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Application of Six Sigma in Construction Industry

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ABSTRACT: In the 1980s, Six Sigma was developed and became popular in the automotive industry as a process control technique. The application of this principle of construction is therefore new and the aim of this study is to evaluate Six Sigma in the sense of construction as a method of process improvement. This Study contains the Literature Analysis, Survey and the Sigma Expert Questionnaire. The Literature Review had discussed process improvement methods used in construction industry and examined Six Sigma's fundamental characteristics and concepts. Questionnaires were conducted about the basic principles of Six Sigma and Quality Concept. Stakeholders are Project Managers, Architects, Contractors, sigma Experts and Clients. The methodology of this Six Sigma survey and questionnaires is focused on changes in efficiency, output and processes. Within the sense of construction, Six Sigma is discussed in the manufacturing and construction industries because of the discrepancies in management approach. Because of several unrepeatable functions and numerous process-design methods, the Six Sigma method in production appears too not be applicable as a whole. Six Sigma as a management strategy, owing to discrepancies in the processing and building sectors, is discussed in the construction sense. Although the construction industry involves several unrepeatable activities and various process design methods, Six Sigma does not seem to be relevant as a whole to the management of the construction industry. It can also be merged with the company's current management practises. With all in mind, Six Sigma obviously has a lot to accelerate fundamental and cultural problems that the construction industry needs.

KEYWORDS: Six sigma, defects, quality, CTQ, construction defects, sigma experts

I. INTRODUCTION

Six Sigma is a data driven, customer focused, and result oriented methodology which uses statistical tools and techniques to systematically eliminate the defects and inefficiencies to improve processes. For example, in order to make a medical scanning breakthrough, the GE division of the medical system (GEMS) used the Six Sigma modelling methods. Today, in half a minute, patients will scan the whole body relative to the previous technologies in three minutes or more. Hospitals will expand their use of the equipment and reduce scanning costs.

Its Total Quality Control, a theory of management, focuses on job processes on an ongoing basis. In particular, Six Sigma has become a useful technique for companies in various industries as a performance predictor and process improver. The numbers of businesses are starting to implement the full consequences of Six Sigma.

Six Sigma is a quality control mathematical method used by Motorola for the first time in the eighties. That lowers costs, improves performance, and reduces production time by adjusting processes. Six Sigma has insights into the mathematics and business, and Six Sigma Academy improves its applications. [1]. The Six Sigma method was already applied in numerous industries and was luckily advantageous. According to the Six Sigma Information Body 1, which comprises a DMAIC (Define, Measure, Analyse, Improve and Control) mechanism, it has improved time, efficiency and cost control for projects. [2]

However, building work has fractured and projected work procedures in contrast with the industrial industry. The measurement of Six Sigma thus becomes an important subject for research in the field of construction and takes account of efficiency, performance and management aspects. Today, more precise controls are required for each business sector. Six Sigma is responsible for the mission. It can also boost performance and time consumption. The construction industry is in progress and, with the introduction of Six Sigma in

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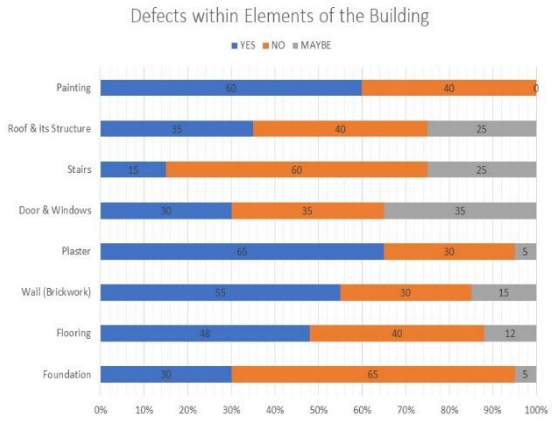
this field, it will enhance the management of its projects' efficiency and duration.

A survey was conducted to identify the critical activities which affect the quality of the construction in residential Building. This Survey was conducted between various stakeholders including Architects, Contractors, Professionals and Clients(occupants). From figure 1, it was concluded that majority of the defects were identified in Brickwork, Plaster and Painting and Least defects were present in the stairs. If the majority of defects were removed then ultimately quality of the construction will also be improved and the cost can be reduced at some extent. The Application of six sigma in construction activities would be a different approach to improve the quality and reducing defects beforehand. That is why the study explores Six Sigma as a process improvement tool in many research fields, seeking to explain its features and consequences as a quality initiative, success indicator/improvement and management approach. This study therefore deals with Six Sigma as a method of process improvement in several research questions and aims at understanding its characteristics and implications. show dynamic behaviour under various operating and environmental conditions and demonstrate advantages of adaptive control over the non-adaptive type.



