Total Quality Management In Construction Industry

Ahmed S. Agha

Abstract: Total quality management (TQM) is a management philosophy which has been widely implemented in the manufacturing and other services industries, and it shows how significant it can improve the quality in these fields. Few articles and studies attempted to bring the benefits of this philosophy to construction industry. The objective of this paper is to point out the latest studies which focused on increase the business quality through implementing TQM in construction industry and its suitable applications in the different phases of project construction.

Introduction

To be competitive in today's market, it is essential for construction companies to provide more consistent quality and value to their owners/customers. Now is the time to place behind us the old adversarial approach to managing construction work. It is time to develop better and more direct relationships with our owners/customers, to initiate more teamwork at the jobsite, and to produce better quality work. Such goals demand that a continuous improvement (CI) process be established within the company in order to provide quality management. Recently CI has been referred to as Total Quality Management (TQM) [1].

The construction industry has arrived late to TQM, probably due to the tendency to easily brush aside anything in management that is new, or to dismiss TQM as a fad[1].But the implementation of TQM in other industries shows clearly that the TQM is not a fad and confirm the benefits of implementing this philosophy and how much it can improve the customer satisfaction as the measure of business quality.

Objectives of study

The objective of this study is to point out the latest studies that examine the suitability and applicability of the TQM principles and tolls in construction industry at two stages:

1. Planning and develop a conceptual design of small and large scale projects.
2. Construction and implementation of small and large scale projects.

To accomplish this objective, we will indicate the summary of results and conclusions of three studies shows how we can benefit of using TQM tools in planning and design stage, and we will indicate the summary of results and conclusions of one study shows how we can benefit of using TQM tools in construction and implementation stage, and finally, a case study about improving the quality, saving time and reduce cost of an under construction project.

1-Planning and develop a conceptual design stage

In planning and design stage it is extremely important to clearly identify the customer requirements and integrate it with the constructability knowledge and information to develop an effective design that meet the customer satisfaction.

1.1- Adaptations of QFD for constructable designs

(Yang, Wang, Low and Goh) [2] adapted the quality function deployment (QFD) tool commonly referred to as the house of quality (HOQ) for concurrent constructable designs. A new proposed HOQ model, called the HOQCD, is developed to support constructable designs based on the conventional QFD rationale, as shown in Fig. 1

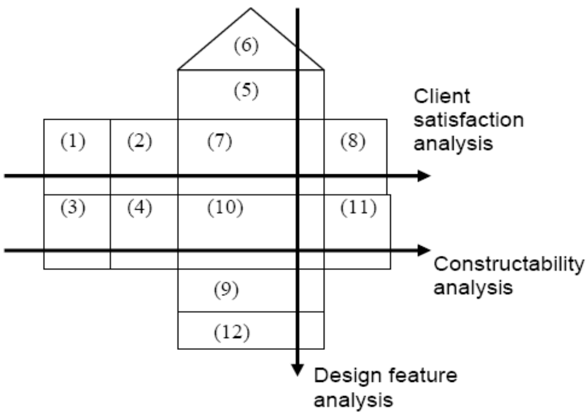

Fig. 1. The HOQCD

(Yang, Wang, Low and Goh) [2] demonstrates an intelligent decision support system DSS to support constructable designs in the early design phase. The HOQCD is developed to facilitate the use of integrated client information and constructability knowledge and information. Under the HOQCD platform, intelligent design experts are constructed to support the sharing and processing of the integrated design-relevant QFD information. The integrated information is captured and stored within a concurrent information environment, which is supported by an Industry Foundation Classes (IFC) based product model, so that a design team can easily acquire and share the information.

The system is already developed on a personal computer platform. Future research can focus on extending the system on the Internet platform and on further assessing and improving the information representation model, which was proposed to integrate the client information and constructability information within the IFC-based concurrent information environment.

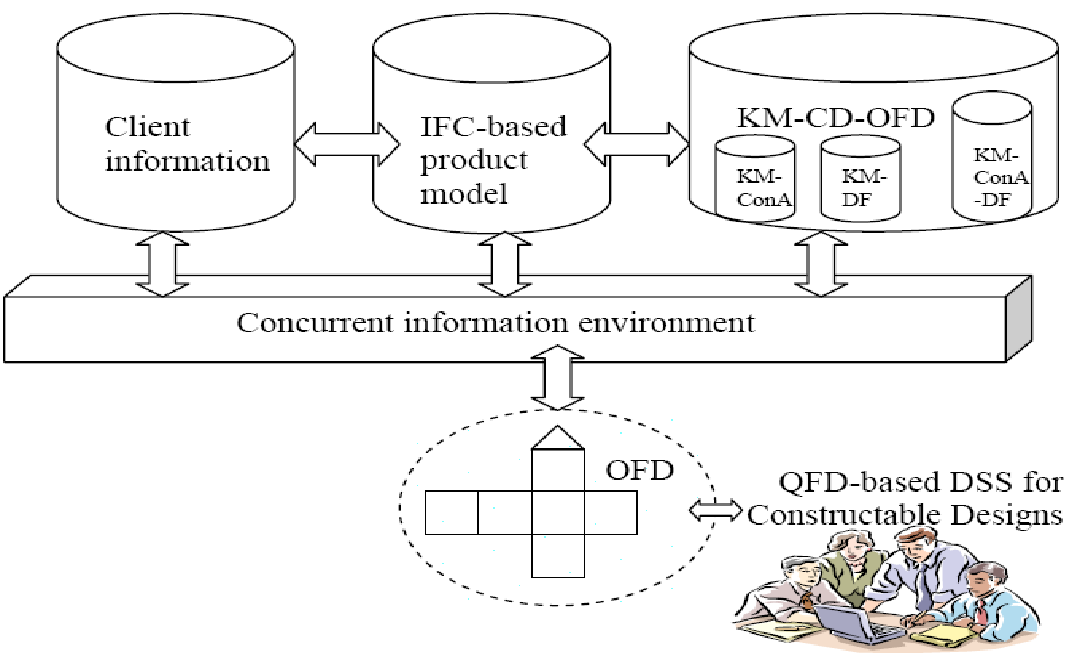

Fig. 2. Architecture of concurrent information environment for constructable designs

1.2- QFD in construction projects

(Eldin and Hikle) [3] examined the feasibility of using QFD as a project management tool in the preliminary engineering phase to develop the conceptual design for a large classroom for college students. The QFD team evoked the voice of the customers (VOC) through focus groups that represented the entire population who would affect or be affected by the classroom design—faculty, students, administration, Information Services staff, Facilities Services staff, and Communication Media Center staff.

This exercise revealed that designers' perception might differ from that of the customers. For instance, at the outset of this investigation, the QFD team intuitively perceived that the proposed classroom would have to be a ''high-tech'' room with computer connections at every student seat. However, the VOC revealed that neither the students nor the teachers wanted computers at every seat. Contrary to the initial perception, such heavy access to computers was viewed as a distraction by the focus groups. Both the students and the teachers wanted a complete communications station (including computer capability and video projection) only at the teacher's station.

The team utilized the HOQ to compile the needs voiced in the focus group sessions, to determine the necessary design attributes and to resolve conflicts among such attributes. At the completion of this study, several layouts for the large classroom, a list of teaching-aid equipment, a description of equipment features/ specifications, equipment cost estimates, and the project total cost were presented to the administration of the university. These deliverables were well received.

(Eldin and Hikle) [3] demonstrates that QFD could be used successfully in the development of conceptual designs of construction projects. The QFD process made it possible for a group of individuals with different interests to listen clearly to the customers' needs, communicate their own functional group needs, find compromises that were acceptable to all, and approve critical decisions on a timely basis. The QFD process provided procedures that always moved the project forward and eliminated the need to loop backward to correct an oversight or a design requirement.

Based on the success in this small design construction project and the success of others in more complicated manufacturing projects, it is sensible to conclude that the application of the QFD should be successful also on larger projects in the construction industry.

