The application of six sigma - supported expert system in construction projects

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Abstract: Certain methods and techniques are usually applied in the construction industry to ensure a level of quality necessary to make a project proportionally capable of meeting the terms and requirements set in its contract. The research was conducted on Al-Rumaitha residential project where lack of quality was detected in a number of concrete samples. Actually low-quality samples picked up indicated that low-quality concrete was casted onto the third-story roofs of buildings A25 and A26 and second-story roofs buildings A27 – A 33. The same holds true to the samples taken from the upper roofs of the buildings A15, A16 and A19. This is a research that aims at improving the quality of the concrete used in construction projects while reducing, to the extent possible, any deviations from the quality targeted. To achieve that goal, the process capability was checked via the application of the components of the Six Sigma approach, namely: the define measure, analyze, improve, control (DMAIC). Additionally, dispersions, whenever found, were also taken into considerations with the aim being to improve each stage of the project separately. Moreover, an expert-system program was devised to facilitate the application of first, second and third elements of the (DMAIC) (i.e. the definition, measurement and analysis) while leaving the fourth element (improvement) to suggestions on what changes to be made to enhance the quality to the targeted level. Finally, accomplishing the fifth element (control) was to be done by reviewing and controlling the improvements attained through the preceding stages so as to maintain the level of Sigma accomplished. Besides its ability to achieve accurate results necessary to reach the targeted quality level, the application of the Six Sigma approach also enriches the overall process since the data collected by the tests would be part of the database to be used to feed the expert-system program, hence improving the quality of the project. As a conclusion, the research shows that applying the Six Sigma index to construction projects helps in improving the quality of the concrete consistently while maintaining the costs within specific ranges. This makes Six Sigma an appropriate approach to be adopted whenever improving the quality desired would not affect the costs, which is contrary to raising the quality of the concrete to the highest level possible, where Six Sigma appears to be inappropriate and where CPk index proves to be the best suitable alternative.

1. Introduction
Quality, is accordingly, considered a prime target in any project, as well as a critical indicator to the success of failure of that project. Moreover, the need to control the level of quality from the very
beginning is utterly significant whenever constructional projects are concerned. This is true simply because of the fact that once a project is finished it is impossible to make improvements on its quality, contrary to software projects for instance, where the possibility of changing the forms of the activities involved in the makeup of the software after their completion is high.

The current research derives its significance from its ability to detect the quality level of a given project as soon as possible while yielding accurate results that make it possible to uncover the key problems or defects leading to the decrease in quality, and thus identifying the main causes of the issues arising and planning an improvement mechanism consequently. Actually, enhancing the quality of a project is extremely important to the extent that is could not be overcome especially that the results aimed to be reached in constructional projects extend to long periods exceeding that of a 50-year milestone. Consequently, the significance of the current research could be summarized as follows:

- By delivering a high-quality project, the company is able to achieve a competitive advantage (over its rivals), which in turn leads to the continuation of works to be executed by that company. Likewise, the quality achieved maintains the partnerships between vertically connected companies and constructional companies, which in turn results in a flourishing national economy.
- Providing a practical approach on how to apply the Six Sigma as a scientific method in enhancing the quality involved in constructional projects, which is a procedure to be adapted by the resident engineer office so that to monitor and follow up on the works through an expert-system program.
- Enhancing the performance of the project's management team in executing residential projects based on a calculated (computerized) system that shows the requirements of executing the project within the required specifications.

2. The Concept of Constructional Industries

The construction industry is responsible for planning, designing, constructing, maintaining and final demolishing buildings and works that enable carrying out economic and social activities. In essence, it is an industry of a bunch of services that collect revenues from different correlating economic sectors which are already complicatedly connected within [1].

Therefore, the construction sector is a vital one that significantly contributes to the economies of all nations. Now, for the construction industry to be able to adapt to the changes the world is continuously facing as well as to the social, economic and technological challenges impacting all kinds of industries, it has to be dynamic enough in the first place [2].

Thus, the construction industry is, in fact, a key factor in the socially and politically integrated fabric of society, hence it is classified as being one of the major streams feeding the national budget. In fact, it has been proven that the constructional industry is the cornerstone as well as the main model in the rapidly growing economy of any country. Its products are seriously needed in services that it aids in creating since the majority of commercial, social, religious, economic and industrial activities contribute to the building up of the infrastructure [3].