Survey- Defects within Building Elements

The Aim of this study is to analyse Six Sigma within construction context and its application in the processes like Brickwork. Major objectives of this study are

- To identify processes which can implement six sigma and its statistical tool for Brickwork during Construction process.
- To analyse the statistical tools used in the Brickwork.
- To develop a new methodology using six sigma to improve quality of wall.

II. SCOPE

Six Sigma can be used in Low Storey residential House and improved the Brickwork defects. Furthermore, this study will attempt to improve the standard of habitable space by removing the post construction defects.

III. LITERATURE REVIEW

Six sigma is a well-structured method and approach to product quality management.[1]. Six sigma is a methodology that brings advancements in almost all sectors and fields of general organisational excellence [2]. Six sigma is a competitive initiative to increase sales, raise market share and improve consumer satisfaction by means of predictive instrumentation that will serve to make a major difference in efficiency. Six is the sigma count calculated in a method where only 3.4 outputs out of 1 million are defects in order to produce a drift of up to 1.5 standard deviations over the long run [3]. The key goal of 6 sigma is the creation or development of a modern process such that it has extremely high process capabilities and an error rate closer to zero. [2]. Six sigma can be considered a management approach and scientific technique designed to minimize production and service costs as well as to increase customer loyalty and important savings by convergence of methodology and production processes and management process methodologies into an organized process, product and service model. Customer focus is at the top of the line in six sigma. Improving customer loyalty and value are determined in six sigma changes [4]. The Six Sigma definition was presented in 1987 by Motorola. Bill Schmith of Motorola is thought of as "Father of Six Sigma."

Six Sigma initiatives must be related closely to the corporate purpose and basic problems of an enterprise. However, projects are often chosen from isolated pockets of departments that no one considers to be important to the organization or its clients when this sort of project is selected, and people in the organization can believe that those projects are not important to the organization. And this turns into a disappointment of the initiative, since the project struggles to gain the encouragement and approval of people in the company in the first place. [5]

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IV. CONCEPT OF SIX SIGMA

Two main approaches are found in six sigma:
DMAIC Methodology and Deming Period of Plan-Do-Check-Act methodology [6]

- DMAIC
- DMADV

DMAIC

The DMAIC means identifying, evaluating, assessing, enhancing and tracking. The DMAIC system is formed together by all parties. This method is particularly relevant in the six-sigma process because it helps to pull together a diverse team. This helps you to finish a process or prepare to share your work to complete the task. For an internal market method, DMAIC is used [6], [7]
The following phases are used in DMAIC:
•Defining the process improvement goals that are liked with customer demands and the enterprise strategy.
•Measure the current process capability by collecting relevant data.
•Analyse the data collected by the control of cause-effect relationships. Determine and take into account the causes and relations of all the future disputes. Develop existing procedures by the application of analytical solutions using strategies such as experiment design.
•Control step is to ensure that before errors occur all variations from the destination are overcome. Set a pilot process capable of continuing, generating, establishing control systems and constant monitoring of the process.[6], [8]

DMADV

The DMADV means Define, Measure, Analyse, Design and Verify. Where DMAIC is used to enhance the present market operation. The new product or process prototypes are produced by DMADV. DMADV consists of following steps:
•Establish process enhancement priorities that satisfy consumer needs and organization policy.
•The operation is a stage for the identification and processing of data to assess the characteristics of quality essential.
•Analyze options for the production and design, build high-level design and assess the opportunity to choose the right design.
•Project information, design optimization and design verification preparation. Simulations may be needed for this level. [6], [7]

V. DMAIC METHODOLOGY

D: Define

This is the overall description of the problem. It takes a lot of time and resources to spend for a favourable outcome in this is one of the crucial stages of DMAIC technique. The fundamental concept is to define and relate important client specifications to company goals.[9], [10]

The aim of identifying the project phase is to describe and recognize the procedures that meet the customer's needs, including the title and the task, complexity of the project, the project team and the risks involved. The size and complexity of the problem is specified in this step. The first task is to create a project charter that includes the project goals, resources, team members' responsibilities, project scope and limits, expected project financial benefits, length of project, etc. to help team members understand clearly the project. This gives the project a sense of ownership which avoids conflicting messages from being sent to project managers and team members. [2] [11]
In this step, the chosen problems should be addressed in the following ways.
•Fixing an interpretation of the issue.
•Build a process diagram at high level to explain the process [2]