	DESIGN REQUIREMENTS	SPACE							SEATING								SOUND					Video					AESTHETICS						AMBIENT								
Component Characteristics		Room aspect ratio	Teacher to student max. distance	Teacher to student mean distance	Teacher area (minimum area)	Inter-person dist. of group members (max)	Minimum student work-space (left-to-right)	Minimum distance for passage	Seat size (minimum)	Seats to meet ergonometric standards	Work surface height	Seat level to work surface	Power available for lap-tops	Student-to-screen max distance	screen max viewing angle	Group set-up time (maximum)	Door noise (db at 10 ft from door)	Audio system min db at student seats	Sound attenuation, front-to-back	Max level of room generated noise	db limit for noise from outside room	OSU campus network	Bexell network	WEB	Conference calling	Multimedia	Aisles	Aisle minimum width	min ceiling height @ screen wall	Risers for terraced floor (max)	Natural lighting level	Decor to please 60% of people, min.	Room illumination range	Fresh air CFM per person	Percent make-up air	CO_2 maximum limit	Room temperature range (winter)	Room temperature range (summer)	Weighted relative importance	Relative importance (%)	Design specifications
	Relative Importance	18							20								14					19					14						15								
Room Geometry	Appropriately terraced floor																													126									126	1	
Room Geometry	High walls for screens													20															126										146	1	
Room Geometry	One, 5 ft. middle aisle	54	54	54			18	18						20													126	126											470	5	
Room Geometry	Two, 4 ft. side aisles	54	54	54			18	18						20													126	126											470	5	
Room Geometry	Width of teacher area		54	54	162																																		270	3	
Room Geometry	Depth of teacher area (> 10 ft)		54	54	162																																		270	3	
Decor	Light, non-intrusive colors																														42	126	45						213	2	
Decor	Pictures of peaceful scenes																															126							126	1	
Decor	Green plants (perhaps silk)																															126							126	1	
Decor	Windows type ______																	42			126										126	126	45						465	5	
Decor	Sky lights type ______																	42			126										126	126	45						465	5	
Room Layout	Work groups arranged in 2 rows					162	54	18																															234	2	
Room Layout	Use work benches or tables	54				162																																	216	2	
Room Layout	workbenches: 6 rows spaced @5ft	162	162	162																																			486	5	
Room Layout	Three rows of tables spaced @ 8'	162	162	162																																			486	5	
Room Layout	Seats fixed in place					162														126																			288	3	
Room Layout	Seats to pivot 360 degrees																			126																			126	1	
Room Layout	Seat specification No._______																			126																			126	1	
Room Layout	Workbench / table specification No.	162	162	162																																			486	5	
Noise	Quiet seats																			126																			126	1	
Noise	Sound isolating doors																126				126																		252	2	
Noise	Door style																126				126																		252	2	
Noise	Door hardware type (quiet)																			126																			126	1	
Audio	Audio system type ______																	126																					126	1	
Audio	Well placed audio speakers																	126																					126	1	
Audio	Appropriate sound baffles																		126	126																			252	2	
Audio	Telephone with speaker system																								179														179	2	
Audio	Carpeted floor:spot-hiding pattern																			126																			126	1	
Audio	Sound-absorbing surfaces																			126																			126	1	
Audio	Sound isolating walls																				126																		126	1	
Visual aids	Two screens, mounted high, at left and right corners of room													180	180											179													539	5	
Visual aids	Two multimidea ceiling projectors													180	180											179													539	5	
Visual aids	Cable hook-up to networks																					179	179	179		179													716	7	
Air	Air conditioning																																	135	135		135	135	540	5	
Air	Fresh air mixed wit recirculated air																																		135	135			270	3	
Air	CO2 monitor on air return																																			135			135	1	
Power & Lighting	Power supplied to group locations											180																											180	2	
Power & Lighting	future computer cables to all desks																					57	57	57															171	2	
Power & Lighting	1000 Hz Fluorescent light panels																																135						135	1	
Power & Lighting	Radially polarized screens																																135						135	1	
Power & Lighting	parabolic grids 4 inch deep cell																																135						135	1	
Power & Lighting	Light intensity 75cp, dimable to 20db																																135						135	1	
Power & Lighting	Geometry of panel layout to be compatible with VDTs and Video																																135						135	1	

Fig. 3. Second house of quality for large classroom project

1.3- QFD in civil engineering capital project planning

(Ahmed, Sang and Torbica) [4] examined the suitability of quality function deployment (QFD) in the planning and design of capital projects, and to propose a QFD application model that can be readily used in the planning and design process.

Civil engineering capital projects, irrespective of type, size, and complexity, go through a typical development life cycle that can be divided into two stages: planning and design, and construction and implementation.
This study is concerned with the application of QFD in the planning and design stage. Four development phases for civil engineering capital project planning can be identified as follows: project requirement, feasibility study, preliminary design, and detailed design.
As shown in Fig. 4-1

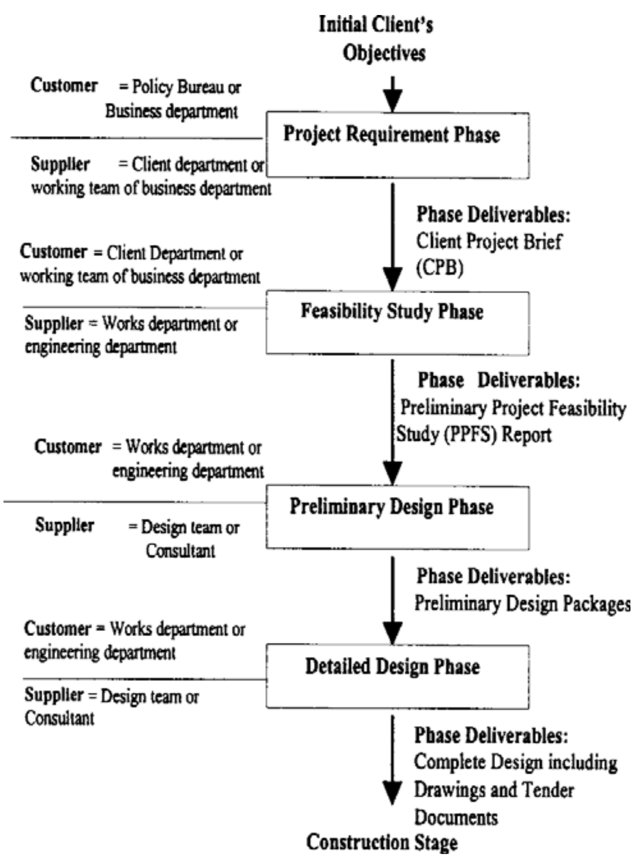

Fig. 4-1. Model of project planning process

Each phase seems to follow a similar flow path of development. Fig. 5 shows the typical flow chart of a phase in the project planning process that describes the customer-supplier relationship, major activities, and main inputs and outputs of the phase.