3. Factors of Success in Construction Projects

Success and failure of any project are based on a number of common points that allow us to identify a bunch of general factors that apparently diminish the chance of a project failing to achieve its desired objectives. Following are factors highly significant in causing a project to meet success [4]:

- Clearly defined objectives: Including the general philosophy of the project or its overall goal or mission, and the adherence to those objectives by project team members.
- The competent project manager: A skilled project leader who has the required skills, personally, technically and administratively.
- The support provided by the senior management: the commitment of senior management to support the project that has been communicated to all parties concerned.
- Competent Project Team Members: Selecting and training competent team members who have the necessary expertise (skills and knowledge) to support the project.
• Allocation of adequate resources: resources that come in the form of money, personnel, logistics, etc., while must be adequately available to the project.
• Adequate channels of communications: sufficient information should be available on the project objectives, its status, changes, regulatory conditions and requirements of customers in a timely manner.
• Mechanisms of control: enough mechanisms should be available to monitor the actual events and to identify deviations from the project's plan.
• Ability to make observations: this means that all parties involved in the project should be enabled to review its status as well as to provide suggestions and corrections when needed.
• Customer Response: All users of the project are to be concerned with its current status, which is a point that requires advanced options over time.
• Troubleshooting mechanisms: this means the existence of a system or a set of procedures that can address problems as they show up, pinpointing the root causes of those problems and suggesting resolutions.
• The continuous involvement of project employees in it: this means the continuous participation of key staff members in the project throughout their lifetime. The recurrence of staff recycling, on the other hand, can lead to a lack of accumulated knowledge of the concerned team.

4. Managing the Quality of a Project and Supervising it
The control and monitoring process is to include all the tasks and scales or parameters required to ensure that the approved and adopted project lies within the scope and timescale associated with the budget allocated so that the project carries on with the minimum amount of risks [5].
It is quite possible that good control management is one of the fields of knowledge that is unfairly dealt with by the manager and team members of a project. Thus a good quality control program is to have the three following points [6]:
• Quality planning process.
• Quality guarantee process.
• Quality monitoring process.
Planning for quality is considered part of the main planning process. Initial estimations of scope and budget, as well as those of the relevant timescale or schedules, are used to determine the processes or the services or the products that need a specific degree of quality provided. Furthermore, a risk analysis is applied to determine which of the risks the project is facing might affect quality [7].

5. The use of Six Sigma to improve project quality
This could be described as the process of producing a unique product, regardless of its size (magnitude) or cost or whether being tangible or intangible. This way the project would have inputs and activities or a set of activities and outputs or a set of outputs that entail a set of delivery events.
All projects in general and constructional projects, in particular, are usually executed by specialized companies. The widespread knowledge that has become possible through the development of the many tools of communications has enabled the beneficiary or the user of the project to compare the outputs of the competing companies. Consequently, it has become a must for the construction companies to find methods and procedures for developing constructional projects.
Six Sigma is implied in constructional projects through the use of DMAIC method. It is an approach that is applied in case of a need for an improvement which in turn is related to the requirements set by the customer, who is not merely the final user (of the product of service), since customers in such cases could come from within. This is true if we consider that a number of deliveries might occur along with the milestones of a given project and which require a certain degree of quality. Likewise, the individuals involved in the project could express their opinions about any of its parts in order to carry out the desired improvement.
The quality aimed at in constructional project is usually technical in nature and is represented in the form of the relevant materials used and works involved that occur repetitively. It is upon such works
that the Six Sigma statistics could be applied. Accordingly, the Six Sigma has been chosen as a technique aimed at improving the quality of constructional projects.

6. The Six Sigma Concept
The Sigma level is defined as being the number of standard deviations occurring between the mean (average) operation or process and the limits set according to the customer specifications. With the increase in Sigma level comes more outputs, products and services that meet the requirements of the customers, which in turn leads to a reduction in defects. The actual Six Sigma covers 99.9997% of defect-free tests – which is near perfection [8].

According to the researcher, Six Sigma is a philosophy that was developed as a result of the tough competition in (achieving and maintaining) quality and the attempt to reach zero-defect outputs. Subsequently, a specialized team was developed to achieve the results behind this philosophy, in addition to the five-stage methodology known as DMAIC.