M: Measure

The calculation process is a phase of data processing. The method of computation is a data processing step. If the issue is established, the more calculations to quantify it must be determined. [2], [9]
This is mostly a data compilation period in which current conditions are captured and the current sigma quantity for the activity is measured. Depending on the type of input, various methods may be used to calculate the Sigma level. [2]
The two main issues are dealt with in this process.
•Data collection
•Calculation of present sigma level
Where,
Number of defects = number of rejections (i.e., at least one defect exists to impute the product as defective).
Number of opportunities = number of CTQs.
Number of units = number of units produced [2], [11]
However, when the data is constant, it first defines the distribution, and then measures the sigma rating accordingly.

A: Analyze

The purpose of the research process for a project from Six Sigma is to classify the possible causes of the problem being analysed and then to use evidence and their analysis to select the root causes. The next step is to prepare clarification on the basis of process data, where a list of potential triggers is created [12] [13][14]

I: Improve

The process of change is the stage of operation. In the updating process it is important to define and successfully deploy solutions to the root causes validated. In the theoretical process, according to the brainstorming sessions of the Squad. [13]

After knowing the root cause of the matter and providing unbiassed evidence, we can define possible explanations. The improve phase spotlights on emerging views to get rid of root causes of discrepancy, challenging and regulating those results. [10] [14]

C: Control

A control diagram is a run diagram, which is supplemented by two horizontal lines, the upper control limit and the bottom control limit. Control limits are selected statistically to ensure that points are highly likely (more than 0.99) if controlled between them. Control diagrams give only the signal if the process trends get out of hand and the source of the problem cannot be identified. Control charts allow operators to identify problems of quality in the processes as tools for problem solving.

VI. TOOLS & TECHNIQUES USED IN SIX SIGMA

These are some of the types of charts and charts most commonly used:

- Control Chart
- Check sheets and Spreadsheets
- Pareto Diagram
- Cause-and-Effect or Fishbone Diagram
- SIPOC Diagram
- Flow Chart
- Histogram

Pareto Diagram

Pareto analysis is a method based on the Pareto theory of the few who are important and the rest who are negligible. The theory of Pareto is also known as the law 80-20. This basically means that 80% of issues with either process product or transaction are triggered by 20%. A diagram from Pareto is a summary diagram which shows how often or how many things are involved. The objects are displayed from left to right in the descending order of significance.

Cause-and-Effect or Fishbone Diagram

This diagram gives the correlation between quality and its influences. It is a pictorial display showing the potential causes and consequences. A number of factors or triggers may trigger a problem. It is similar and easier to solve the problem if the only real factors can be identified. Kaoru Ishikawa of Japan presented the cause-and-effect diagram. It is the easy, graphical way to view and sort causes and to arrange relationships between variables in a chain of causes and effects. It is also recognized as a fish bone diagram due to its shape.

SIPOC Diagram

SIPOC is an acronym for suppliers, inputs, systems, outputs and consumers. SPEOC is the acronym for the consumer. SIPOC is used at the DMAIC Determining Level and is also a favoured tool for the creation and identification of major business processes. The SIPOC diagram is used to view main operations or sub- processes, along with the processes, as the sources, inputs, outputs and customers depicted in a business operation. A SIPOC diagram is used to describe the limits and essential elements of a process without being so complex that the overall image is lost.

Check sheets and Spreadsheets

Checkboards are data storage and organization types. The control sheets are best built by a Black Belt and/or team and have two main goals:

•In order to ensure that the correct information is gathered, with all the relevant facts, such as where, how many and which consumers. These factors are called stratification factors

•To promote data processing for collectors as far as possible.

Check sheets can range from plain tables and surveys to diagrams for showing mistakes or losses. Checklist data are compiled and organized in spreadsheets. A well-designed table encourages the use of the data.

Histogram

The histogram displays the distribution or variance of data over a variety of different types of bars, weight, expense, height, time period, ages, etc. We know, for example, that a major portion of pizza suppliers are late, but how late or how early

they are arriving is not understood. Then you could calculate the time it takes to supply the consumers with pizzas and then compile the data over multiple days or weeks. You may search the bar shape or slope, the width or band wideness, from top to bottom or the number of hulls in the bars when examining histograms. You will easily see how much of what you are doing meets or not fulfilling the needs of consumers as you collect consumer demands for a histogram.

