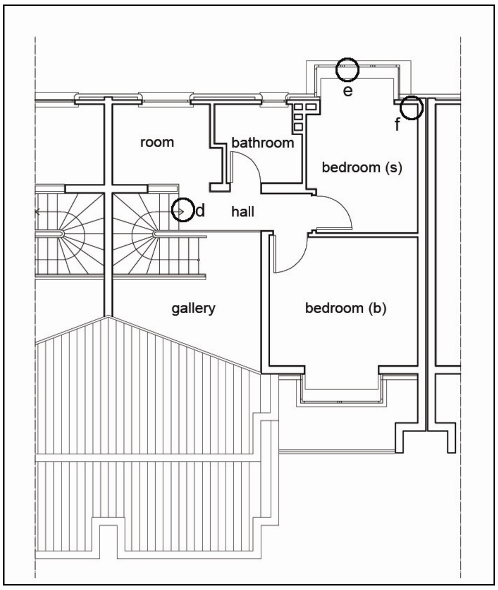


Figure 4.20a First floor (left) and ground floor (right) plans of Unit B indicating the points of defects

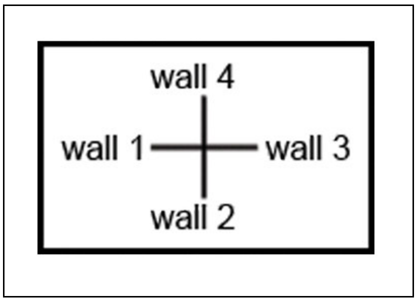


Figure 4.20b Key for direction of walls

a. Workmanship quality

- Floor joints in bathroom and WC are not aligned and consistent with wall tiles.
- Side of hall2 slab is not aligned and straight where hall2 meets with staircases. The Figure 4.21 shows the defect 'd' shown on floor plan in Figure 4.20a.

Figure 4.21 slab side out of alignment (defect ‘d’)

Figure 4.22 Inconsistent joint widths

- As seen in Figure 4.22, tiles are not with consistent joint widths in bathroom and WC.
- There is visible alignment/evenness problem on wall surfaces. Figure 4.23 shows the alignment problem on bedroom (s) wall-4, distance on the middle part of the wall above the window is shorter than left and right side of the wall. It is a photo showing defect ‘e’ seen on floor plan in Figure 4.20. Thus, edges of wall above the window do not appear straight and aligned.

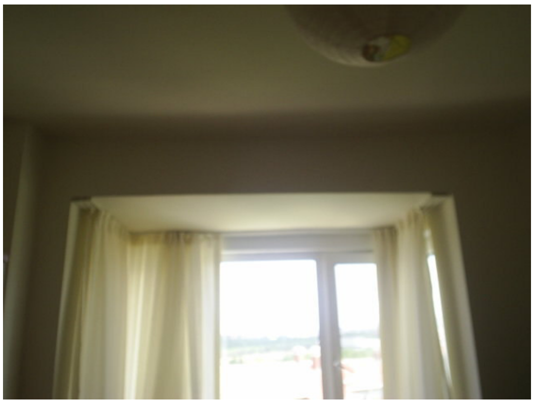


Figure 4.23 Wall out of alignment (defect ‘e’)

Figure 4.24 Problems with ceiling and wall alignment (defect ‘c’)

- The alignment problem on wall-3 of entrance hall is shown on Figure 4.24, a photo showing defect ‘c’. The beam above the door is not aligned. Thus, there is an alignment problem for the ceiling resting on beam.
- As the wall surfaces are not even, there is visible gap between wall and skirting in living room and dining room.
- Joints and corners are not straight.
- There are paint splashes on tiles’ surfaces in bathroom and WC especially near the edges of ceiling.
- Surfaces of walls are rough at the bottom parts of walls. For example, wall-4 of hall in the first floor.
- Cracks are seen on walls. Room wall-2 is an example.
- Walls do not meet at right angles because of evenness and alignment problem. This kind of defect is observed between walls 3 and 4 of bedroom(s) shown as defect ‘f’ in Figure 4.20.
- Water leaks through skylight on the ceiling of the living room. Discolouration has appeared on the walls near the left side of the window.
- Surface of WC ceiling is uneven.
- Corners of ceiling especially in bathroom and WC are not straight.
- As the walls are uneven, provision of alignment/level of doors and windows with walls is difficult. For example, the kitchen window on wall-4 is not aligned/level as wall opening is not aligned and straight.
- There is gap between door frame and leaf in hall door on wall-1.
- Dining room door opening to balcony, bedroom (s) and WC doors do not close completely. This problem in dining room is caused because of the door is lopsided. Left part of door is nearly same level with floor as seen in Figure 4.25 that shows defect ‘a’.

Figure 4.25 Lopsided door (defect ‘a’)

Figure 4.26 Gap between window frame and shutter

- Figure 4.26 indicates gap between window frame and shutter in bedroom (s) wall-4.
- There are gaps between window frame and wall. Skylight on ceiling is an example.
- The windows are not sealed evenly with gasket as indicated in Figure 4.27. Gaskets of windows are missing or do not meet properly at corners.

Figure 4.27 Window is not sealed with gasket evenly

Figure 4.28 Radiator is not level (defect ‘e’)

- Most of the radiators are not level and aligned. For example, the radiator on bedroom(s) wall-4 is not straight. It is shown on Figure 4.28, a photo indicating defect ‘e’. The radiator in dining room wall-2 and living room wall-2 is not aligned.

b. Design of components quality

- Edges of carpet floor are not properly sealed. There is no skirting or material to fit carpet in bedrooms, room and hall. This is noted as floor-jointing problem.
- As seen in Figure 4.29, the structural and architectural designs were not coordinated. The beams cross in the middle of kitchen ceiling. Also the beams crossing the entrance hall do not meet with walls properly.

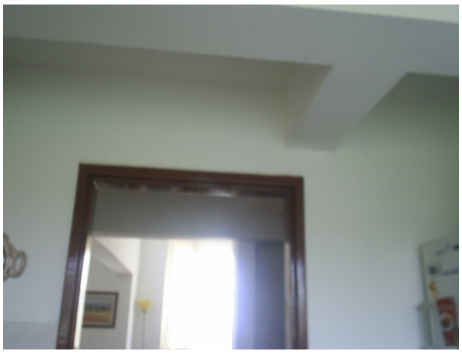


Figure 4.29 The structural and architectural designs were not coordinated

Figure 4.30 Mirror is not aligned with washbasin.