7. Objectives of Applying Six Sigma
The objective behind applying the Six Sigma is to aid the processes designed to achieve big tasks and the individuals working on them by providing defect-free products and services. The idea of having a zero-defect outcome does not work here as the Six Sigma company believes that there will always be some possible defects even in the case of Best run processes or with the best products. Still, at a performance of 99.9997%, Six Sigma identifies a target of performance where defects in many processes and products almost do not exist [9].

Accordingly, it is not a surprise that Six Sigma puts the customer first as its main focus, employing facts and data for the best solutions so that to win the satisfaction of the customers. Also, by doing so, more profits are achieved. Consequently, there are three main domains or areas targeted by Six Sigma [10]:
- Improving the customer’s satisfaction.
- Reducing the time cycle involved.
- Minimizing defects.

8. Elements of Six Sigma
The Six Sigma methodology represents a development in the mentality of (achieving and maintaining) quality which has massively grown over years and which is also an ongoing process. However, it is possible to summarize the main elements of Six Sigma as follows [11]:
- Focusing on the strategic direction of the organization.
- The value of the customer comes at the core of this approach.
- It is a carefully organized approach aiming at understanding the requirements of the customer and reducing wastes and deviations.
- Managing according to facts.
- Establishing a strong structure of support.
- Creating clear connections for the benefit of works and businesses.

9. Stages of Applying the Six Sigma (DMAIC)
There are lots of information about the DMAIC methodology (define, measure, analyze, improve, control), and DMAIC is more used on current processes. It is an approach that does not use different technologies only, but rather includes other concepts like financial analysis and developing the program of the project.

The DMAIC approach is considered excellent when dealing with an ongoing process where reaching a certain level of performance leads to expected benefits [12].

There are five main stages in applying the Six Sigma methodology aimed at improving the performance of a process. They are: define, measure, analyze, improve, and control, hence is the acronym (DMAIC), which in turn encompasses a circle of improvements embedded in the original plan of: Plan, Do, Check, Act (PDCA). The DMAIC in the Six Sigma approach provides a
breakthrough strategy of disciplined ways to be used to collect specific data and then to make statistics-driven analyses aimed at identifying sources of defects and the ways to eliminate them. It has become quite common within the so-called Six Sigma organization that more and more people are referring to the DMAIC projects [13].

10. Process Capability and the Six Sigma
The quality in any transformational process should be the responsibility of those running that process. However, in order for those people to carry out their task, they should be provided with the necessary tools [13]:

- Determining whether the process is capable of meeting the requirements or not.
- Checking if the process is capable of meeting those requirements at any given time.
- Carrying out proper corrections on the process or on its inputs in case they do not meet the requirements.

To apply the statistics to Six Sigma, we will be introduced to a number of concepts as follows:

Group 1: Monitoring the capability of the production process through the use of control panels.
The production capability has been defined as being the parameter of the variables accompanying the production process. It is also the capability of the production process that conforms to the statistical measurements and which is able to achieve quality within a limited set of requirements. Thus, it is quite obvious that the capability of a production process is a parameter related to the precision implied in the manufacturing process. This capability is represented by the qualitative performance potential of the machine involved and its ability to meet the requirements set by the design. It is a must, in respect, to note that the capability of a machine to perform qualitatively is affected by a number of factors and conditions on top of which the following [14]:

- The nature (quality) of the raw materials used in the production process.
- The workers’ workmanship involved in the production process.
- Tools of measurements and the dexterity of those in charge of carrying them out.

The panels most commonly used in determining the capability of the production process and in monitoring it are the average panel, the scope, and the steps needed to make up the picture [15]:

Measurements of the characteristic, of which the capability of the production process to achieve is to be tested, are taken through the use of a high-precision measuring tool, with the number of samples taken aren’t less than (10) samples of (5) items each.

The mean average and the mean range for all samples are to be calculated according to the two formulas below:

\[
\bar{X} = \frac{\sum_{i=1}^{n} X_i}{m} \quad (1)
\]

\[
\bar{R} = \frac{\sum_{i=1}^{m} R_i}{m} \quad (2)
\]

The center line and the panel controlling limits of the mean are calculated according to the following formulas:

\[
\text{UCL} \bar{X} = \bar{X} + A_2 \bar{R} \quad (3)
\]

\[
\text{LCL} \bar{X} = \bar{X} - A_2 \bar{R} \quad (4)
\]

The value of the coefficient \(A_2\) depends upon the sizes of the selected samples and is to be calculated by use of the table