The following elements are absolutely essential to successful implementation of Six Sigma:

•Upper administration commitment and involvement
•Six sigma methodology, tools and strategies adequately knowing.
•Combining the corporate plan of six Sigma ventures.
•Linking six sigma projects to customer needs.
•Project collection, project analysis and project surveillance were right.
•Enough facilities for the company.
•The cultural transition. The cultural change.
•Project management skills for the middle level managers.
•Link six sigma ventures to providers.
•Both managers and workers are educated.
•Connecting six sigma ventures to individuals.

VII. CRITICAL SUCCESS FACTORS OF SIX SIGMA

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VIII. APPLICATION OF SIX SIGMA IN CONSTRUCTION INDUSTRY

•The goal of process management in the building industry is to manufacture something of equivalent or superior efficiency at lower prices. However, there are few systemic ways to reach absolute output and develop procedures in the building industry.

•One of the most significant performance drivers for a quality control system is the expense of quality. In order to alert management who should carry out proactive measures and helpful practices, low quality impacts on cost and efficiency should thus be calculated.

IX. METHODOLOGY

The number of faults and rework in the smaller houses is in some cases higher (Sommerville 2007). Due to a construction method and the condition of the building minor defects can occur. There are several definitions of defects, but perhaps the simplest is provided by the Oxford English Dictionary, “a short coming or failing short in the performance of a building element”.

The study aims to identify the common structural defects in residential building of Vijayawada, Andhra Pradesh and it can be helpful in future for the development of building maintenance which will eventually benefit to save the loss of property and human lives. This Study presents the introduction including study area, literature review about defects,

methodology adopted for this study, finding of the study and in the end conclusion and recommendations are added for further research. Brickwork was the major activity where more defects are occurred as it was identified in questionnaire.

X. DATA COLLECTION AND DATA PROCESSING

Define Phase

Problem identification and definition

•Problem: Defects in the process of blockwork in walls leading to wastage of resources and need for rework in future

•Goal: To identify various defects in block walls on site and to work on reducing the occurrences of the said defects with the involvement of all site personnel dealing with the process.

CHECKLIST FOR DEFECTS

- Voids (joints not filled properly)
- Joint between masonry and RCC not filled properly
- Adhesive drips
- Inaccurate alignment of blocks
- Broken blocks
- DPC layer not being in perfect dimensions

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- Damages done at the time of electric fitting installations

SIPOC Analysis

SIPOC analysis is a method of mapping the operation. This allows one to consider all facets of inputs and outputs. It helps record the procedure so that you can retain visibility and reduce the difference due to improvements over time. It is primarily to research the process that we are working on taking into account different relevant factors such as supplier, input, process, output and client. SIPOC Study of blockwork in the walls of the chosen building, carried out by consultation with site staff and observation.

Opportunities for Defects

The opportunities of defects in the block walls prior to plastering are:

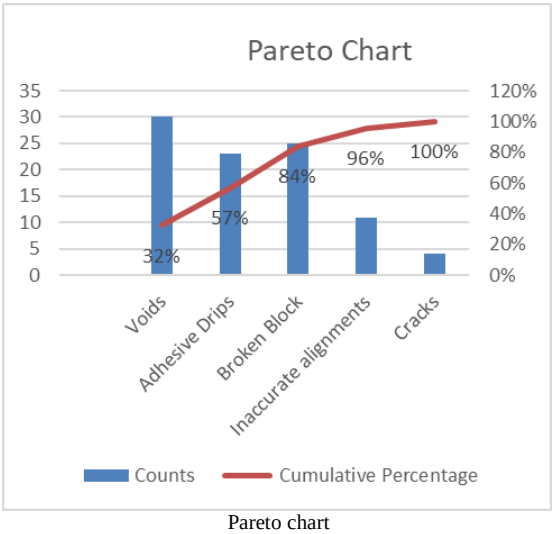
1.Voids (joints not filled properly)
2.Joint between masonry and RCC not filled properly
3.Adhesive drips
4.Inaccurate alignment of blocks
5.Broken blocks
6.Cracks along joints or in blocks
7.DPC layer not being in perfect dimensions
8.Damages done at the time of electric fitting installations

