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Application of Six Sigma Methodology in BIM Models - A Case Study

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Abstract - Several modern tools of construction and engineering design have evolved over time to bring efficiency and quality in the construction and infrastructure sector. Due to rising client expectation in terms of quality, cost, and time of delivery; contractors and engineering design teams are under pressure to deliver quality in the very first stance leaving no scope for re-work. AutoCAD drawings have been replaced with advanced designing software helping engineers to simulate the project and eliminate any clashes among various services, beam, pillar etc before the contractor implements this model at site. Any redundant work at site due to defective 2-D drawings imposes cost, delays, and dissatisfied client. Modern 3-D software like Revit, MicroStation, Naviswork etc takes care of this shortcoming of 2-D drawings. But now the onus shifts from contractor to design teams to produce highly accurate designs., drawings and models as construction industry moves towards mass production of pre-cast slabs, walls, and beams and automate several aspects of construction. It is thus imperative to implement high levels of quality assurance programs in the design process. This paper narrates how Six-Sigma approach can help to improve the quality of BIM models, enable measurement of quality, and maintain it over time. As per the data described in this paper, it was observed that Six-Sigma approach helped improve the quality level of BIM models from 3.05 to 3.77 sigma over a period of 11 months. However, more research and efforts are needed to make construction sector as close to automation as possible to bring down the cost and time involvement. This will be possible when design engineers produce quality approaching Six-Sigma levels by skill improvement and making BIM and other design software more intelligent.

Keywords- Automation, BIM, Construction, Quality, Six Sigma, Statistical Models

I. INTRODUCTION

The construction industry is full of examples where costly and time-consuming re-work had to be done due to clashes observed at site between diverse services which were not taken care of during 2-D drawings or 3-D design model preparation. The modern construction industry has evolved two tools, namely Lean Project Delivery System (LPDS) and Building Information Modelling (BIM). LPDS was defined by Sam Spata, AIA (Air Impact Assessment) (American Institute of Architects) (Patata, n.d.) as "A Project management Process that strips away unnecessary effort, time and cost in the planning, design and construction of capital projects to deliver what the owner values." A vital element of the Lean Six Sigma methodology in construction is the delivery of construction materials, products, equipment for Just-In-Time (JIT) performance (Ivars Linde, 2020). But, for a contractor working with 2-D drawings, it is almost impossible to manage JIT inventory at site. This happens because despite all the care exercised by the designer to resolve clashes between various building elements, several of them find their way at site which wastes sufficient time in resolution and inventory management goes for a toss. The second tool widely adopted in construction industry called BIM created an environment to design a project in 3-D to simulate the project virtually, obviate clashes between various civil and MEP objects before delivering the model to contractor at site. With highly accurate BIM models free of clashes,

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contractor can undertake mass production of construction elements off-site and implement JIT inventory at site. The author has restricted the scope of this research to the application of Six-Sigma for quality improvement in the production of BIM models which brings efficiency and quality of construction at site.

1.1. BIM

BIM stands for Building Information Modelling which is an automation tool in the AEC (Architecture, Engineering and Construction) industry for producing high quality coordinated drawings. Revit and BIM 360 are one of the most collaborative tools in BIM and are most often used as a part of global coordination between engineers and designers. BIM 360 provided a unique platform where multiple people can work on the same model, buildings, floors etc which improves the efficacy and coordination for architects, engineers, technicians etc. BIM is a process rather than a tool or a software (McCool, 2015). BIM is defined as a modelling technology and associated set of processes for producing, communicating, and analysing building models (Eldeep, 2021). In traditional era, AutoCAD technicians used to prepare drawings in isolation limited to their specific discipline like mechanical, plumbing, electrical and civil with very less coordination among themselves due to which the implementation of designs at site was a challenge. BIM has eliminated this problem as the design team, site team, cost managers, building owners work closely together from the early stage of design creation leading to a comprehensive approach where every stakeholder can provide their inputs thus avoiding costly change orders. An exciting feature of BIM is that it makes administration more transparent (Eldeep, 2021). BIM reduces wastes and ineffectiveness of creating a distinct set of detailed drawings (Eastman, 2011). A university project design with AutoCAD (2-D) drawings took almost 4 months while the same project modelled in BIM (3-D) with Revit and Navisworks took only two months (Eldeep, 2021).