- The control panel of the mean is drawn in a way that the X-axis represents the samples arranged in the order of their selections, and the Y-axis the \(\bar{X}\) value in the mean panel, with each panel having three lines: the central line, and the controlling upper and lower limits.
If it is shown that the production process is centered, then its capability is calculated from the following formula:

$$\bar{R} = \overline{\bar{d}}$$  \hspace{1cm} (5)

The percent of the production capability index, which depends on the total variation (T) calculated from the upper limit (U) and the lower limit (L) of the specifications, which, in turn, were deducted by adding and subtracting the variation value of the original dimension divided by the production process capability as is shown in the following formula:

$$C_p = \frac{T}{6\bar{d}} = \frac{U-L}{6\bar{d}}$$  \hspace{1cm} (6)

Whereas the process capability direction is calculated by applying the process capability index $C_{pk}$ formula and is consisted of either of two directions depending on the dispersion of the process. When the dispersion gets closer to the lower limit i.e. when the value of $C_{pkL}$ is greater than that of the $C_{pkU}$, or the contrary that occurs when the dispersion gets closer to the upper limit. The value of $C_{pk}$ can be calculated from the following equation:

$$C_{pk} = \min\left\{\frac{U-SL-X}{3\bar{d}}, \frac{X-LSL}{3\bar{d}}\right\}$$  \hspace{1cm} (7)

Where X represents the median average or the center line of the statistical control panel.

Also, it is possible to calculate the level of Sigma through:

$$3*C_p = \text{Level of Sigma}$$  \hspace{1cm} (8)

11. Running the Expert System to Improve the Quality of the Project
The system that was applied at the location had the DMAIC approach embedded into the structure of the relevant computer program so that to facilitate the application process and gain precise results. Thus the application of DMAIC would be programmed with the inclusion of the first three steps or stages. As to the fourth one, it would be implemented by determining the most important points that must be followed in order to execute the improvement desired. The fifth stage is carried out by reviewing the developments achieved from previous stages.

12. Sample information
After reviewing the samples collected by the Housing Directorate from the Al-Rumaitha residential project, it was discovered that some of the low quality samples were taken collectively from casting the third roofs of the buildings A25 and A26 and the second roofs of the buildings A27 – A33. The same held true to the samples taken from the upper roofs of the buildings A15, A16 and A19. The samples to which the detecting (i.e. quality checking) system would be applied as shown below.

13. Running (Operating) the System
Window (1) appears after starting the system which shows its interface. After clicking the "start" button, the user is then driven to the window shown in figure 2, which is the "log in" window.

![Figure 1. The main interface of the system](image1)

![Figure 2. The log in window](image2)
The "log in" window has two dialogue boxes. The upper one showing the "user name" while the lower the "password". After entering the name and the password, we click "log in", to be taken to the window displayed in figure 3 which is regarded as the system's main window. The window contains three buttons: the "Add Project", the "Add material check" and the "Next" button. We choose "Add Project" which feeds the info into the database as is shown in figure 4 that displays the dialogue boxes that enrich the system with data.

After that we click "add" then "Back" so the main window is shown as in figure 3. Following we choose the "add material check" and upon clicking on that button we are taken to the window displayed in figure 5. This window includes dialogue boxes related to the material required to be tested or checked. It covers the name of the material to be checked, the type of the test to be applied to the material and the limits of the technical specifications, the unit of measurement, the number of samples involved and the number of the items (observations) derived from modeling the test.

We feed the window with the information of the concrete used at Al-Rumaitha project then we click add. It is noticed that the least compression to be applied to the concrete sample was 22 N/mm², while the highest possible compression force was 28 N/mm². It is worth mentioning that the more compression to be applied the better the quality to be regarded by the customer provided that no additional costs are added. The contrary holds true from the contractor point of view, for the less costly the concrete is the better, provided that the compression force limit remains in line with the agreed upon specifications.

Following we click the "back" button to be taken to the main window displayed in figure 3. Then upon clicking "Next" we get the window shown in figure 6. This window includes information about the projects and material checks carried out previously and which are desired to be tested by the program as we would have to choose the number of the project and that of the material to be tested. The panel also includes the "All" button which means displaying all the inputs stored in the database and which is located in tow spots. The button to the right displays all the inputs relevant to the ongoing test. The button on the left side is related to choosing the project to which the test is to be applied. The third selection button is as shown in the window is designed in a distinctive way since it is considered the biggest in size within the same window and is responsible for executing the overall test of the material and the project as well as moving to the next window in the system, the DMAIC window.
After clicking the "select" button that shows on the side, the DMAIC window is displayed as is shown in figure 7. The DMAIC window has three buttons representing the defining stage, the measurement stage and the analysis stage.