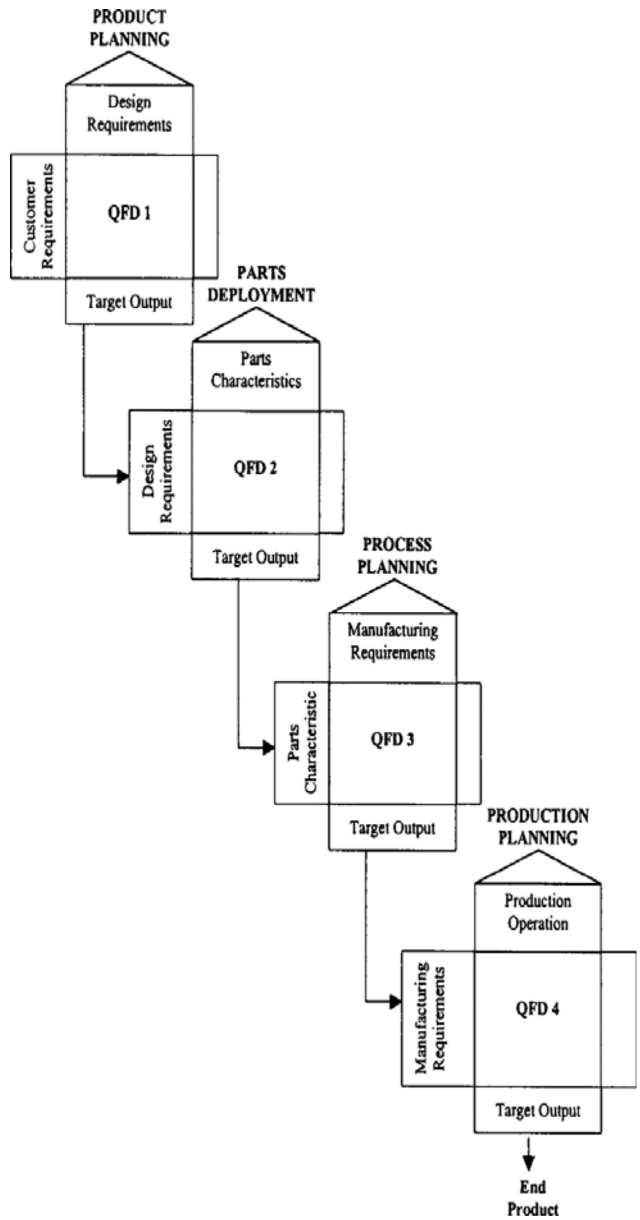

Fig. 4-2. Chain of QFD matrices

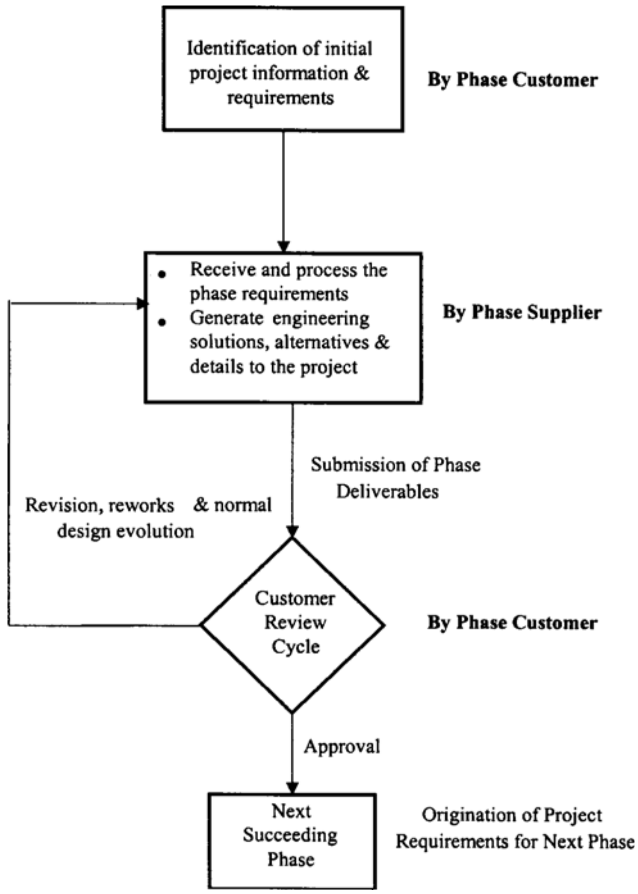

Fig. 5. Typical process flow in project planning phase

A model that merges the QFD process with the project planning process is shown in Fig. 6. The left-hand side of the model is part of the project planning process (Fig. 4-1), while the right-hand side is the QFD process (Fig. 4-2). The underlying premise of this model is that QFD can be used in parallel with the respective phases of the project planning process to enhance the quality of the output of each phase.

The model starts with the initial client's objectives. The splitting arrows from the initial client's objectives enter into the project requirement phase and the ''what'' section of the QFD level 1; the same information is fed into the two parallel processes. It must be noted that QFD is a planning tool and is not meant to replace the main purpose of the phase, which is engineering in nature. The civil engineering project planning process is still heavily reliant on the talent and professional capabilities and skills of the designers. Instead, QFD is used here in parallel with the respective phases to enhance the quality of the output of each phase.

A set of initial engineering solutions on alternatives is developed through the works of the phase and is then fitted into the ''how'' section. What follows is the effectiveness of the QFD in helping prioritize the client's requirements as well as optimizing the engineering solutions to yield a set of target values. The output arrow of the QFD then goes back to the main work of the phase for formalizing the phase deliverables. This indicates that the decisions, prioritization, and other information generated by the QFD process become an integral part of the output of the phase. Since the output of the QFD forms an integral part of the output of the respective phase, the project criteria or requirements in the two outputs should not be different; there should be no deviations between the requirements of the output going into the succeeding phase and those entering the corresponding QFD matrix. The process repeats in the second level onward, and the two parallel processes will still work in harmony, resulting in quality enhancement. The output of the preceding QFD also enters the ''what'' section of the succeeding QFD; this is to ensure that the requirements are maintained throughout the deployment process. Any item at any level of QFD can be traced back to the original initial client's objectives. Dotted arrows represent the looping process should any change occur in the project planning process. Minor, non-significant changes may directly reenter the main function of the phase and undergo a design evolution. If a change is significant, however, the change shall go one phase backward; that is, the change must go through the work of the previous phase to determine the impact on the project. Whether a change is considered significant or non- significant depends on how severe an impact the change brings to the project in terms of cost, time, quality and risk.

It can be seen that the use of QFD for the detailed design phase is left out in this model. In the detailed design phase, the decision-oriented functions of the project should already have been finalized. The remaining work is the production of construction drawings, engineering details, and specifications, which transform the design intent into a full set of contract documents. Therefore, the opportunities for QFD are limited only to discrete applications.

An HOQ template is presented for use in the capital project planning process. The ‘‘what’’ section is developed by collecting, grouping, sorting, eliminating duplicates, and combining all the basic elements required in the phase deliverables. The basic requirements of a typical civil engineering capital works project can be categorized under the following areas: scope (objectives), budget (costing), scheduling (program), land requirements, technical and safety requirements, and statutory (regulatory) and environmental requirements. These are considered standard categories of ‘‘what’’ in most capital works projects. Progressively further detailed derivatives would flow from these categories across the project planning phases. The typical ‘‘what’’ section with main category and subitems of the HOQ template is shown in Fig. 7. Development of the ‘‘how’’ section is the professional work of the phase supplier, while the basic purpose of QFD remains to assist the phase supplier to better meet the phase customer’s needs. There are no standard technical solutions to each item in the ‘‘what’’ section. Since the ‘‘how’’ responses (technical solutions) must be fully in line with the client’s basic business objectives of scope, cost, schedule, technical and safety, and regulatory compliance, it is possible to use the same categories in the ‘‘what’’ section as in the ‘‘how’’ section. Therefore the supplier could follow the main categories in the ‘‘what’’ section and generate technical solutions corresponding to each sub item in it.

The next step is to combine and evaluate a set of supplier generated responses (how) to a structured set of customer generated requirements (what) through the HOQ matrix. Fig. 7 represents a generic HOQ template constructed for use in the project planning process of a typical civil engineering capital project. The generic HOQ template presented here is not all-inclusive; each and every civil engineering project has its own uniqueness. The HOQ template must be adjusted to suit the needs of an individual project and may or may not reflect all project planning processes of individual organizations or companies.
(Ahmed, Sang and Torbica) [4] explores the applicability of QFD in civil engineering capital project planning. A QFD model is proposed that concentrates on the six basic project management areas.

Data from two projects of different type, scale, and nature are fed into the model for validity testing. Verification has given encouraging results, suggesting the validity of the QFD model. It is found that the use of QFD can enhance the project planning process in the following ways:
1. QFD serves as a road map for navigating the planning process and always keeping track of customer requirements and satisfaction. This actually helps eliminate human inefficiency;
2. The process of building a QFD matrix can be a good communication facilitator that helps break through the communication barriers between the client and the designer and among members of the design team;
3. QFD can be an excellent tool for evaluating project alternatives, balancing conflicting project requirements, and establishing measurable project performance targets; and
4. QFD can be used as a quick sensitivity test when project requirements change.

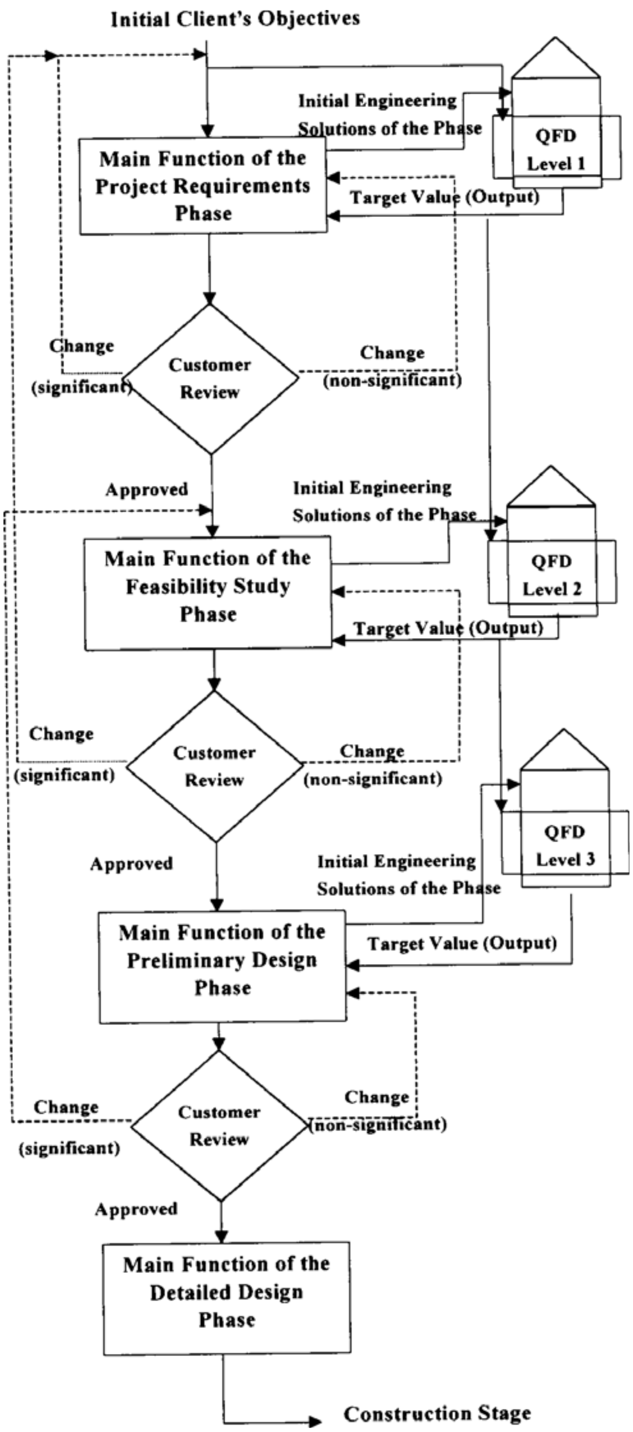

Fig. 6. QFD model of project planning process

To ensure the best utilization of QFD in the project planning process, the following points need to be taken into consideration:

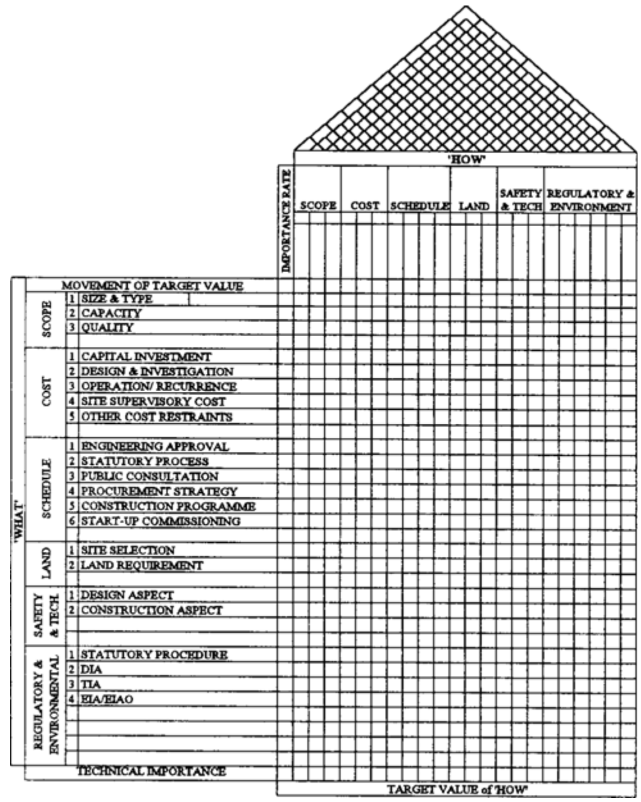

Fig. 7. Generic house of quality (HOQ) template

1. While there are many different ways to apply QFD, it must be applied as early as possible in the planning process, starting with the original customer's requirements. QFD has no magic to get a quick result, nor is it a remedial measure to save a project when its original customer's requirements are already sidetracked.
2. Empowerment from the client side is necessary. A client who is just there to provide the necessary funding and land for the project is not enough. To ensure success, a client must actively participate in the QFD process and work with the designers to provide policy directives, refine the project objectives, set project priorities, and make decisions when conflicts occur.
3. Total involvement of team members is necessary. All team members, who represent different fields, need to work to-gether to share the common goal of the project and make their valuable contributions supplement each other.

The HOQ for one of the two tested projects is shown in Fig. 8.

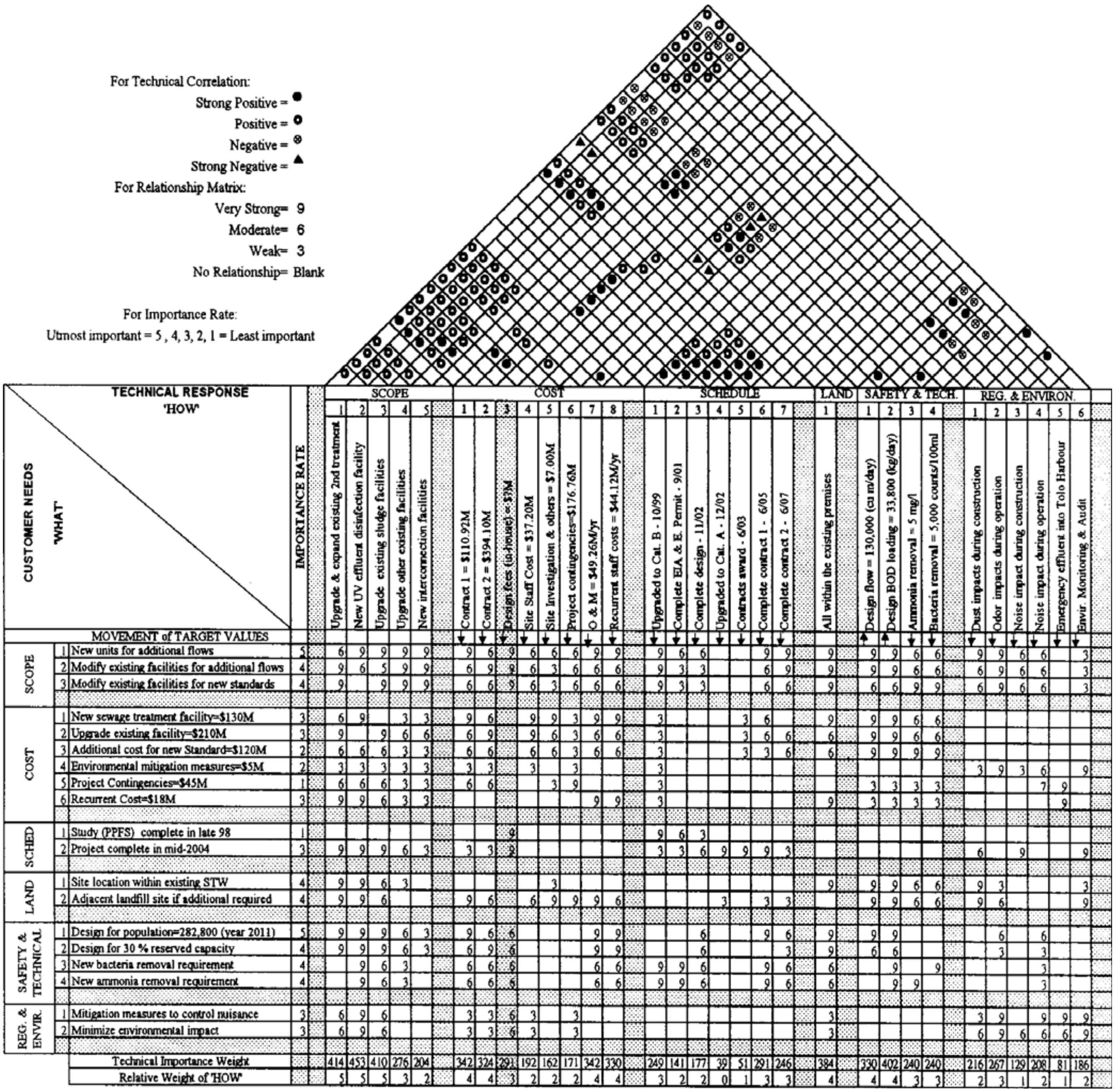

Fig. 8. House of quality (HOQ) level 2

2- Construction and implementation stage

In construction and implementation stage it is essential to implement TQM for controlling the process and reduce defects, rework, time, cost, and increase the quality of the product to meet the customer satisfaction.

2.1- Implementing SIX SIGMA in construction

(Pheng and Hui) [5] described the Six Sigma concept as a quality initiative that may be applied in the building industry.

Because Six Sigma is a relatively new concept for many organizations, relevant training is essential for those involved. This typically lasts

for 4 weeks and may spread over a few months. After each week of training, the Black Belts go back to the workplace and put into practice what they have just learned. The purpose is to allow trainees to practice what they have learned so that the learning curve sinks in better.
There are four core phases of training to match the four main points of the Six Sigma strategy: How to measure, analysis, improve, and control the processes that produce increased customer satisfaction, company savings, and a healthier bottom line. These four phases of training would include statistics, quantitative benchmarking, and design of experiments.

The case study of the Housing and Development Board (HDB) in Singapore is presented in this section to highlight its implementation processes The HDB is organized into three divisions, each consisting of several departments:
1. Building and Development Division (BDD): consisting of Departments of Architecture, Building & Project Management, Civil Engineering, Contract Administration, Electrical& Mechanical Engineering, Land Survey & Administration, and Structural Engineering;
2. Estates and Lands Division: consisting of Departments of Commercial Properties, Estates Administration & Property, Housing Administration, and Industrial Properties; and
3. Administration and Finance Division: consisting of Departments of Corporate Development, Finance, Information Services, Legal, and Research & Planning (Source:{www.hdb.gov.sg}).

The Deputy CEO of HDB's Building and Development Division (BDD) first came across the Six Sigma concept in late 1999 when several large financial institutions with local offices that have implemented Six Sigma shared their experiences with him. Impressed by the benefits that Six Sigma could bring and being convinced that this quality initiative could bring the HDB to an even higher level of quality, he decided to implement Six Sigma within the BDD.
A taskforce headed by the Divisional Six Sigma Coordinator, and assisted by nine members (called the Departmental Six Sigma Coordinators), was formed in early 2000 to look into implementing Six Sigma within the BDD. Members of the task force came from all the departments within the BDD as well as one representative each from the Estates and Lands Division and the Administration and Finance Division.
Following the appointment of the task-force members, the first most important thing to source for was training for the task force and senior management. The task force studied the training programs and course details provided by various Six Sigma trainers and consultants and drew up a brief Black Belt program before inviting quotations using its specifications. Black Belt training for the 10 members of the task force begun in April 2001. The 4-week training was spread over 4 months. The task force also worked on three pilot projects for a period of 6 months from September 2001 to February 2002. Upon completion of the pilot projects, a report was submitted to the Black Belt training consultants for evaluation. The Black Belt certification for the 10 members of the task force was issued in March 2002. The task force also trained a group of Green Belts (from June to July 2002) before embarking on the second round of projects.