1.2. Six Sigma process

Six Sigma is a process that can be applied to any walk of life for the improvement of processes producing quality output in the first instance instead of making costly alterations. Today, from as simple a process of cooked food distribution by Mumbai Dabbawalla (Thomke, 2012) organization to automobile industry is practicing Six-Sigma process for high and efficient quality delivery. The Dabbawallas organization comprises of four basic pillars—**organization, management, process, and culture**—which are perfectly aligned and mutually reinforcing. Six-sigma methodology was first endorsed at Motorola in the mid-1980s (Soham Rathod, 2018). Motorola engineers did a study and observed that the cost associated with fixing a defective product that fails in the hand of customer and the cost associated with calling back, repairing, and sending them back to customers weighed heavily against the cost of component itself and was eating into the profits in addition to spoiling brand value. Motorola then came forward with the concept of First Time Quality (FTQ) i.e., producing components within tolerances in the very first attempt (Palekar, 2016) . It is a cost intensive exercise as machines, instruments and processes must be highly efficient and calibrated. But once implemented, the profits in the company's balance sheet see no limit as FTQ becomes part of DNA of the organization. Toyota called it Toyota Production system (Toyota, 2017) and how successful Toyota brand is needs no description. Six-Sigma is a term which became popular for automobile industry, but one can adopt 3-Sigma, 6- Sigma, 9-Sigma, 12-Sigma, and so on depending on the application, need, criticality of the process and cost-benefit analysis. The defect rate in Six-Sigma process, defined as Defects Per Million Opportunities (DPMO) can be one tool to examine the quality level of the instituted process (Table 1).

Simplified Sigma Conversion		
Sigma	DPMO	Yield
1	690,000	30.90%
2	308,537	69.20%
3	66,807	93.20%
4	6,210	99.40%
5	233	99.98%
6	3.4	99.9997%

Table 1: Simplified Table of DPMO in Sigma Terms (Ramadan, 2013)

The defect rate in a three-sigma process (mean +/- 3 Sigma) will be 66,807 per million parts produced (Table 1). If a circuit board is considered as an object with say 100 parts, the probability of failure of each part at six-sigma level being 0.001349 [use formula 1-Norm.s.dist(3,1) in excel], the probability that no part fails is (1-0.001349) ^100 =0.874 which is equivalent to failure probability of (1-0.874 = 0.126) which is a remarkably high probability i.e., 12.6% (Palekar, 2016). This kind of failure rate is certainly going to bring the business to a close. This also cannot be the quality level acceptable in aviation or in nuclear power plants and can be catastrophic. (Ili16)As sigma level increases, cost to produce quality also increases exponentially. Thus, a discretion is to be exercised about the reasonable sigma level based on criticality of industry for whom process improvement plan is contemplated.

In construction sector, the operations are not as critical as they are in the aviation or nuclear power plant industry. Still, there are many aspects where safety of human life must be ensured, and thus elevated level of quality is expected in the design of bridge, structure, and electrical components. Elevated level of accuracy provided by BIM has brought construction industry a step closer

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to automated production sector. Now, relying on accurate designs, contractor can get the pre-cast slabs manufactured elsewhere in a factory and transport the same for faster assembly at site instead of In-Situ construction.

II. METHODOLOGY

The objective of this study was to identify the causes of variation in quality produced by designers, apply statistical tools to determine if the quality level can be defined in Sigma terms and establish quality improvement programs. This study brought significant insight in identifying the causes of variation in quality which were categorized as Common Cause Variation (CCV) and Special Cause Variation (SCV) in the Six-Sigma terminology. This study helped to analyse how a well-defined process can help in achieving high quality level in BIM model creation which is defect free so that quality can be measured in statistical terms and may be understood by all on equal footing. Another objective was to document the process undertaken. The process if documented will help for future research and development.