Figure 6. Selecting project and testing materials  
Figure 7. DMAIC window

From the three options the window includes, we choose the first upper "define stage" as being the first stage in the DMAIC to be taken to the window shown in figure 8 which is related to identifying the defect and is the window through which inputs data are fed into the system and which is designed to have the defects and the frequencies (occurrences) sorted. This is done by entering the name of the defect in the far upper left dialogue box and its frequencies on the opposite side. The "add" button is selected next to add another defect. The defects in the concrete were resulted from problems related to the raw materials used as well as to the making process. The information included in the figure was derived from observing the data as well as from interviewing concerned engineers. After feeding all the defects and their frequencies and clicking "arrangement", as is shown in the figure 8, the defects appear arranged in a descending order. Next we click on the "Chart" button and get a chart displaying which of the defects had more frequencies. From that we understand that the most prominent defect in the concrete was caused by poor workmanship (which indicates the quality of the tasks carried out by the workers directly in charge of constructional concrete-making processes) as well as the sand used. Once causes are identified, we are able to make the rectifications needed, as we click back and then carry on with the remaining stages as in figure 9.

Figure 8. Sorting problems  
Figure 9. Histogram

After pressing "back" we are taken to the DMAIC window as in figure 7 so as to carry on with the remaining stages. After clicking the "measurement stage" we are led to the window shown in figure 10 which contains dialogue boxes related to the name of the table that is automatically created in accordance with the data of the project and that of the test carried out. The table appears after clicking the "create" button. The number of observations is also determined in this stage. Additionally, the window includes separate fields for average values, and maximum and minimum values, as well as the "range" field. Below the "average" and "range" fields there are the dialogue boxes of "AVGx" and "AVG".

Figure 10. Window where test samples data are entered
After that we specify the number of observations by clicking on the button responsible for that which opens a table to be filled with the results driven from the test which are 36 in number with each sample containing three observations to be manually fed into the system by using the computer keyboard. After that we click "create" so the information of the project and that of the test are automatically fed as in figure 11.

![Figure 11. Entering samples data](image)

After manually feeding the table with data resulted from the test, we press the "calculation" button and get the fields filled as in figure 12 which contains fields of average, maximum, minimum and range that helps in centering the test panel.

![Figure 12. Performing calculations](image)

Then we click on the "save in database" button which leads to the window shown in figure 13.

![Figure 13. Saving test results](image)

Following we click on "Next" which in turn leads to the window shown in figure 14 which contains the statistical constants tables and dialogue boxes represented by constants $A_2$, $D_2$, $D_3$ and $D_4$ that are
used in adjusting the panel. Also, there are the boxes or slots related to "material" and "check type" as well as those related to the limited technical specifications. All the dialogue boxes are filled automatically.

![Figure 14. Statistical constants panel](image)

Upon clicking on the "find statistical" button, the boxes (or blanks) get filled according to the title of each slot or box as is shown in the window displayed in figure 15, noting that the values of the statistical constants depend upon the number of sample observations which was programmed into the system's memory. Likewise, the boxes related to the values of the statistical constants are filled depending on the following formulas:

$$\text{UCL}_X = \bar{X} + (A_2 \bar{R})$$

$$\text{CL}_X = \bar{X}$$

$$\text{LCL}_X = \bar{X} - (A_2 \bar{R})$$

![Figure 15. Calculating statistical constants](image)

After clicking on the "Chart" button, we are led to the window in figure 16 that shows the distribution of the samples and how the panel was not centered.
By clicking on the "back" button, we get back to the window shown in figure 13 and then by clicking on the exclusion button as in figure 17, a message shows up stating that sample number (21) that bears the value (20.833333) was excluded, noting that the system calculates the sequence of the samples starting from (0), i.e. sample number (21) is in origin sample (22) and is the farthest sample outside the controlling area. This is because the system is designed to exclude samples outside the limits of the statistical control starting from the farthest sample onwards. Then a new series of calculations are carried out again and so on and so forth till all the uncontrolled samples are excluded.