An example of how Six Sigma may be applied for improving the quality of internal finishes for public housing projects is now described. As the major provider of public housing in Singapore, the HDB is keen to ensure that high quality standards are achieved for its completed flats. The Construction Quality Assessment System (CONQUAS), developed by Singapore's Building and Construction Authority (BCA) [formerly the Construction Industry Development Board (CIDB)], is the national yardstick for measuring the quality level achieved in completed buildings.
CONQUAS assessment consists of three components:

• Structural works (45%);
• Architectural works (50%); and
• Mechanical and electrical (M&E) works (5%).

A CONQUAS score of 100 points is theoretically possible for a perfect building. A building is assessed based on workmanship standards achieved through site inspection (CIDB 1998). [More information about CONQUAS can be found in BCA's website: (www.bca.gov.sg&)] HDB projects have been assessed, through CONQUAS, to determine the CONQUAS scores achieved by its contractors. Experience suggests that architectural works, being exposed, are likely to be a major source of complaints by HDB flat-dwellers. Unlike structural works and M&E works which are predominately concealed, Architectural works deal mainly with the finishes and components. This is also the part where the quality and standard of workmanship are most visible, thus giving rise to the possibility of more complaints by HDB flat-dwellers. 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. For this purpose, a defect grouping guide for assessing internal finishes, as part of the CONQUAS assessment system, was drawn up by the BCA as follows:

• Floors and walls: finishing, alignment & evenness, cracks &damages, hollowness, and jointing;
• Ceilings: finishing, alignment & evenness, cracks & damages, roughness, and jointing; and
• Doors, windows, and components: joints & gaps, alignment & evenness, materials & 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 CONQUAS specified standards, it is considered failed and a ''X'' will be 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. This can be achieved through CONQUAS scores relating to internal finishes of completed HDB flats. To do so, the CONQUAS scores relating to internal finishes of a past HDB project recently completed by Contractor A were reviewed. The CONQUAS score sheets of Contractor A relating to the recently completed project were then subject to Six Sigma analysis. An example of such a ''Six Sigma Data Collection Sheet for Internal Finishes (Stage A)'' is shown in Table(1) for one flat unit in the project recently completed by Contractor A.

As explained earlier, assessed items in CONQUAS are given a check (√) for meeting the specified standards in the data collection sheets and a cross (X) for not complying with the standards. The yield is then calculated as follows:

Yield(%)=(total No. of ''√'')/(total No. of ''√'' and ''X'')

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
Bedrooms	Wall 1	√	X	√	√	√	√	√	√	X	√	X	√	√	√	X	X	X	√	√	X	√	√	√	√	√	X	√	√	√	√
	Wall 2	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	X	√	√	√	√	√	√	√	√	√	√	√	√	√	√
	Wall 3						X	√	X	√	√																				
	Wall 4						√	√	√	√	√																				
Hall	Wall 1	√	√	√	√	X	√	√	√	X	X	√	√	X	√	√	√	√	√	√	√	√	√	√	√	√					
	Wall 2						√	√	√	√	√																				
	Wall 3						√	√	√	√	√																				
	Wall 4						√	√	√	√	√																				
Kitchen	Wall 1	X	√	√	√	√	X	X	X	√	√	√	√	√	√	√											√	√	√	√	√
	Wall 2	X	√	X	√	X																									
	Wall 3																														
	Wall 4																														
Toilets	Wall 1	√	√	√	√	X	√	√	√	X	√	√	√	√	√	X	√	√	√	√	√	√	√	√	√	X	X	√	√	√	√
	Wall 2	√	√	√	√	X	√	√	√	√	X	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
	Wall 3						√	√	√	X	X																√	√	√	√	√
	Wall 4						√	√	√	X	√																√	√	√	√	√
No. of Defects		8					13					4					4					1					2				
No. of Checks		35					65					30					25					25					35				
Total Number of Defects																											32				
Total Number of Checks/Opportunities for Defects																											215				

Table 1. Six Sigma Data Collection Sheet for Internal Finishes (Stage A)

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
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				

Table 2. Six Sigma Data Collection Sheet for Internal Finishes (Stage B)

The DPMO relating to the internal finishes of one flat unit recently completed by Contractor A was then calculated based on the data collected and presented in Table 1:

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

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

Based on the sigma conversion, the equivalent sigma for 148,837.21 DPMO was approximately 2.66σ.

Contractor A was encouraged to supervise its on-going building projects more closely to ensure that the level of workmanship for internal finishes complies with the quality standards specified in CONQUAS.

Over a period of 10 months, special attention was paid by Contractor A to ensure that its on-going building projects were closely supervised to meet the quality standards specified in CONQUAS for internal finishes. In addition, measures were taken to ensure that only skilled tradesmen were employed in the works. Contractor A also reviewed the quality track records of its trade subcontractors to ensure that only those with good past performance were employed. The same review was also made for the suppliers where products (such as doors, windows, and components) were used in the projects.

Following the completion of the on-going projects at the end of 10 months, the internal finishes were assessed for their CONQUAS points. This assessment exercise also provided the data for computing the sigma of completed works to ascertain if the improvement measures taken by Contractor A have indeed helped to raise the sigma to at least 3.8 σ. The ‘‘Six Sigma Data Collection Sheet for Internal Finishes (Stage B)’’ for one flat unit in the completed buildings is shown in Table 2. Based on the checks in Table 2

$$\text{DPMO} = \frac{2}{215 \times 1} \times 1{,}000{,}000 = 9{,}302.33$$

Based on the Sigma Conversion, the equivalent sigma for 9,302.33 DPMO is approximately 3.95σ.

This was higher than the 3.8σ set earlier for Contractor A to achieve.

The entire exercise showed that the initial sigma (2.66σ) was able to provide a warning sign that the quality standards of internal finishes achieved initially by Contractor A were found lacking. The higher sigma (3.95σ) achieved at the end of the 10-month period showed that the improvement measures taken by Contractor A were effective. If Contractor A continues to implement these improvement measures, it can expect to get the quality standards for internal finishes right more than 99% of the time.

Based on this finding, Contractor A was encouraged to work towards getting the quality standards for internal finishes right all the time, i.e., moving towards achieving 6σ.

Although Six Sigma is a relatively new quality initiative in the building industry, the lessons from the HDB’s case study are relevant for all other organizations, both large and small, in the building industry. The HDB is a large and sophisticated organization with processes and procedures that are likely to be more complex than many smaller organizations both in the private and public sectors. The training programs and selection criteria adopted by the HDB can, with appropriate modifications, be generalized for use by other design and/or construction firms. It is really up to these design and/or construction firms to review their needs in the light of the HDB’s experience, and formulate a plan of action for implementing Six Sigma to suit their own organizational needs. An example of how Six Sigma was applied to improve the quality of internal finishes was also presented where improvement measures taken by Contractor A have helped to raise the Sigma from 2.66σ to 3.95σ. The operational principles that can be derived from this example can equally be applied by other design and/or construction firms.

2.2- Case study

In this case study the construction of a 22-km2 reclamation area in new Doha international airport (NDIA) (adopted from (Terra et Aqua-No. 103-June 2006)

The New Doha International Airport (NDIA) in the State of Qatar will have two parallel runways, 80 terminal gates and a capacity for handling 50 million passengers and 2 million tonnes of cargo per year. It is the first airport to be specifically designed for the use of the new Airbus 380-800 Super Jumbo. The first phase of the NDIA is scheduled for completion in 2008 at a cost of $2.5 billion.

The airport is expected to be completed in its entirety between 2015 and 2022 at a total cost of $5.5 billion.

As part of the first phase, some 22 km2 of land must be prepared – half of which is reclaimed from the sea – with 60 million m3 of sand and rock fill. The reclamation should be completed within 24 months, resulting in required productions of approximately 3 million m3 per month. The € 337 million platform reclamation contract was awarded to a consortium of four partners: Qatar Dredging Company, Dredging International, Boskalis Westminster Middle East and Great Lakes Dredge and Dock Company.

2.2.1 Compaction works for the NDIA project

Part of the reclamation work (Figure 9) is the compaction of the fill material to an in-situ dry density as a percentage of the maximum dry density (MDD). Guidelines of the US Federal Aviation Administration (the FAA) have been followed to draw up the compaction requirements.

In order to achieve the required degree of compaction, a combination of three techniques is used in the following order:

1. Hydraulic Compaction: During the deposition of the hydraulic fill, the material is compacted by drag forces of the discharge water by the weight of bulldozers driving up and down in front of the pipeline (Figure 10);
2. High Energy Impact Compaction (HEIC): This novel compaction technique is discussed in more detail in the next paragraph of this article;
3. Conventional Vibratory Roller.

Fig. 9. Dredgers at work in front of the reclamation area.