- Mirror in WC is not aligned with washbasin. It is seen in Figure 4.30, a photo showing defect ‘b’. Same problem is observed in bathroom.

c. Material quality

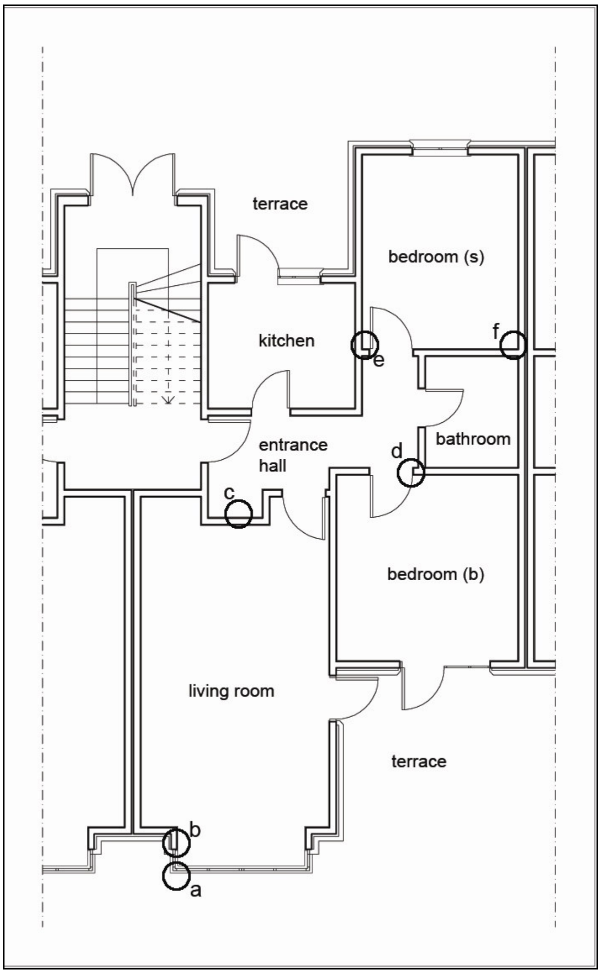
- The carpet used for bedrooms, hall and room is thin and of poor-quality.
- Floor tiles used in entrance hall, kitchen, WC and bathroom are of poor quality.

Quality Assessment of Unit C

Construction Materials: Construction materials used for floors, walls, ceilings, doors and windows in Unit C is expressed in Table 4.3. Carpet with plastic on top is used as a skirting material in living room and bedrooms; plastic skirting is used in kitchen and halls.

Table 4.3 Construction materials of Unit C

	Floors	**Walls**	**Ceilings**	**Doors**	**Windows**
Living Room	Carpet on screed floor	Plaster and paint	Plaster and paint	1. metal framed wood veneer 2. PVC + double glazed	PVC + double glazed
Kitchen	25x25 cm ceramic tile	60 cm ceramic tile over countertop, other surfaces are plaster and paint	Plaster and paint	1. metal framed wood veneer 2. PVC + double glazed	PVC + double glazed
Entrance Hall	25x25 cm ceramic tile	Plaster and paint	Plaster and paint	metal framed wood veneer	
Bedroom(b)	Carpet on screed floor	Plaster and paint	Plaster and paint	metal framed wood veneer	PVC + double glazed
Bedroom(s)	Carpet on screed floor	Plaster and paint	Plaster and paint	1. metal framed wood veneer 2. PVC + double glazed	PVC + double glazed
Bathroom	25x25 cm ceramic tile	25x30 cm ceramic tile up to ceiling level	False ceiling	metal framed wood veneer	
Hall	25x25 cm ceramic tile	Plaster and paint	Plaster and paint		



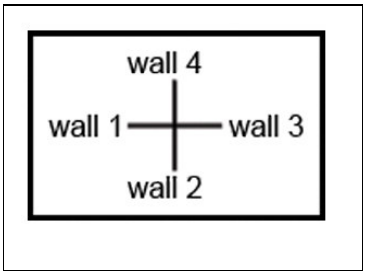


Figure 4.31 Plan of Unit C indicating the points of defects (left) and key for direction of walls (right)

a. Workmanship quality

- There are stain marks, mortar splashes on bathroom floor.
- Cracks on bathroom floor are observed.
- There are paint splashes on floor tiles of hall.
- Tiles are not with consistent joint size in bathroom**.**
- There are obvious dips in the floor slab.
- Floor screed under the carpet is uneven, it is unduly rough in living room and bedrooms and carpet on the floor is not stretched. Figure 4.32 shows the unevenness on living room floor.

Figure 4.32 Uneven floor surface

Figure 4.33 Floor tiles are not aligned with wall tiles

- Floor joints in bathroom are not aligned with wall tiles even though dimensions for floor and wall tiles are same as seen in Figure 4.33.
- There is visible gap between wall and skirting near the corners because of a piece of plastic used for corners in halls. There is no gap between wall and skirting in rooms because carpet skirting is stuck on wall.
- Walls do not meet at right angles in rooms. Internal corners are shown to be more than 90°. Angle between walls 2 and 3 of bedroom(s) seen in Figure 4.34 is an example. The photo indicates defect ‘f’ in Figure 4.31. Also there is no right angle between the living room walls 1 and 2.

Figure 4.34 Walls do not meet at right angles (defect ‘f’)

Figure 4.35 Stain marks on hall wall above skirting (defect ‘c’)

- Figure 4.35 showing defect 'c' shows stain marks and paste splashes observed on hall wall above skirting. Also there are spaces between the end of floor tile and wall. These spaces are filled with uneven plaster roughly.
- Water leaks between wall and sill in living room wall-1.
- Roughness is visible above skirting on wall 1 and 3 of living room.
- Some walls like bedroom(s) wall-1 in Figure 4.36, hall wall-2 are uneven.

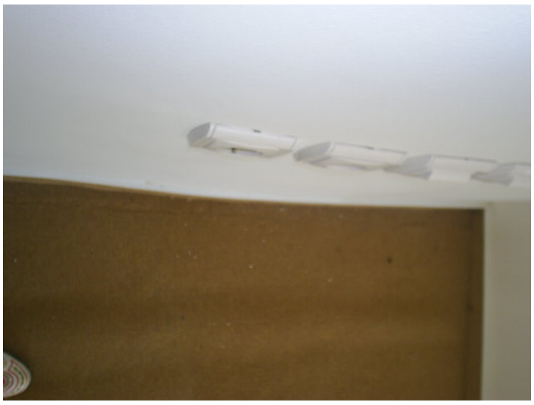


Figure 4.36 Uneven wall

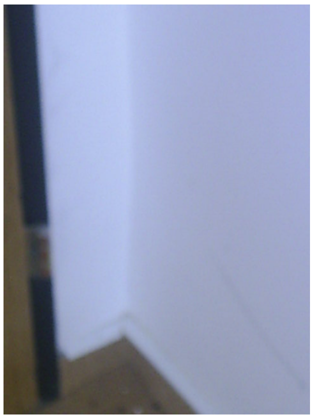


Figure 4.37 Corner is not square (defect 'e')

- Corners and joints are not straight. For example, corner between wall 1 and 2 of bedroom(s) shown in Figure 4.37. It is the photo of defect 'e'.
- Cracks are seen on walls. Bedroom(s) wall-1 is an example.
- Corner of kitchen ceiling is not straight.
- Doors made of PVC and all windows are not sealed with gasket evenly. Gaskets of windows are missing or do not meet properly at corners.
- The bedroom (b) door on wall-4 does not close properly.
- Figure 4.38 shows the gap between door leaf and frame more than 5 mm in kitchen door opening to terrace, same problem is seen in living room door opening to terrace and bedroom (b) door.