A base line was established in terms of defect opportunities permitted in randomly selected BIM models created by modellers (Table 2). In a BIM model, there can be multiple defects like BIM/ AUTOCAD model issues which can be further categorized into clash coordination, sheet annotations, incorrect view range, wrong placement of fixtures etc and the list goes on. Every such defect was considered as a defect opportunity and total of 12 major defect categories were created. The approach used in this study is working out Continuous Improvement (CI) by analysing quality pattern using DPMO (Defects per Million Opportunities), FMEA (Failure Mode & Effect Analysis) and Statistical tools to find out the improvement in sigma level with a hypothesized number of defects to be less than four in a project. Most common reason for industries to implement Sigma approach is to resolve issues facing the industry like cost reduction, cycle time reduction, error, and waste reduction, increasing competitive advantage, improvement in customer satisfaction, change of company culture (Mbachu V.M, 2015) .

The method of selection of projects was put in place e.g., frequency of audit (selected as end of month), parity on project selection viz. its size (minimum 500 man-hour effort spent), gender, and experience of modeller. The objective of categorization of defects was to bring out the areas of concern and find a solution using fish-bone diagram to improve upon it. This could be software issue, improper input at kick-off stage, not asking enough questions from client, lack of training and/ or skills, continuous updates from other stakeholders like architect or structural designers, software automation, and so on which went unnoticed by the person whose project is under audit.

Repeated defects by a person or various persons in a specific category would call for up-skilling the person for futureproofing. There can be issues related to processes that organization follow or automation needs. Subsequently, a monitoring and control mechanism needs to be put in place to help and monitor the efficacy and continuity of the improvement steps taken to improve upon their quality. The data so collected from this audit exercise would be used for statistical analysis to compare the efficacy of the process.

III. SIX SIGMA PROCESS DMAIC

The Six-Sigma process is a methodology based on 5-step process called DMAIC. The acronym stands for Define, Measure, Analyse, Improve, and Control. This 5-step process helps auditors and auditee to align on similar language to be used between them. This is also the key to define entire control process leading to improvement in quality which is termed as Six-Sigma process. DMAIC process was defined in the beginning of this study as below:

i. DEFINE

Our main concern here is identification of problem, defining the scope of the study and identifying the affected party. This step requires defining the boundaries and scope of the process, Voice of Customer (VOC) or the quality level expected, constituting the team and dissipating project charter, project plan and most importantly key metrics, progress monitoring plan, improvement plans, control plans and end-of-phase reviews. This is the most important stage for the DMAIC process which requires high level expertise to define the actual problem and brief the team so that all the members can work collectively for continuous improvement (CI).

A team consisting of passionate Senior Modellers from different teams was constituted supervised by Team Leaders. Quality boundaries or VOC (Voice of Customer) was defined in terms of number of defects allowed per model (a maximum of 4 defects per project) e.g., there can be 2 errors in annotation, then there cannot be more than 2 defects in model set up or clash among services etc. It was agreed to keep the baseline (VOC) or allowed defects as 4 or less as it was critical to quality (CTQ) based on the actual impact on the deliverables. This assumption was based on experience, overall impact of the defect on the project and BIM managers quality review feedbacks. This limit was imposed to have rigorous check on quality levels but also to allow human errors because BIM is a human centric process.

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S. No	Defect Categories	S. No	Defect Categories
1	Incorrect View templates	7	Clash/ coordination issues
2	Link Model management	8	Sheet annotation
3	Placement of fixtures (all services)	9	View range issues
4	Material and fittings selection as per the service	10	Legend Notes
5	Object check in section and 3D view	11	Pdf generation issues (Revit)
6	Consistency check in 3D and schematics	12	Timely architectural changes update or review

Table 2- Defect Opportunities in BIM

It is especially important to allay any insecurity that broods among employees by this kind of audit for instilling quality as they feel threatened if the object is not made clear to them at the early stage. The project owner must mitigate these concerns if they want realistic data to come out of audit findings. Initially, there were some misgivings among employees, but the senior modellers played their role very well. Whenever any project was audited, the modeller responsible for the project was counselled on how to remove the mistakes by training and handholding. This approach helped to a great extent as every employee started putting in their heart and soul into it and they took active part in following the process for achieving the overall objective of the organization. Once the confidence started to build up, the employees surprised the audit team by bringing in likely-bad projects for audit themselves. This is the power of Six-Sigma process, and the transparency and involvement of every stakeholder is needed to achieve the objective.

ii. MEASURE

Measure phase of DMAIC process helps to measure and quantify what is being measured. The measure phase helps to compare where the process started and how much it has improved by the Six-Sigma process. It establishes a baseline, defines Key performance Indicators (KPI), parameters on which evaluation will be done and finally tools to be used for such measurement including their calibration, if any.