Table: sipoc analysis

Supplier	Inputs	Process	Output	Customer
Builder	1.Brick trowel 2.Old board 3.Tape measure 4.Spirit level 5.Brick/string line 6.Shovel 7.Club hammer 8.Bolster 9.Stiff brush	Visual inspection of blocks Surface preparation Shuttering/formwork for Damp Proofing Course (DPC) Pouring PCC (1:2:4) upto 200 mm height Allow the DPC layer to set Clean the DPC surface and the faces of columns and beams before starting out block laying process Mix adhesive powder and appropriate quantity of water to form a paste with suitable consistency Wet block before laying Apply adhesive paste on the DPC layer and on the column face at the starting point. And also on the lower side of the block Place the block Apply adhesive on the face of the block where next block is to be placed. Compact and fix the block. Continue the blockwork upto 1 m height maintaining a stretcher bond. Construct shuttering for about 100- 150 mm height of RCC band/Patli Pour PCC and lay two steel bars horizontally and pour PCC again and discontinue the blockwork for that particular wall for the day.	Completed wall	Owner

Measure Phase

In order to quantify the number of defects for the above-mentioned opportunities, the number of units (120 wall units) was carefully calculated and the defects were registered. Defects were found by visual inspection, measurements and instruments such as plumb bob or height. When calculating faults, if the device was found to be faulty for an opportunity, it was deemed to be one fault for that
particular opportunity. Defects have been specified as per requirement.



Pareto chart

Analyze Phase

In this step, a study of the causes of the defect described above has been carried out. Cause & Effect diagrams have been planned. FMEA (Failure Mode Impact Analysis) was also conducted to better explain the causes, consequences, magnitude, detectability and therefore the danger priority number of faults, as well as the related required steps and responsibilities.

It indicates the number of actual defects along with the total percentage of all defects from the largest to the least current defect. As a result, voids may be inferred, adhesive drips and broken blocks represent the bulk of faults, i.e. 79.2 per cent. This means that we need to focus on removing these faults so that the procedure can be strengthened by around 80 per cent. The first four defects were then chosen for the measurement and enhancement process.

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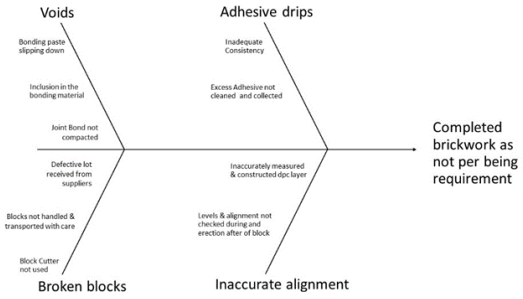
Fishbone diagram/ cause and effect diagram



Improve Phase

This process requires focusing on the improvement of existing on-site procedures that can lead to a reduction in previously established deficiencies. The areas of development were calculated on the basis of the root causes resulting from the cause-and-effect diagram formed during the study process. In addition, in the continuity of the FMEA, areas of progress and forms of improvement have been confirmed by multi-voting and awareness of process makers. It was determined that the fields of change in current practice were as follows:

•Having predetermined and consistent mix of quantities of bonding chemical and water.

•Tools such as wooden or rubber mallet be used to tamp the block to shove it properly in place and so that the applied adhesive gets well compacted and the excess comes out.

•Training programs to be arranged for workers.

•Better or more frequent supervision be provided

Steps taken for Improvement

•An external training program was arranged for workers.

•Demonstrative training was included as a part of training sessions arranged on site

•To have a consistent mix of the bonding material, different proportions of adhesive chemical and water mix were tried and outputs were observed.

•The manual of Magic bond block joining adhesive suggests using about 14-16 litres of water for a 40kg bag.

•By experimentation, 250-300 ml water for 1 kg of adhesive chemical was finalized to be used as a constant proportion.

•It is difficult to accurately measure the quantity of materials mixed in the present labour culture. However, it was advised to use any kind of container available on site to measure mix proportions and maintain it throughout the work. After implementing some of the suggested improvements, the sigma level was found to have increased from 2.365 to 3.305. 3.5.

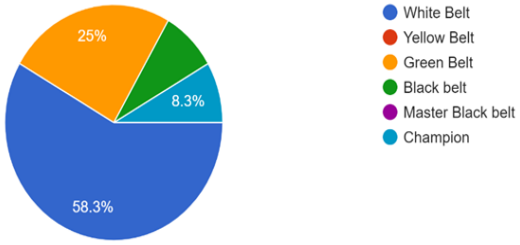
Control Phase

The control phase will require the execution of the process control of the change process and verify if the planned improvement has been accomplished with the aid of the control plan. A control plan is a written summary of the processes, controls or actions required to verify that the performance of the operation is in compliance with the desired quality standard. In this situation, the responsibility of the continuous implementation of the suggested improvements was handed over to the site management.

Now the Six Sigma Level is calculated with the Help of DPMO formula.