Figure 4.38 Gap between door frame and leaf

Figure 4.39 Right angle is not maintained between door and frame

- Right angle is not maintained between door and frame corner of bedroom (b) seen in Figure 4.39. The photo shows defect ‘d’ seen on floor plan in 4.31.
- Alignment/level of windows with wall openings is not provided. For example, according to Figure 4.40a and Figure 4.40b, distance from the window frame to edge of wall at lower part of wall is longer than upper part in living room wall-1. Figures show defect ‘b’.

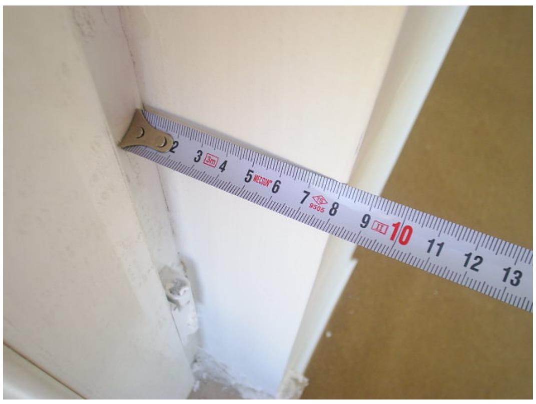


Figure 4.40a distance from the window frame to edge of wall (lower part)

Figure 4.40b distance from the window frame to edge of wall (upper part)

- Radiators in bedroom (s) and bathroom are not level and aligned.
- Corrosion sign is observed on taps.

b. Design of components quality

- The hole over the light fixture in the false ceiling is smaller than the tube-light which is to be inserted there.
- As seen in Figure 4.41, opening direction of window on wall-2 in living room is not appropriate. Window does not open entirely as it is hindered by handle of window on wall-1.The photo shows defect 'a'.

Figure 4.41 Inappropriate window opening direction

Figure 4.42 Inappropriate material for skirting

- The washbasin selected is too small and the shelf over it is too near for comfortable use. An occupant have removed the shelf above the washbasin and mounted it on the side wall.

c. Material quality

- Tiles are broken easily when something drops on it because tiles are of poor-quality.

- The carpet used in living room, bedrooms are thin and of poor-quality. It is not cleaned easily.
- Poor quality door handle and locksets are used and gaps between the doors and the frames are very large so they do not close completely.
- Walls are made of gypsum board. Joints are poor-quality and damaged easily.
- As gypsum board is used and there is no sound insulation material for walls, the sound in the next house is heard easily.
- Edges of carpet floor are not properly sealed. As shown in Figure 4.42, carpet is used as skirting material with a plastic top. This skirting is not functional as lower part of it is not properly secured on wall.
- Skirting in halls and kitchen is made of very thin plastic sections and is damaged easily.

Although it is not related with assessment of internal finishes, the materials used for external heat proofing especially plaster and net that must be resistant to rain cold and chemicals, are inappropriate and materials dropped down from the outer wall of Unit C as seen Figure 4.43. This building is only a three-year old building. Moreover, because of drainage problem, when it rains all water run to house and collected in front of outer wall of bedroom(s).

Figure 4.43 Poor quality of workmanship and material is visible even from the building exterior

3.4. Data Collected

The defects mentioned above were marked on the evaluation charts of each unit as to calculate DPMO and sigma values of each unit. The data gathered from 'Total Number of Defects' and 'Total Number of Checks/Opportunities for Defects' on the evaluation charts, presented in the following pages, were used for the calculation of defect per million opportunities (DPMO) relating to internal finishes of units. For two-paper charts total of these numbers is used for the calculation.

On the following pages, Table 4.4-4.5 show the evaluation charts for Unit A, Table 4.6-4.7 indicate evaluation charts for Unit B and Table 4.8 shows evaluation chart for Unit C.

Table 4.4 Evaluation chart of METU housing blocks – Unit A1

Locations		Floors					Walls					Ceilings					Doors					Windows					Components				
		Finishing	Alignment&Evenness	Cracks&Damages	Hollowness	Jointing	Finishing	Alignment&Evenness	Cracks&Damages	Hollowness	Jointing	Finishing	Alignment&Evenness	Cracks&Damages	Roughness	Jointing	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Accessories Defects	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Acccessories Defects	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Accessories Defects
L. Room	Wall 1	X	√	X	X	X	√	X	√	√	√	√	√	√	√	√						X	√	√	√	√					
	Wall 2					X	√	√	√	√	X						X	√	√	X	√										
	Wall 3					X	X	X	X	√	√											√	X	X	X	X					
	Wall 4					√	X	X	X	√	X											√	√	X	√	√	X	X	√	√	√
D. Room	Wall 1	X	√	√	√	√	X	X	√	√	X	√	√	√	√	√															
	Wall 2					√	√	√	√	√	√																√	√	√	√	√
	Wall 3					X	√	√	√	√																					
	Wall 4					√	√	X	√	√	√						X	√	X	√	√	√	√	X	√	√					
Hall	Wall 1	X	√	X	√	X	X	√	√	√	√	√	√	√	√	√															
	Wall 2					X	X	√	X	√	X						X	√	√	X	√										
	Wall 3					X	X	√	√	√	√																				
	Wall 4					X	√	√	X	√	√																				
Kitchen	Wall 1	√	√	√	√	√	X	X	X	√		X	√	√	√	√	√	√	√	√	√										
	Wall 2						X	X	X	√	X											X	X	X	√	√	√	√	√	√	√
	Wall 3						√	√	√	√	√																√	√	√	√	√
	Wall 4																														
WC	Wall 1	√	√	X	√	X	X	X	√	√	√	X	X	X	X	X											√	√	√	√	√
	Wall 2						X	√	√	√	√											X	√	√	√	√	√	√	√	√	√
	Wall 3						X	√	√	√	√						X	√	√	√	√										
	Wall 4						X	√	√	√	X																				
Room	Wall 1	X	√	√	√	X	√	√	X	√	X	X	√	√	√	√						X	√	√	√	√	√	√	√	√	√
	Wall 2					√	√	X	X	√	X																√	√	X	√	√
	Wall 3					X	√	X	X	√	X											√	X	√	X	√					
	Wall 4					X	X	X	X	√	X											√	√	√	√	√	√	X	√	√	√
Bathroom	Wall 1	X	√	√	√	X	X	X	X	√	X	X	X	X	X	X											√	√	√	X	√
	Wall 2						X	√	√	√	X											X	√	√	√	√	√	√	√	√	√
	Wall 3						√	√	X	√	√																				
	Wall 4						√	√	√	√	√						√	√	√	√	√						√	√	X	√	X
No. of Defects				22					51					12					7					15					7		
No. of Checks				47					133					35					30					50					65		
Total Number of Defects																													114		
Total Number of Checks/Opportunities for Defects																													360		