After that we click "calculation" to find the statistical values after carrying out the rectifications as in figure 14. Then we click on "Next" to find the statistical constants after the rectifications. From that we notice that margins have been centered as follows:

\[
\begin{align*}
\text{UCL} &= 25.702319047619 \\
\text{CL} &= 23.904619047619 \\
\text{LCL} &= 22.1072047619048
\end{align*}
\]

After that we click the "chart" button and we find out that no off center samples are there, i.e. the panel is now statistically centered as in figure 18.
By clicking "back" we are taken to the none-statistical constants finding interface, as in figure 15. Following we click on "next" to get the range chart centered as is calculated in figure 19, where the range chart appear to be centered.

![Figure 19. Centering the range chart](image)

Upon finding the range chart statistically centered, we go back to the same "statistical constant finding" window shown in figure 15 to calculate the process capability, the percent of the process capability, the process capability index and the level of sigma. Following we click "Next" to carry out capability and Sigma calculations shown in figure 20 which includes a moving table containing Sigma levels and number of defects for each level.

The dialogue boxes are represented by process capability $P_c$, the percent of process capability $C_p$, the index of the process capability $C_{pk}$, and the Level of Sigma, noting that the $C_{pk}$ has two readings: The first one is $C_{pku}$ which refers to the dispersion range of averages heading towards the upper specifications limit.

The second reading is $C_{pkL}$ which refers to the dispersion range of averages heading towards the lower specifications limit. By default, the system was designed to compare between the two readings to find out which one is the lowest (smallest) in value so a message showing the direction of the dispersion of averages is followed.

A list of Sigma levels is also included in the same window, along with the number of defects calculated for each million chances per level.

![Figure 20. Six sigma statistics window](image)

After that we click on "Calculation" so we get values of the process capability, the ratio of the process capability, the process capability index and the level of Sigma as is shown in the figure 21, with the dropdown list appearing to the lower right representing levels of defects per a million chances parameter.
The floating table shows that the Level of Sigma approximates 2.9 which represents 80800 defects per a million chances. This is a level considered very low compared to the level targeted by the DMAIC system. Additionally, the $C_{pk}$ index shows that the samples average nearing to the lower limit (bound) of the set specifications which represents 22 N/mm$^2$, which is in paradox with the concrete quality parameter that increases more and more as the averages get closer to the upper limit. Still, this does not mean that a decrease in the level of Sigma due to the dispersion of averages towards the upper bound of specifications indicates a decrease in concrete quality unless it affects the architectural (design) cost.

Next we click the “Back” button to get back to the DMAIC window as in figure 7 to choose the “Analysis stage” button so that we are taken to the window shown in figure 22.

During the analysis stage, all possible defects would be listed and according to the listing, the actual reasons leading to the decrease in concrete quality would be identified. The graph embedded in the program would be set by filling the dialogue box (structuring of the problem) to show that the concrete compression is the root cause of the problem. Thus, “concrete compression” is written in the dialogue box and we click on "add" button and mark the arrow. Whatever additional element added by pointing the arrow would be set as a branch of the main element (the arrow). Likewise, by marking any branch element, the newly added element would be the secondary branch of the first marked branch, as is
Following the analysis derived from individual interviews it became evident that the main reason behind the failure of sample (21) was the addition of big amounts of water during the initial stage of the casting process, where water is added (to the machine responsible for injecting and distributing the concrete) at early stages of works in order to facilitate injection, a process usually taken as part of the preparations followed. In fact sample (21) was taken from the piece of concrete that was injected at the beginning of the process where the water to cement W/C ratio was relatively high so it became short of the targeted specifications.

Poor workmanship and the low quality of the sand used which contained a high percentage of SO₃, led to the dispersion of the remaining samples. The nested flowchart intended to show the possible reasons behind the failing concrete urged interviewing engineers who were experienced in managing projects and who were also in charge of quality about the reasons that led the sampled concrete to fail. Following are the points that were possible responsible for the sampled concrete failure:

- Workmanship, which included the following:
  1. The water to cement ratio – that is the amount of water added to the mixture. Controlling that ration is usually related to the professionalism and commitment (compliance) of the workers by the specific standards.
  2. Addition of auxiliary materials like plasticizers and fixers. This depends on the concrete mixture need for such materials, which is to a big degree related to the temperature in the location. Also, controlling the added portions depend upon the workmanship and compliance of those working on this task.
  3. The delay in delivering and distribution the concrete mixture to the casting site was behind the low quality in some samples.