XI. RESULT AND DISCUSSION

A Questionnaire survey was conducted and various Six Sigma Experts holding Belts from beginner to Champion were part of this Survey.



six sigma experts belt distribution

Six Sigma Belt Holder graph shows that 58.3% were from White Belt arena and the least expertise were from champion. Various Six Sigma Experts took part in this survey and came up with the solutions for the existing defects which led to the removal of variations in Brickwork.

Brickwork consisting of defects were resolved by Experts and Provided the solutions.

Defect 1:

Questionnaire survey result 1

From the above graph, it shows that maximum Sigma Experts voted for “Joint Bonds Not compacted” for the Voids in Masonry Wall and the least was the “Inclusion in the Bonding

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Machine". So, they come up with the solution for Voids Defects in the masonry wall and it was with the majority decision and they responded that if the Grouting is done to fill joints then this defect can be reduced and followed by many solutions.

Defect 2 :

Questionnaire survey result 2

From the above graph, it shows that maximum Sigma Experts voted for "Inadequate consistency of mortar" which caused the adhesive patches on the wall and 16% was the "Lack of Professionalism". So, they come up with the solution for Adhesive Patches in the masonry wall and it was with the majority decision and they responded Hydrophobic sealant would reduce the leaking of adhesive mortar.

Defect 3:

Questionnaire Survey result 3

From the above graph, it figured out that 41.7% Sigma Experts concluded that seasonal changes are the major reason for cracks in wall as there is thermal expansion takes place and which causes cracks in the wall and also mostly Broken Blocks are supplied by the suppliers. To solve this problem Skilled labour need to repaired the block with plaster or cement and always lay the bricks in half bond rows.

Defect 4:

Questionnaire Survey result 4

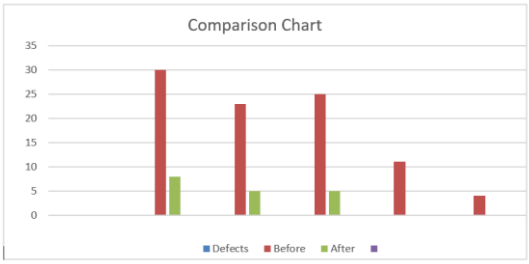
From the above graph, it figured out that 91.7% Sigma Experts think that poor workmanship is the major cause for Inaccurate alignment of Bricks and if the Labour is not skilled then he would not follow the proper procedures. So, Proper supervision should be Provided and also the proper tools need to be provided.

After applying the absolute improvements, same number of units were again detected for any defects and the defect count is given below.

Defects	Count
Voids	8
Adhesive Drips	5
Broken Blocks	5
Inaccurate alignments	0
Cracks	0
Total No. of Defects	18

Defect count after Improve phase	
New Sigma Level	
DPMO = (18 / 480) x 100000 = 37500 From the sigma conversion table, sigma level is4.1	
Total Number of Defects found in Sample	1000000
Sample Size	120
opportunities per defect	4
Number of Defects Opportunities per Unit in the Sample	18
DPMO Formula =	0.0375
	37500
	sigma Level= 4.1

It was now found that the Sigma Level was Improved from 2.36 to 4.1 after taking precautions and applying solutions given by Sigma experts. It was assumed that Defects were removed from the given solutions and Sigma level was calculated with the DPMO Formula. It shows that the implementation of DMAIC methodology of Six Sigma resulted in reduction of defects previously found in the block work.



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XII. CONCLUSION

•Various little aspects have considerable impact on the quality of processes and the final output of the process.

•Most of the defects found in the process were related to human errors. Thus, with proper training, careful supervision and making easy changes in the working method, the defects can be eliminated.

•It can be seen that the Six Sigma approach for improvement can be very helpful in maintaining the process quality and saving various costs associated with poor quality, if implemented effectively.

•It was found that during and after the implementation of Improve phase, considerable improvement could be observed in the finished block masonry walls on site.

•With the increase in Sigma level of the process, cost of poor quality, cost of labour, wastage of resources including time are reduced.

XIII. FUTURE SCOPE OF STUDY

•Six sigma is likely to remain as one of the key initiatives to improve the management process. The focus should be on improving overall management performance, not just pinpointing and counting defects.

•Construction Industry should try to integrate six sigma with other existing innovative management practices that have been around to make six sigma even more attractive to different organizations that might have not started or fully implemented.

•This Process could be the major change to improve the quality of Construction activities and which would reduce the cost, time and improve the efficiency of work.

•Majorly, it would improve the Habitable standard.

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