Table 4.5 Evaluation chart of METU housing blocks – Unit A2

Locations		Floors					Walls					Ceilings					Doors					Windows					Components				
		Finishing	Alignment&Evenness	Cracks&Damages	Hollowness	Jointing	Finishing	Alignment&Evenness	Cracks&Damages	Hollowness	Jointing	Finishing	Alignment&Evenness	Cracks&Damages	Roughness	Jointing	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Accessories Defects	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Acccessories Defects	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Accessories Defects
Bedroom(s)	Wall 1	X	√	√	√	X	X	√	√	√	X	X	√	√	√	√	√	X	√	X	√										
	Wall 2					X	√	√	√	√	X																				
	Wall 3					X	X	X	X	√	X																				
	Wall 4					X	X	X	√	√	X											√	√	X	√	√	√	X	√	√	√
Bedroom(b)	Wall 1	X	X	X	√	X	√	X	X	√	X	X	√	√	√	√	X	X	√	√	√	X	X	X	X	√					
	Wall 2					X	X	X	X	√	X											X	X	X	√	√	√	√	√	√	√
	Wall 3					X	X	X	X	√	X											X	√	√	√	√					
	Wall 4					X	√	√	√	√	X																				
Store	Wall 1	X	√	X	√	X	√	√	X	√	X	√	√	√	√	√															
	Wall 2					X	√	√	√	√	√						X	√	√	√	√										
	Wall 3					X	√	√	X	√	√																				
	Wall 4					X	X	√	√	√	X											X	√	√	√	X	√	X	√	√	√
Big store	Wall 1	√	√	√	√	X	√	√	√	√	√	√	√	√	√	√															
	Wall 2					X	√	√	√	√	√																√	√	√	√	√
	Wall 3					X	X	√	X	√	X																				
	Wall 4					X	√	√	X	√	X																				
Boiler	Wall 1	X	X	X	√	X	X	√	X	√	X	X	X	√	√	X											√	X	√	X	X
	Wall 2					X	X	X	X	√	X																				
	Wall 3					X	X	X	X	√	X																				
	Wall 4					X	X	√	√	√	X						√	√	√	√	√										
Hall	Wall 1	√	√	√	√	X	√	√	X	√	√	√	√	√	√	√															
	Wall 2					X	√	√	X	√	X																				
	Wall 3					X	√	√	√	√	X																				
	Wall 4					X	√	X	X	√	X																				
No. of Defects				33					52					5					5					11					5		
No. of Checks				48					120					30					20					25					25		
Total Number of Defects																													111		
Total Number of Checks/Opportunities for Defects																													268		

Table 4.6 Evaluation chart of METU housing blocks – Unit B1

Locations		Floors					Walls					Ceilings					Doors					Windows					Components				
		Finishing	Alignment&Evenness	Cracks&Damages	Hollowness	Jointing	Finishing	Alignment&Evenness	Cracks&Damages	Hollowness	Jointing	Finishing	Alignment&Evenness	Cracks&Damages	Roughness	Jointing	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Accessories Defects	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Acccessories Defects	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Accessories Defects
L. Room	Wall 1	√	√	X	√	X	√	X	X	√	X	X	√	X	X	X															
	Wall 2					X	√	X	√	√	X											√	X	X	√	√	√	X	√	√	√
	Wall 3					√	√	X	√	√	X																				
	Wall 4					√	√	√	√	√	X																				
D. Room	Wall 1	X	√	X	√	X	√	X	√	√	X	√	X	√	X	X															
	Wall 2					√	√	√	√	√	√						√	X	X	X	√	√	X	X	√	√	√	X	√	√	√
	Wall 3					X	√	X	√	√	√																				
	Wall 4					√	√	X	√	√	X																				
Hall	Wall 1	√	√	√	√	X	√	X	√	√	X	√	√	√	√	X	X	√	√	√	√										
	Wall 2					X	√	X	√	√	X																				
	Wall 3					X	√	X	√	√	X						√	√	√	√	√										
	Wall 4					X	√	X	√	√	X																				
Kitchen	Wall 1	√	√	X	√	X	√	√	√	√	√	√	X	√	√	√											√	√	√	√	√
	Wall 2					X	√	√	√	√	X																				
	Wall 3						√	X	√	√	√																√	√	√	√	√
	Wall 4						√	X	√	√	X											√	X	X	√	√	X	√	√	√	X
WC	Wall 1	√	√	X	√	X	X	√	√	√	√	√	X	√	X	X	√	√	√	X	√						√	X	√	X	√
	Wall 2						X	√	√	√	√																				
	Wall 3						X	√	X	√	X																√	√	√	√	√
	Wall 4						X	√	√	√	√											√	√	X	X	√	√	√	√	√	√
No. of Defects				16					31					12					5					8					6		
No. of Checks				35					100					25					20					20					40		
Total Number of Defects																													78		
Total Number of Checks/Opportunities for Defects																													240		

Table 4.7 Evaluation chart of METU housing blocks – Unit B2

Locations		Floors					Walls					Ceilings					Doors					Windows					Components				
		Finishing	Alignment&Evenness	Cracks&Damages	Hollowness	Jointing	Finishing	Alignment&Evenness	Cracks&Damages	Hollowness	Jointing	Finishing	Alignment&Evenness	Cracks&Damages	Roughness	Jointing	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Accessories Defects	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Acccessories Defects	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Accessories Defects
Bedroom(s	Wall 1	X	X		√	X	X	X	√	√	X	√	X	√	√	X	X	X	√	X	√										
	Wall 2					X	√	√	√	√	X																				
	Wall 3					X	√	X	X	√	X																				
	Wall 4					X	√	X	√	√	X											X	X	X	X	√	√	X	√	√	√
Bedroom(b	Wall 1	X	X		√	X	√	√	√	√	X																				
	Wall 2					X	√	X	√	√	X											X	X	X	X	√	√	√	√	√	√
	Wall 3					X	√	√	√	√	X																				
	Wall 4					X	√	X	√	√	X						X	X	X	√	√										
Room	Wall 1	X	X		√	X	√	√	√	√	X	√	√	√	X	X															
	Wall 2					X	√	X	X	√	X																				
	Wall 3					X	X	X	√	√	X																				
	Wall 4					X	X	X	√	√	X											√	√	X	X	√	√	X	√	√	√
Bathroom	Wall 1	√	√	X	√	X	X	√	√	√	√	√	X	√	X	X											√	√	√	√	√
	Wall 2						X	√	√	√	√						X	√	√	√	√						√	X	√	√	√
	Wall 3						X	√	X	√	X																√	X	√	X	√
	Wall 4						√	√	√	√	√											√	√	X	X	√	√	√	√	√	√
Hall	Wall 1	X	X		√	X	√	X	X	√	√	√	√	√	√	√											√	√	√	X	√
	Wall 2					X	√	X	√	√	X											X	X	X	√	√					
	Wall 3					X	√	X	√	√	√																				
	Wall 4					X	√	X	√	√	X																				
No. of Defects				26					37					7					7					15					6		
No. of Checks				33					100					20					15					25					40		
Total Number of Defects																													98		
Total Number of Checks/Opportunities for Defects																													233		