Fig. 10. Initial compaction with bulldozers in front of the discharge pipe.

2.2.2 Why new compaction techniques? Why a SIX SIGMA management system?

One of the primary reasons was that the contract had an extremely short schedule, requiring over 65 million m3 of fill to be placed in less than 24 months, with many important early milestone handover dates.
In addition, different areas of the fill had varying, but very strict, compaction criteria and specific density requirements that were difficult to meet given the nature of the material sourced from the available borrow areas. The sand was coarse and calcareous, often shelly and thus extremely crushable. Heavy dynamic compaction techniques were unusable since they would have converted the material into an unsuitable powder.

After many compaction trials using several different methods, an optimum technique was found. The required results could be achieved in the short treatment time allowed using multiple passes of an asymmetric (almost square) roller manufactured by the Australian company Broons. The system proved to be extremely efficient as the tractors pulling the rollers could operate two to three times faster than vibrating rollers used for road construction.

The reclamation fill had many variables: quality, gradation, water content and layer thickness, each condition requiring a varying number of passes by the rollers.
In order to attain a uniform compaction in a non-uniform environment on an extremely congested site, a high level of quality control was needed.
To help meet these challenges the consortium decided to adopt Six Sigma Management system.

The consortium Qatar Dredging – Dredging International – Boskalis Westminister and Great Lakes Dredge & Dock applied the management program to a new and very specified field of large-scale compaction. The exercise proved very successful under the careful supervision of a super "Six Sigma" specialist, a so-called "black-belt" inspector from Bechtel.
The technical article adjoining describes in more detail how the two new techniques were introduced on site:
– Firstly the new compaction system,
– followed immediately by a new management and "follow-up" system

2.2.2.1 High energy impact compaction (HEIC)

The High Energy Impact Compaction mechanism is compared with traditional compaction rollers in Figure 11.
The Non-circular compactor module is towed along the ground by a tractor. In every rotation, the module rises up on its contact point with ground and drops to create an impact energy, which provides the compaction. The impact compaction mechanism enables the compaction energy to reach deeper levels than can be reached by static or vibratory compaction methods.
For the NDIA project, the HEIC process is carried out using nine impact rollers produced by Broons Hire (SA) Pty Ltd.
Six of these impact rollers are equipped with 8 tonnes weight modules and the other three have 12 tonne weight modules (Figure 12).

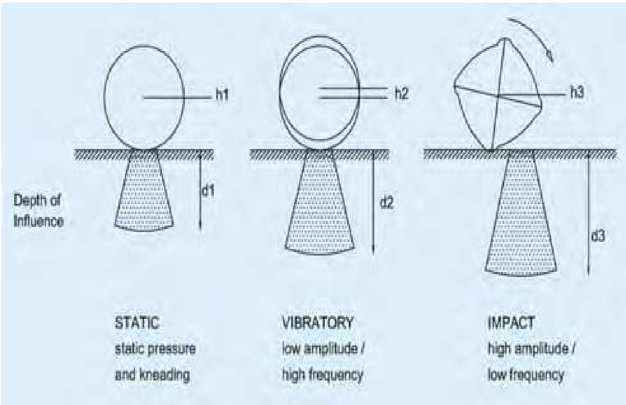

Figure 11. Mechanisms of static, vibratory and impact compaction.

Figure 12. HEIC compactors on the NDIA project

Impact rollers are driven in fixed patterns and reverse their direction from clockwise to counter-clockwise after every ten passes.
This provides a more uniform distribution of the impact energy to the ground and to achieve a better coverage of the compaction area.
The speed of impact rollers should be 10-12 kph, which is the optimum speed for this type of compactors.
Occasional heterogeneity of sand, variability of geo-environmental factors, operator faults, and difficulty in maintaining optimum moisture content adversely affect compaction quality resulting in failures of the compliance tests.
In order to make optimal use of this compaction method and attain a level of control to achieve the specified degree of compaction, the compaction progress was analyzed using the Six Sigma management system. The main target of the campaign was to achieve a dry density of minimally 95% of the maximum dry density above mean sea level.

2.2.2.2 The SIX SIGMA approach

The concept of Six Sigma is that of a data driven process management and improvement process. It takes the process under control by decreasing the variability of the input parameters and thereby enabling the process team to control the outcome parameters (i.e. time, quality and cost).

The goal of the Six Sigma implementation in NDIA compaction process is to increase the compaction quality and to eliminate the results which remain below the minimum requirement for compaction density (in-situ density of 95% maximum dry density).
The Six Sigma Campaign on the compaction at the NDIA project started in August 2005.
The Six Sigma team at NDIA was built upon the synergy existing between the Compaction and the Geotechnical Departments. A training course for the Six Sigma methodology was provided by Overseas Bechtel Inc. (OBI).
NDIA compaction Six Sigma campaign can be perceived at three levels:

1. Metric: The target is to achieve the contractual requirement for the compaction quality: in-situ density of 95% maximum dry density.
2. Methodology: DMAIC
3. Philosophy: Identify the most important input parameters for the compaction process, measure them, analyze and reduce the variation of the input parameters and take customer-focused, data driven decisions.

2.2.3 Implementing SIX SIGMA

The heart of the Six Sigma implementation of the compaction process at the NDIA site is a five-phase improvement cycle called DMAIC flow chart: Define, Measure, Analyze, Improve and Control.
The DMAIC is used as a guideline to ensure that relevant data is collected, analyzed, and converted into information. In order to convert data into information other tools are utilized. The tools used in the framework of the Six Sigma implementation for the compaction process are as follows:

– Compaction Process Map (or flow chart) to identify potential causes;
– Cause & Effect diagram to generate a list of root causes;
– Prioritisation matrix of the most important root causes.

2.2.3.1 The compaction process map

In Figure 13, the NDIA Compaction Process Map is presented. The compaction process has been subdivided into the following critical stages:

– Initial compaction or hydraulic compaction;
– High Energy Impact Compaction (HEIC);
– Watering to optimal moisture content (OMC);
– HEIC compaction;
– Assessment by means of geotechnical testing.

Quality Control (QC) has been included in each of the stages. The QC jobs are executed by quality controllers who are based in the field and stay in direct contact with the foremen of the respective operations to take immediate action where needed.

The compaction process as a whole involves the collaboration of three different departments, namely reclamation, compaction, and geotechnical department.

The clear mapping of the process has created clarity to all the parties involved.

2.2.3.2 The cause-effect diagram of the compaction process

The Cause-Effect diagram of the NDIA Compaction Process, depicted in Figure 14 has been drawn up in four steps:

– Step 1 – List the problem in the ‘effect’ box: Not meeting the compaction requirements as defined in the contract;
– Step 2 – Identify main categories for causes of a problem: Manpower, Machines, Materials, Methods, Measurements & Geo-environment;
– Step 3 – Systematic fact-finding & group discussion: During brain-storming sessions anything that may result in the effect of not meeting the contract requirements is put down as a potential cause;
– Step 4 – Record all potential causes under the relevant category: After recording and categorization of the all the causes, each item, e.g. roller pattern, is discussed to combine and clarify the causes. Eventually, the diagram gives an overview of all the “root causes” that could have an effect on the compaction.

Not all of these root causes have the same impact, and the most important root causes are selected to build up a prioritization matrix that is discussed in the following section. After thorough investigation, the following root causes were found necessary to prioritize in the compaction process:

– Category Manpower:
    * Optimal driving speed;
– Category Machines:
    * Impact rate;
– Category Methods:
    * Roller track width;
    * Timing of added water.

2.2.3.3 The prioritization matrix

The prioritized root causes become so-called “upstream process indicators” (often denoted by the symbol Xs). Controllable/ measurable systems have to be developed and put in place along with the definition of optimum values. The controllable parameters of the compaction process, roller speed, impact rate, roller track width and the timing for the water spraying are the key upstream process indicators.

The optimum values and specification ranges for these parameters are given in Table 3.

For the compaction process at the NDIA project, quality controllers have been appointed to continuously measure the upstream process indicators:

– Roller speed, – Impact rate,
– Roller track width,
– Timing for water spraying.

The measurements method applied on the compaction process are conceptually explained in Figure 15. As indicated in the Compaction Process Map (Figure 13), the quality controllers reported directly to the respective foremen when readings outside the specification range were measured.

The data is statistically analyzed on a daily and weekly basis, following the DMAIC improvement cycle.