- Sand: which usually fails when there is an elevation in the concentrations of salts and sulphates (SO₃).

After touching upon the three stages that were applied to the program, we come to the fourth and fifth stages:

**Stage Four**: the improvement stage during which it is possible to add procedures that lead to increasing Sigma level needed to check the concrete. The results of the analysis showed that the executing company had to take into considerations the following procedures:

- Making sure that the sand to be used is in good quality since salts and sulphates aren't allowed to exceed the upper limit allowed. Also, the sand should be washed, and if needed, changing the source of the sand in order to develop a new good concrete formula compatible with the standards.
- In regards to workmanship, it is the responsibility of the executing company to train those working on manufacturing concrete on adding fixed portions of water to the concrete to be compatible with the engineering standards, taking into considerations factors like temperature, humidity and the casting location or spot (whether being foundations or roofs), since a certain balance between the water added to the cement and the surrounding conditions should be achieved.
- Training workers on how to add auxiliary materials to the concrete which depends on the casting conditions. Accelerating admixtures are added in damp and cold weather which is contrary to the procedure taken when working in dry, high-temperature weather, noting that the best temperature for casting is 35 °C.
- It is the responsibility of the executing company to carry out previous procedures, in addition to do the follow ups till it is assured that executing works are being done in a way that meets the targeted quality.

**Stage Five**: The control and monitoring stage, during which fortifications are made to maintain the quality level, in addition to doing whatever necessary to deal with any possible skewing or deviation from the quality achieved.

In order to improve the project through improving the quality of the concrete, the executing company has to following the below steps:
• Setting up a specialized team with salaries mirroring those given to the Six Sigma team, which is termed as salaries of holders of black belt and holders of green belt, in addition to the chief executive and head of the team.
• Training the team on implementing the DMAIC stages.
• Dividing the concrete into its components and analyzing the manufacturing process down to its smallest activities or tasks so that to carry out the DMAIC approach whenever there is a decrease in targeted quality.

14. Conclusions
• The Six Sigma technology is aimed at using sample materials that fall within the required specifications in the first place, and then reducing the dispersion in targeted quality to a minimum until reaching the near-zero level.
• Six Sigma was devised to make improvements wherever necessary.
• Construction projects encompass a series of processes or operation from the beginning to the end that have the subsequent processes or works dependent on the preceding ones. From this, we understand that whenever the level of quality at the initial stages is high, its impact on the future stages would be positive.
• The project was divided into controllable stages with the sought-after improvements to be carried out separately.
• The possibility of applying DMAIC approach to improve quality in Al-Rumaitha project through dividing the project (into stages) and then verifying the quality of each stage.
• The possibility of using a computerized system for the sake of storing the checking results as well as to show quality control panels in addition to showing the project's level of Sigma.
• Through examining random samples from the Al-Rumaitha residential project, it became evident that the level of sigma was very low compared to the levels sought after in modern technology.
• The use of Six Sigma approach in determining the quality of the concrete could be viewed in two ways as follows:
  A- From the point of view of the contractor whose concern is reducing costs while maintaining quality. The use of Sigma index in this case would be very appropriate since the Six Sigma statistics are aimed at reducing the dispersion from the targeted quality. Thus, the quality level would be limited to a certain force of compression.
  B- From the viewpoint of the customer whose concern is about having a higher level of quality while maintaining the costs intact. Using the Six Sigma index here is inappropriate and the Cpk index should be applied instead since testing the quality of the concrete in this case requires checking the compression within the highest limits of specifications and not the average. Consequently, it is possible to use the DMAIC approach in constructional projects to improve the process, while using the Sigma index to reduce defects in some cases is possible during the checking stage. However, the latter approach may be inappropriate in some cases.

15. Recommendations
• The research recommends that checking results be stored using computer programs (software) which facilitate the manageability of those data (such as in the case of using Microsoft Excel for instance)
• The research stresses the importance of observing dispersions from targeted quality as well as excreting efforts to reduce that dispersion. This is especially valuable since the projects executed by the Directorate of Housing are very costly and of far-reaching effects.
• The Directorate of Housing must take into consideration the quality factor in construction projects, so that the reliability of their outputs be real, especially that the results of the project are in most cases sold to people with limited incomes via an installment system. There should be no maintenance carried out by the buyer across the payment period.
• The research recommends the setting up of a team that has the time and ability to apply the DMAIC approach wherever needed.
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