Table 4.8 Evaluation chart of METU housing blocks – Unit C

Locations		Floors					Walls					Ceilings					Doors					Windows					Components				
		Finishing	Alignment&Evenness	Cracks&Damages	Hollowness	Jointing	Finishing	Alignment&Evenness	Cracks&Damages	Hollowness	Jointing	Finishing	Alignment&Evenness	Cracks&Damages	Roughness	Jointing	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Accessories Defects	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Accessories Defects	Joints&Gaps	Alignment&Evenness	Material&Damages	Functionality	Accessories Defects
Hall	Wall 1	X	√	X	√	X	√	X	√	√	√	√	√	√	√	X	√	√	√	√	√										
	Wall 2					√	√	X	√	√	√																				
	Wall 3					X	√	X	√	√	√																				
	Wall 4					√	X	X	√	√	X																				
L. Room	Wall 1	X	X		√	X	X	√	√	√	X	X	√	√	√	X						√	X	√	√	√					
	Wall 2					X	√	X	√	√	X											√	X	√	X	√	√	√	√	√	√
	Wall 3					X	X	√	√	√	√						X	√	√	√	√	√	X	√	√	√					
	Wall 4					X	√	X	√	√	X						X	X	√	√	√										
Bedroom(s)	Wall 1	X	X		√	X	√	X	X	√	X	√	√	√	√	√															
	Wall 2					X	√	X	√	√	X						X	X	√	X	X										
	Wall 3					X	√	X	√	√	√																				
	Wall 4					X	√	√	√	√	X											√	X	√	√	√	√	X	√	√	√
Bathroom	Wall 1	X	√	X	√	X	√	√	√	√	√	√	√	√	√	√	X	X	X	√	√						√	√	√	X	√
	Wall 2						X	√	X	√	√																√	√	√	X	√
	Wall 3						X	√	X	√	√																√	X	√	√	√
	Wall 4						√	√	√	√	√																√	√	√	X	√
Hall2	Wall 1	X	√	X	√	√	√	X	√	√	√	√	√	√	√	√															
	Wall 2					√																									
	Wall 3					√	√	X	√	√	√																				
	Wall 4					√	√	√	√	√	√																				
Kitchen	Wall 1	X	√	X	√	√	X	X	√	√	√	√	X	√	√	X											√	√	√	√	√
	Wall 2					√	√	X	√	√	√						√	√	√	√	√										
	Wall 3					√	X	√	√	√	X																X	√	X	√	√
	Wall 4					√	√	X	X	√	√						X	√	√	X	√	√	√	√	√	√					
Bedroom (b	Wall 1	X	√		√	X	X	X	√	√	X	√	√	√	√	X															
	Wall 2					X	√	X	√	√	X						√	√	√	√	√	√	X	√	√	√	√	X	√	√	√
	Wall 3					X	√	√	√	√	X																				
	Wall 4					X	√	X	√	√	X						X	X	√	X	√										
No. of Defects				28					41					6					15					6					8		
No. of Checks				50					135					35					45					30					45		
Total Number of Defects																													104		
Total Number of Checks/Opportunities for Defects																													340		

3.5. Data Analysis

The following equation was used to calculate the sigma values for the quality assessment of the case study units.

$$\text{DPMO} = \frac{\text{Number of defects}}{\text{Number of opportunities x Number of units}} \text{x } 1000000$$

a) For Unit A: $\text{DPMO} = \frac{225}{628 \text{ x } 1} \text{ x } 1000000 = 358280.25$

Based on the sigma conversion table in Appendix D, the equivalent sigma for calculated DPMO of 358280.25 for Unit A is 1.86σ and which means that percentage of items executed properly by contractors is only 64.2%.

b) For Unit B: $\text{DPMO} = \frac{176}{473 \text{ x } 1} \text{ x } 1000000 = 372093.02$

Based on the sigma conversion table in Appendix D, the equivalent sigma for calculated DPMO of 372093.02 for Unit B is 1.83σ and which means that percentage of items executed properly by contractors is only 62.8%.

c) For Unit C: $\text{DPMO} = \frac{104}{340 \text{ x } 1} \text{ x } 1000000 = 305882.35$

The equivalent sigma for calculated DPMO of 305882.35 for Unit C is 2.01σ according to the sigma conversion table and which means that percentage of the items executed properly by contractors is only 69.4%.

According to the calculated values, the quality of internal finishes was sub-standard in all the three units because they are under the minimum acceptable sigma level of 3.8σ (99% of items comply with standards). With 1,83σ quality level the worst quality is seen in Unit B. Unit A and Unit B are constructed nearly at the same time and their sigma levels are nearly the same. Unit C that was constructed in 2003 has better quality than the other units but it is still under the acceptable level.

As it is seen from the study, all items have the same weightage but they do not have the same importance in construction quality assessment and customer satisfaction. For example, blistered surface on wall and gap between wall and window frame do not affect the resident's life and satisfaction equally. Thus, different weightages should be allocated to items but deciding which item is more important and which weightage could be given to items is a complex issue and is required a more detailed study. However, defects could be categorized as defects affecting life, satisfaction; repairable defects and the most common defects. Producing solutions to these defects could provide increase of quality level and customer satisfaction.

a) Defects affecting life, satisfaction: Some defects affect our lives whereas the others bother us aesthetically. Some of these defects are given as follows:

- gaps between walls and window frames that cool interior spaces in winter
- dip and depressed floors
- doors do not close completely especially doors opening to outside
- windows do not open completely
- sound passing through walls
- small hole over the light fixture
- small washbasin
- drainage

b) Repairable / irreparable defects: Doing things right for the first time is preferred but solution for houses having defects could be repairing the defects. Thus, defects could be separated as repairable ones such as cracks on walls, gaps between walls and window frames and irreparable ones like beams and walls that are not aligned.

c) The most common defects: Eliminating the most common defects could increase quality level. The most common problems according to the evaluation charts and images were as follows:

Floors

- Non-existence of a skirting to fit carpet or usage of inappropriate materials.
- Usage of poor-quality carpet.
- Tiles used for WC, bathrooms and halls are not of good quality. They are damaged easily.
- According to interview with an authorized person from facility management office, deformed and depressed floor is one of the most common problems in ODTÜKENT. It is observed in Unit A also.
- Floor surfaces of some rooms are uneven.
- Floor tiles are not aligned with wall tiles.

Walls

- Wall surfaces are uneven, thus there are gaps between walls and skirting.
- Water leakage problem is observed on walls near the sills that causes discolouration on walls.
- Cracks are seen near the sills.
- Surfaces of walls are rough especially above the skirting.
- Walls do not meet at right angles.
- Alignment/evenness is the most important problem on walls with straightness problem. Corners and joints are not straight.

Ceilings

- Water leakage problem is observed on ceilings of wet spaces.
- Corners of ceiling are not straight especially in bathroom and WC.
- Surfaces of some rooms' ceilings are uneven.

Doors and Windows

- Gap between frames and leaves/shutters is one of the most common problems for doors and windows.

- As the walls are not aligned and even, alignment/level of windows and doors with wall openings is not provided. Moreover, there exist gaps between wall and frame especially in windows.
- Because of inappropriate opening direction or not providing right angle between frames, windows do not function properly.

<u>*Components*</u>

- There is an alignment problem on components also, especially on radiators.
- Also corrosion signs are seen on bathroom and WC radiators.

Six Sigma has some models used in the implementation of this system. DMAIC – acronym for five phases- is one of these models. These phases are Define-Measure-Analyze-Improve-Control. In this study the problem is defined as the quality level of a mass-housing project in ODTÜKENT, METU. In Measure phase, quality level of the three houses from ODTÜKENT is measured and defects are pointed out by using standards, checklists. Data obtained from checklists were analyzed and used in the calculation of sigma values. Before providing suggestions for improvement for this study, it could be said that most common defects are result of firstly poor workmanship, material quality and lastly design of components.