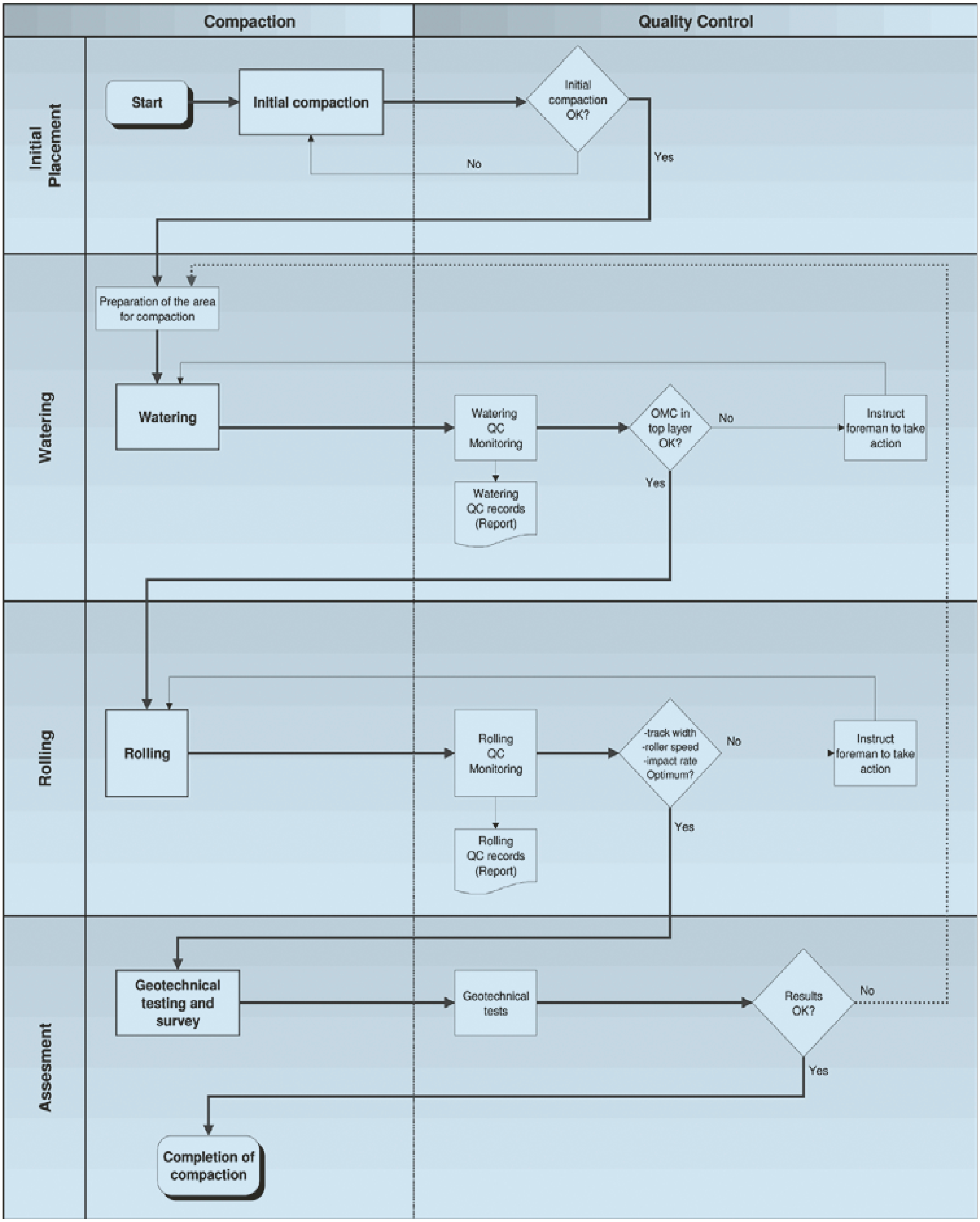

Figure 13. Map of NDIA compaction process.

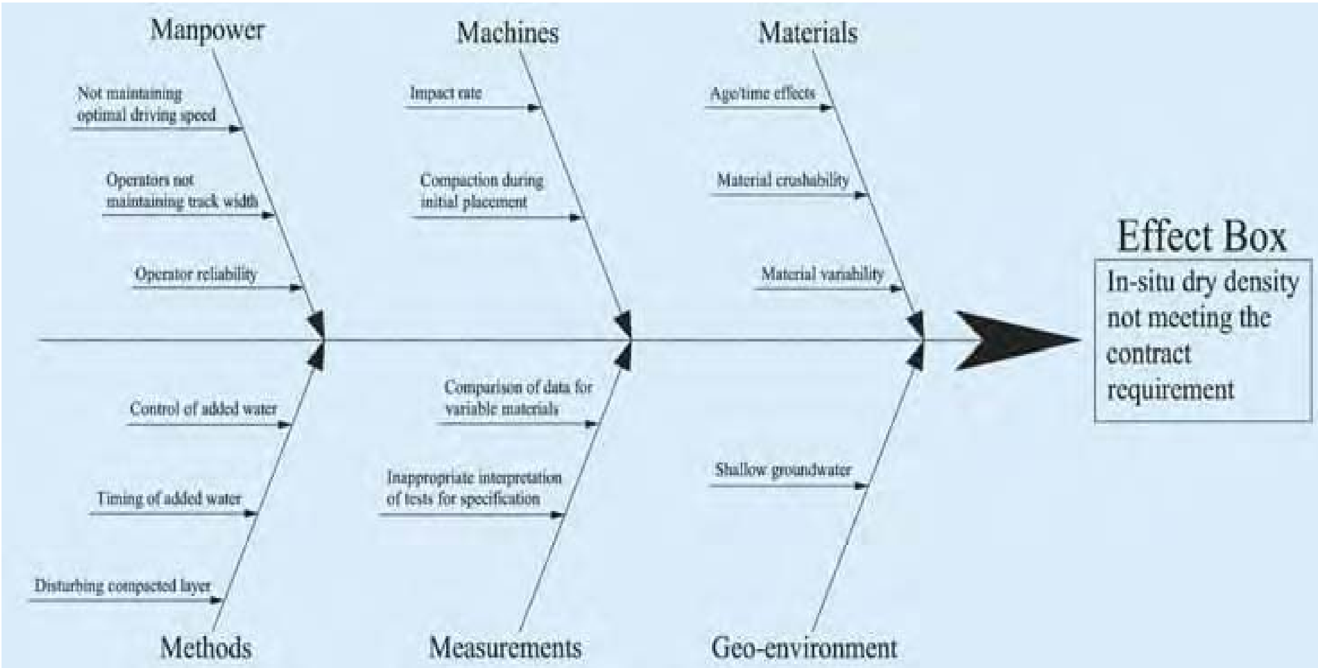

Figure 14. NDIA Compaction Cause-Effect diagram.

Upstream process indicators (X_s)	**Optimum Value**	**Specification range**
Roller speed	11 kph	10-12 kph
Impact rate	2 impacts/sec	1.8 – 2.2 impacts/sec
Roller track width	2.6 m/track	2.4-2.8 m/track
Timing of water	20 min/watering session	15-25 min/watering session

Table 3. Optimum values of process indicators Xs

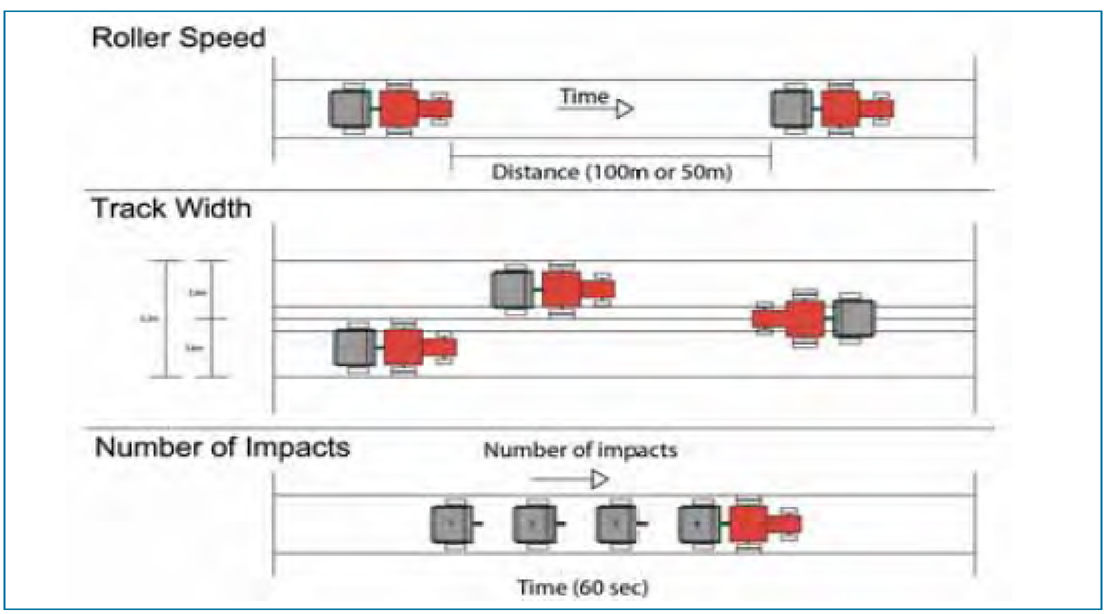

Figure 15. Upstream process indicators measurement methods.

2.2.4Compaction process improvement after implementation of SIX SIGMA

To illustrate the improvement that has been achieved by the implementation of Six Sigma on the compaction process, in-situ dry density data of two compaction areas are presented here:

– HEIC Test Area: Six Sigma quality control was not applied (as denoted by “Before”);

– Area B: This is the area where the quality controllers have been appointed during the Six Sigma campaign to monitor the compaction process for 24 hours/day (as denoted by“After”).