For improvement, poor workmanship problem could be removed by training of workers. Teams could be constituted, skilled and trained staff could train workers, show them how to construct buildings correctly and at high quality. Defects sourced from low-quality material could be eliminated by using high-quality, durable materials that are in accordance with regulations. Construction materials producer firms that have quality certificates should be selected for material supply. The components should be designed properly and carefully. Design errors influencing functionality like inappropriate window opening direction should not be made. The control phase was not taken into consideration in the survey of ODTÜKENT housing units as said in Chapter 3 because it is impossible to control whether there is an improvement in the quality levels according to recommendations or not as there is no new construction.

CHAPTER 5

CONCLUSION

Of late, interest in “quality” and “quality management” has increased world-wide. Quality has gained importance in the construction industry also because of the cost of quality and losses due to lack of quality. Until recently it was thought that due to nature of building construction, it is quite difficult to control its quality diligently and the lack of quality was considered to be a general problem.

Quality, however, is hard to quantify as it consists of both objective and subjective components. Whilst some indicators of quality like workmanship, design of components and usage of correct and high-quality materials can be measured objectively with standards, others depend on the subjective views. For that reason, measuring the quality of housing units poses major conceptual and practical problems.

In this research, in order to reach a clear understanding of the quality management in construction, the fundamentals of quality and quality in construction were studied. The basic characteristics of construction industry that differentiate it from other industries and affecting quality management implementation in construction were described. Advantages and disadvantages of quality management were explained. Quality concept was discussed especially in the housing sector. The parameters of the housing quality indicators and assessment guides were discussed.

In this study, a survey is carried out to assess the level of quality in the ODTÜKENT housing units. For assessment, the procedures of a new quality management system, namely Six Sigma, was utilized with the contribution of CONQUAS quality assessment system. The study started with an extensive review of the concept and requirements of this system and CONQUAS quality assessment system together with the other quality assessment systems being used in the world. The case study further shows that this model can be used to assess the quality level of a construction project and quality improvement efforts of the contractor, and measure the progress over time. By using the model in the project, the areas that need urgent improvement can be determined.

Before the case study of applying CONQUAS quality assessment to ODTÜKENT housing units according to six sigma criteria, interviews were conducted with contractor and site-supervisor and the following results were obtained related to the attitudes towards quality during the construction of ODTÜKENT housing units:

1. No system exists to manage quality throughout the design/construction process.
2. No data collection system and feedback system that could lead to early identification of defects exists. The defects that occur during construction are usually concealed or corrected when the owner, controller or occupant points out to them. Thus, lack of such a system means that conventional procedures do not change; this in turn allows the defects to reoccur during the next project.
3. No standards or assessment systems related with design and construction quality exist and no system exists for implementation of standards.
4. No penalty mechanism for poor quality is utilized. Moreover, tenders continue to be awarded to contractors who did not provide quality in construction.

This research draws attention of professionals to “the low level of quality in mass housing projects”. According to the interviews with occupants, it was noted that they were not fully satisfied with the quality of products or services delivered in their housing units. According to the case of ODTÜKENT, poor quality is a result of firstly poor workmanship, then improper material or of poor quality material usage and lastly design of detailing problems.

Although the units studied were constructed on different dates, the quality assessment results show that same defects were repeated due to lack of feedback and evaluation system. This shows the importance of a system like Six Sigma.

If mistakes are made during the design and construction stages, they cannot be rectified easily, that cause lost of excessive amount of money and time. Therefore a systematic approach is required, from the very beginning, to achieve good standards both in design and construction. The traditional approach of relying on the skill and experience of the personnel, and doing the works in the usual way should be abandoned.

A construction firm which wishes to increase the quality of its projects, must reduce the amount of defects during the construction work. For this, it is important to determine basic architectural, structural and constructional concepts, standards and parameters of quality assessment related with construction and the sources of problems which lead to low quality in the construction projects. Any system to be adopted should clearly identify the inputs and outputs of the works. This would not guarantee quality but, with careful study of the numbers, would reveal the obstacles on the way to quality and would help to figure out losses due to poor quality.

Further research is necessary to examine all dimensions of the problem of poor quality all dimensions since this study is concerning only with the workmanship quality, design of components and quality of construction materials of internal finishes and components, there is a need to investigate the contribution of each party (designer, client, contractor, etc.) in the 'total quality' of construction and its improvement.

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APPENDICES

APPENDIX A

Table A.1. Housing score sheet

(Source: Housing Corporation, 2006)

LOCATION

• geographical centre for amenities
• boundary for liabilities
• noise source to points within the site.

Where a layout is not yet planned add 20% to the straight line distance. A site plan showing the relevant distances will make it easier to answer the questions. Amenities: the geographical centre of an estate is the basis for distance measurements where the project is a single compact area. For a long site, where one direction across a site measures more than twice another, treat the site as several with a diameter equal to the short dimension across the site. In these situations enter a percentage in the appropriate column. Liabilities: use the distance from the item to the nearest point on the site boundary.

Scores

Tick 'Yes' where the scheme has assets or liabilities described and 'No' if not. Tick the planned column if applicable.

1.1 Amenities – how close are they? (80%)

Support services (20%)	**Yes**	**No**
1.1.1 Is there a healthcare facility or GP practice very near (within 500m)?	☐	☐
1.1.2 Is there a healthcare facility or GP practice fairly near (between 500m and 1 km)?	☐	☐
1.1.3 Is there a public house, restaurant or cafe within 1km?	☐	☐
1.1.4 Is there a place of worship or community hall or centre within 1km?	☐	☐
Retail (20%)		
1.1.5 Is there local retail outlets – e.g. food or newsagent – very near (within 500m)?	☐	☐
1.1.6 Is there local retail outlets – e.g. food or newsagent – fairly near (500m to 1km)?	☐	☐
1.1.7 Is there a post office very near (within 500m)?	☐	☐
1.1.8 Is there a post office fairly near (between 500m and 1 km)?	☐	☐
1.1.9 Is there a public telephone very near (within 500m)?	☐	☐
1.1.10 Is there a cash-point/bank very near (within 500m)?	☐	☐
1.1.11 Is there a major commercial centre or 'high street' within 2 km?	☐	☐
Schools (10%) (excluding fee paying)		
1.1.12 Is there a pre-school/nursery very near (within 500m)?	☐	☐
1.1.13 Is there a pre-school/nursery fairly near (between 500m and 1 km)?	☐	☐
1.1.14 Is there a primary school very near (within 500m)?	☐	☐
1.1.15 Is there a primary school fairly near (between 500m and 1 km)?	☐	☐
1.1.16 Is there a secondary school within 1km?	☐	☐
1.1.17 Is there a secondary school more than 1km but within 2 km?	☐	☐
Play and leisure (10%)		
1.1.18 Are there toddler play areas within sight of family houses?	☐	☐
1.1.19 Are there play facilities for 5 – 12s very near (within 500m)?	☐	☐
1.1.20 Are there play facilities for 5 – 12s fairly near (between 500m and 1 km)?	☐	☐
1.1.21 Are there play facilities for over 12s very near (within 500m?)	☐	☐
1.1.22 Are there play facilities for over 12s fairly near (between 500m and 1 km)?	☐	☐
1.1.23 Is there a park/public open space within 1 km?	☐	☐
1.1.24 Is there a leisure/sports facility (eg pool or gym or playing fields etc.) within 1 km?	☐	☐
Public transport (20%)		
1.1.25 Is there a bus or tram stop very near (within 500m)?	☐	☐
1.1.26 Is there a bus or tram stop fairly near (between 500m and 1 km)?	☐	☐
1.1.27 Is there a train or underground station very near (within 500m)?	☐	☐

APPENDIX B

Table B.1 Housing purchase guide score sheet

(Source: Yapı Endüstri Merkezi, 2006)

C	Expert support	General architectural properties	yes	no	irrelevant
1		Is there any approved architectural project of unit?	+	-	—
2		Are there any modifications in unit that are not in architectural project? (If done, learn the reasons)	+/-	+/-	—
3		Are you satisfied with the appearance of unit and interior spaces from aesthetical view?	+	-	—
4		Is unit suitable to meet not only today's needs but also future ones? Does plan give a chance to make new arrangement in such cases? (For example, take care the possibility of joining new individuals to your family)	+	-	—
5		Is unit suitable for the use of a handicapped or old person? (For example, be sure that staircases, landing, corridor widths and other related spaces are suitable for entry/turn of wheel-chair)	+	-	—
6		Are the spaces you spend most of your time exposed to daylight sufficiently? (For example, could you dwell without artificial illumination during daytime?)	+	-	—
7		Does the noise of equipments like elevator, generator. etc. in common spaces disturb your sleep/work?	+	+	—
8		Is the number of rooms in unit adequate to meet needs?	+	-	—
9		Is the plan of unit suitable to position furniture? (Be sure that size of rooms and recess/extension of walls do not cause problem when placing furniture)	+	-	—
10		Is the number of bathroom/WC in unit adequate to meet needs?	+	-	—
11		Is bathroom/WC suitable for the use of a handicapped or old person?	+	-	—
12		Is the number and size of spaces like lumber room/cupboard, etc. adequate to meet needs?	+	-	—
13		Is there any elevator if building is higher than five floors? (Current regulations oblige placing an elevator in houses having more than five floors)	+	-	—
14		Is elevator suitable for the use of vehicles like sedan chair, wheel-chair in emergency state?	+	-	—
15		Is there any garbage shaft?	+	-	—
16		Do balcony and staircase balustrades constitute danger? (For example, does distance between balustrades permit children pass through? Could it be used by children as a staircase? Is balustrade height less than 90 cm?	-	+	—
17		Is there any ramp at the entrance of building that could be used in necessary situations?	+	-	—
18		Are eaves considered at the entrance of building for protection from external effects like snow, rain, wind?	+	-	—
19		Is entrance designed and illuminated in the way that you could enter without fear at midnight and dissuade strangers in bad faith?	+	-	—
20		Is there any shelter in building that applies with the current regulations?	+	-	—
21		Are there any store rooms outside the unit? (For example, is there any space that is allocated for storage in basement floor?)	+	-	—
22		Are entry and exits controlled in basement floor? (For example, could you be sure from safety of your belongings?)	+	-	—

APPENDIX C

Table C.1 CONQUAS quality standards - floors

(Source: Singapore Building Construction Authority, 2005)

QUALITY STANDARDS FOR ARCHITECTURAL WORKS

Part 1 : Internal Finishes

	Item*	Standards
1	**Floors**	
1a	**General Requirements**	1) **Finishing** • No stain marks • Consistent colour tone
		2) **Alignment & Evenness** • Evenness of surface (not more than 3mm per 1.2m) • Falls in wet areas should be in right direction • No ponding in falls for wet area • For staircases, the variance in lengths of threads and risers must not exceed 5 mm; nosing must be straight
		3) **Crack & Damages** • No visible damage / defects
		4) **Hollowness / Delamination** • No hollow sound when tapped with a hard object • No sign of delamination
		5) **Jointing** • Consistent skirting thickness and no visible gap between wall & skirting
1b	**Screed finish**	1) Surfaces should not be unduly rough or patchy
		3) Expansion joints should be provided at interval as stated by architect
1c	**Tiled finish**	1) Consistent and neat pointing
		2) No hollow sound when tapped with a hard object
		3) Joints are aligned and consistent with skirting and wall tiles
		4) Consistent joint size
		5) Lippage between 2 tiles should not be more than 1mm
		6) Expansion joints should be provided at interval as stated by architect

Table C.2 CONQUAS quality standards - floors

(Source: Singapore Building Construction Authority, 2005)

	Item*	Standards
1d	Timber floor	1) No warpage
		2) Timber strips to rest firmly on joists or screed
		3) No visible gap between timber strips
		4) Edges of the floor to be properly sealed
1e	Carpet	1) Stretched and even surface
		2) Joint should not be visible
		3) Proper anchoring at all edges
1e	Raised Floor	1) No loose floor panels or rocking
		2) No protrusion / potential of stripping over floor panels

Table C.3 CONQUAS quality standards – internal walls
(Source: Singapore Building Construction Authority, 2005)

	Item*	Standards
2	**Internal Walls**	
2a	**General Requirements**	1) **Finishing** • No stain marks • Consistent colour tone • No rough / patchy surface
		2) **Alignment & Evenness** • Evenness of surface (not more than 3mm per 1.2m) • Verticality of wall (not more than 3mm per m) • Walls meet at right angles (not more than 4mm over 300mm) • Edges to appear straight and aligned
		3) **Crack & Damages** • No visible damage / defects
		4) **Hollowness / Delamination** • No hollow sound when tapped with a hard object • No sign of delamination
		5) **Jointing** • Straightness of corners and joints
2b	**Plaster Finish**	1) Surface evenness (not more than 3mm over 1.2m)
		2) No hollow sound when tapped with a hard object.
		3) Surfaces should not be unduly rough or patchy esp no brush / trowel marks
2c	**Tiled Finish**	1) Tile joints aligned and with consistent joint size
		2) No hollow sound when tapped with a hard object
		3) Consistent and neat pointing
		4) Lippage between 2 tiles should not be more than 1mm
2d	**Cladding**	1) Proper anchorage for panels
		2) Joints aligned and with consistent joint size
		3) Sealant material compatible with cladding
		4) Consistent spacing and within allowable tolerance
2e	**Architectural Coating**	1) Substrate - see plaster finish
		2) Finished texture and colour to be uniform

Table C.4 CONQUAS quality standards – internal walls
(Source: Singapore Building Construction Authority, 2005)