The in-situ dry density is the bottom line “effect” of the Cause-Effect diagram, as given in Figure 14. Since, it is also a contractual requirement, it is the best variable to illustrate the influence of Six Sigma on the compaction process. It is noted that here, the in-situ dry density is expressed as a percentage of the maximum dry density (% MDD).

In order to show what the variation of the in-situ dry density under uncontrolled (HEIC Test Area) and Six Sigma controlled conditions (Area B) is, a control chart is employed. Such a control chart is in fact two charts in one:

– Chart 1 is used to control the sample average or mean X;

– Chart 2 is used to control the variation within the sample by measuring the range R.

The control chart for the in-situ dry density measurements for both areas (HEIC Test Area and Area B) is plotted in Figure 16. In the chart, changes in the mean in-situ dry density, denoted by X, are given.

The observations to the left of the vertical dashed line are the observations done in the uncontrolled HEIC Test Area, while the observations to the right are done in the Six Sigma controlled Area B. The mean in-situ dry density for the HEIC Test Area shows a drift, while for the controlled Area B a much more stable and higher average is observed. In the lower chart, the range R of each sample is plotted –calculated as the difference between successive values. For the HEIC Test Area it is clear that the variability of the process is changing significantly, even around observations where the process average remains rather constant. For the Six Sigma controlled observations (Area B) the variability is much more limited.

Figure 17 shows the output of the statistical analysis of the data of the HEIC Test Area and Area B. The mean in-situ dry density went up from 99% MDD to 107% MDD after applying Six Sigma, and the variance went down from 83 to 36.

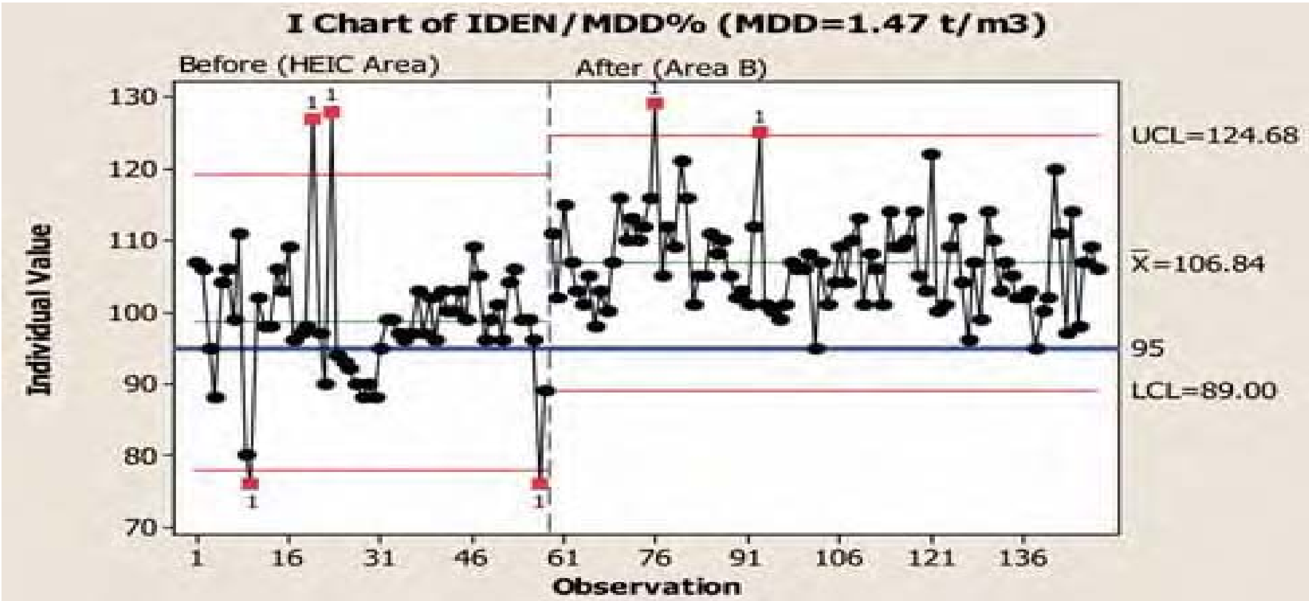

Figure 16. Control chart – In-situ dry density HEIC Test Area and Area B.

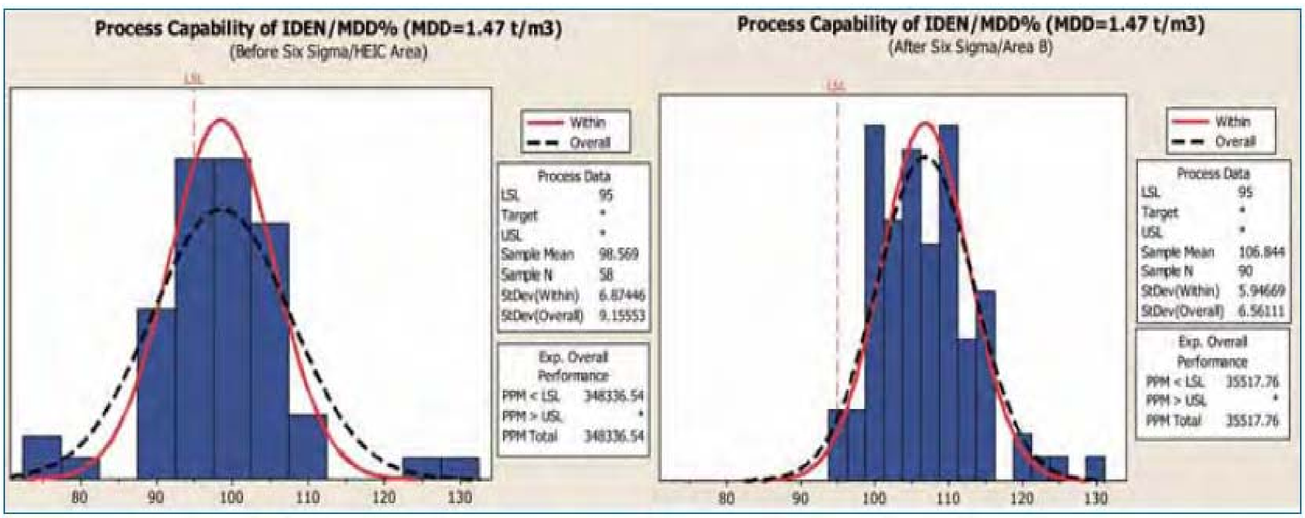

Figure 17. Statistical comparison – In-situ dry density HEIC Test Area and Area B.

2.2.5 Results achieved after implementation of SIX SIGMA

A direct result of the Six Sigma campaign on compaction was that the average in-situ dry density increased by 8% (from 99% MDD to 107% MDD), and the variance decreased with 56% (from 83 to 36).

Roller speed and track width have been identified as the most important upstream process indicators, having a direct in influence on the in-situ dry density. Six Sigma has allowed for a good control of these variables and helps ensuring that the contractual requirements are met (Figure 18).

Six Sigma is much more than just a number crunching exercise. The visual and measurable outputs of Six Sigma allowed all the team members, from workers to management, to have a clear understanding of the processes involved, and their importance and contribution in delivering a solid fill, compacted within the contract specifications.

Figure 18. An aerial overview of the New Doha International Airport site. High Energy Impact Compaction with rollers was checked by the Six Sigma quality management system.

Conclusions

This paper pointed out how construction professionals implement TQM and its tools in their projects in the different stages (design and construction).

From the results and conclusions from each case study included in this paper, it's clearly now that TQM is not a fad and how much benefits that TQM can bring to your construction business (Improve business quality, increase customer satisfaction, reduce cost, save time and much more).

The reason that the construction industry has arrived late to TQM is that the construction professionals unaware of the TQM principles and techniques.

To bring these benefits to the construction industry, more efforts must be made to spread the culture of TQM among the construction professionals and TQM courses must be in the engineering under graduated programs.

References

[1] Total Quality Management: A Continuous Improvement Process; 1996 PHCC Educational Foundation.

[2] Yang Y.Q, Wang S.Q, Low S.PH. and GOH B.H. "Adaptations of QFD for constructable designs within a concurrent construction environment: An information modeling approach”

[3] Eldin N. and Hikle V. “Pilot Study of Quality Function Deployment in Construction Projects” Journal of construction engineering and management/ May/June 2003

[4] Ahmed S.M, Sang L.P and Torbica Z.M. “Use of Quality Function Deployment in Civil Engineering Capital Project Planning” Journal of construction engineering and management/ July/August 2003

[5] Pheng L.S and Hui M.S “Implementing and Applying Six Sigma in Construction” Journal of construction engineering and management/ July/August 2004

[6] Avsar S, Bakker M, Bartholomeeusen G. and Vanmechelen J. “Six Sigma quality improvement of compaction at NDIA project” Terra et Aqua / No. 103 / June 2006