	Item*	Standards
2f	Painting	1) Substrate - see plaster finish
		2) Surfaces are evenly painted with no visible brush marks
		3) Good opacity, no patchiness resulted from touch up works
		4) Free from peeling, blister and chalkiness
		5) No discolouration and fading
2g	Pre-cast concrete planks	1) Alignment with adjacent planks not more than 3mm
		2) Plane tolerance (3mm / 1.2m)
		3) Standard of finishes - see above
2h	Wall Paper	1) Stretched and even surface
		2) Joint should not be visible
		3) Proper anchoring at all edges
		4) Edges should be neatly laid and finished
2i	Glass Blocks	1) Pointing should be satisfactory
		2) Joint should be even
		3) Glass blocks should be properly aligned
2j	Wood / Timber Panels	1) Timber panels to rest firmly on joist or render
		2) No visible gaps between panels
		3) Edges should be properly aligned and sealed
		4) No warpage

Table C.5 CONQUAS quality standards - ceilings

(Source: Singapore Building Construction Authority, 2005)

	Item*	Standards
3	**Ceilings**	
3a	**General Requirements**	1) **Finishing** • No stain marks • Consistent colour tone • No patchy surface
		2) **Alignment & Evenness** • Overall surface should be smooth, even, not wavey • Straightness of Corners
		3) **Crack & Damages** • No visible damage e.g spalling, leaks, cracks, etc
		4) **Roughness** • No rough surface
		5) **Jointing** • Consistent, aligned and neat
3b	**Skim Coats / Boarded ceiling**	1) Not patchy, with no pin holes and with no trowel marks
		2) Formwork joints are grounded smooth
		3) Paintwork with good opacity and with no brush marks
		4) Access door joints should be sharp and in consistent width
3c	**False ceiling / Grid System**	1) Alignment of rails should be visually straight
		2) Surface should be overall level and even
		3) Chipped surfaces or corners should not be seen

Table C.6 CONQUAS quality standards - doors

(Source: Singapore Building Construction Authority, 2005)

	Item*	Standards
4	Doors	1) **Joints & Gap** • No visible gaps between door frame and wall • Consistent & neat joints • Consistent gap between door leaf and frame and not more than 5mm 2) **Alignment & Evenness** • Alignment/level with walls • Door frame and leaf to flush • Door and frame corners maintained at right angles 3) **Material & Damages** • No stain marks and any visible damage • No sags, warps on door leaf • Fire stop provided where necessary • Door joints and nail holes filled up, properly sanded down and with good paint finish (including on top and bottom of door leaf and consistent in colour) • Glazing clean and evenly sealed with gasket • No sign of corrosion for metal frame • Consistent colour tone 4) **Functionality** • Ease in opening and closing • No squeaky sound during swinging the leaf 5) **Accessories Defects** • Lock sets with good fit and no stains • No sign of corrosion in ironmongery • No missing or defective accessories

Table C.7 CONQUAS quality standards - windows
(Source: Singapore Building Construction Authority, 2005)

	Item*	Standards
5	Windows	1) **Joints & Gap** • Consistent gap between window leaf and frame and not more than 5mm • No visible gap between window frame and wall • Consistent gap between window leaf and frame and not more than 5mm • Neat joint between window and wall internally and externally 2) **Alignment & Evenness** • Alignment / level with wall openings • Window leaf and frame corners maintained at right angles 3) **Material & Damages** • No stain marks & visible damages / defects • Louvre windows with glass panels of correct lengths • Glazing clean, evenly sealed with putty or gasket for aluminium windows 4) **Functionality** • Ease of opening and closing • No sign of rainwater leakage • No squeaky sound during swinging the leaf 5) **Accessories Defects** • Lock sets with good fit & aligned • No sign of corrosion • No missing or defective accessories • Rivet at hinges in stainless steel

Table C.8 CONQUAS quality standards - components
(Source: Singapore Building Construction Authority, 2005)

	Item*	Standards
6	**Components**	* Internal fixtures such as wardrobe, kitchen cabinet, vanity top, mirror, bathtub, water closet, shower screen and basin ** External fixtures such signage, emergency lightings, railings, unit nos plate, lift fittings, letter box, lightings, etc
6a	**General Requirements**	1) **Joints & Gap** • Consistent joint width & neat joint • No visible gap 2) **Alignment & Evenness** • Level and in alignment 3) **Material & Damages** • No stain marks • No visible damage / defects • Consistent in colour tone 4) **Functionality** • Functional, secured and safe 5) **Accessories Defects** • No missing accessories • No sign of corrosion • No visible damages / defects
6b	**Railings**	1) Verticality of balusters must not exceed 3mm per metre 2) Welding at joints must be grounded or flushed

APPENDIX D

Table D.1 Six Sigma conversion table
(Source: PANDE *et al.* (2000) Six Sigma Yolu, McGraw-Hill, New York)

SIX SIGMA TABLOSU
(Milyonda Hata'lar Yuvarlanmıştır.)

Uzun Vade Başarı Oranı	Proses Sigma	Milyonda Hata	Onbinde Hata	Yüzde Hata
%99,99966	6,0	3,4	0,034	0,00034
%99,9995	5,9	5	0,05	0,0005
%99,9992	5,8	8	0,08	0,0008
%99,9990	5,7	10	0,1	0,001
%99,9980	5,6	20	0,2	0,002
%99,9970	5,5	30	0,3	0,003
%99,9960	5,4	40	0,4	0,004
%99,9930	5,3	70	0,7	0,007
%99,9900	5,2	100	1,0	0,01
%99,9850	5,1	150	1,5	0,015
%99,9770	5,0	230	2,3	0,023
%99,9670	4,9	330	3,3	0,033
%99,9520	4,8	480	4,8	0,048
%99,9320	4,7	680	6,8	0,068
%99,9040	4,6	960	9,6	0,096
%99,8650	4,5	1.350	13,5	0,135
%99,8140	4,4	1.860	18,6	0,186
%99,7450	4,3	2.550	25,5	0,255
%99,6540	4,2	3.460	34,6	0,346
%99,5340	4,1	4.660	46,6	0,466
%99,3790	4,0	6.210	62,1	0,621
%99,1810	3,9	8.190	81,9	0,819
%98,930	3,8	10.700	107	1,07
%98,610	3,7	13.900	139	1,39
%98,220	3,6	17.800	178	1,78
%97,730	3,5	22.700	227	2,27
%97,130	3,4	28.700	287	2,87
%96,410	3,3	35.900	359	3,59
%95,540	3,2	44.600	446	4,46
%94,520	3,1	54.800	548	5,48
%93,320	3,0	66.800	668	6,68
%91,920	2,9	80.800	808	8,08
%90,320	2,8	96.800	968	9,68
%88,50	2,7	115.000	1.150	11,5
%86,50	2,6	135.000	1.350	13,5
%84,20	2,5	158.000	1.580	15,8
%81,60	2,4	184.000	1.840	18,4
%78,80	2,3	212.000	2.120	21,2
%75,80	2,2	242.000	2.420	24,2
%72,60	2,1	274.000	2.740	27,4
%69,20	2,0	308.000	3.080	30,8
%65,60	1,9	344.000	3.440	34,4
%61,80	1,8	382.000	3.820	38,2
%58,00	1,7	420.000	4.200	42
%54,00	1,6	460.000	4.600	46
%50	1,5	500.000	5.000	50
%46	1,4	540.000	5.400	54
%43	1,3	570.000	5.700	57
%39	1,2	610.000	6.100	61
%35	1,1	650.000	6.500	65
%31	1,0	690.000	6.900	69