The definition for the purpose of this exercise was detailed out to everyone. It was agreed that 20 randomly selected projects will be audited every month. Since projects quantum is measured in terms of number of hours spent from start to delivery by employee(s), projects with a minimum of 500 hours of efforts (Chart 1) were audited. Mid-stage completion of project was also considered as project for the purpose of this exercise. The stratified and discrete sampling technique was adopted by including various groups and subgroups to represent workmen's seniority, gender, project's size, complexity, projects from different geographies, culture and work group, collection of samples at a fixed interval and recording the number of defects under each category. This helped the team to understand the process and importance of measuring the defects which in turn leads to breakthrough improvement. BIM is a process where one can find unlimited number of defects. The main task was to categorize them into certain broad categories which are not only important for quality but also can be understood by each person. (Table-2). The project was measured for all defects noted in that category. The average of one category was used for statistical analysis. Similarly, average of averages (of various categories) was used to establish the process average and utilized for constructing 'C' chart.

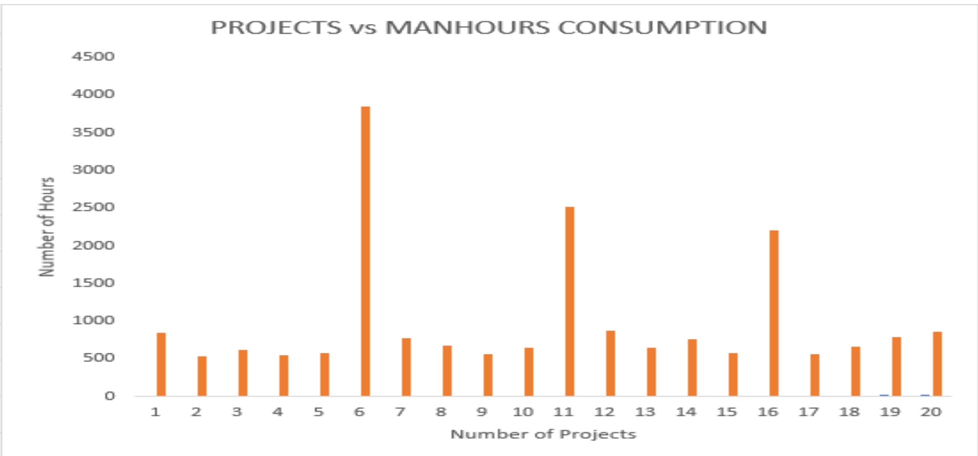

Chart-1: Project Manhours for Sampling Projects

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iii. ANALYSE

The objective of this phase is to analyse the data collected and discover the root cause. Various tools are available and the most popular is Fishbone or Ishikawa diagram. There could be many reasons of root cause of the problem and the Fishbone diagram helps identify each and close on the most important or second most important cause and so on to plan the possible corrective actions and start the Improve phase.

This step also helps us to identify if the difference from VOC is due to Common Cause Variation (CCV) or Special Cause Variation (SCV). The CCV is what may happen due to operator's fatigue, lack of skill, monotonous job etc. It may be noted that CCV cannot be made zero, these can only be minimized as these variations are part of the process and time to time re-calibration (training in this case) is required. SCV are the causes which happen due to special causes like sudden voltage spike in a manufacturing industry or wearing of tools used with machine but not taken care of in time. SCV however can be reduced by taking some mitigation measures. This stage helps us to know about the process performance and the improvement there upon.

To analyse the root cause of defects, a cause and effect (Fishbone) diagram was prepared with the most probable causes for the defects (Chart 2). The fishbone demonstrates in detail the probable causes for the defect.

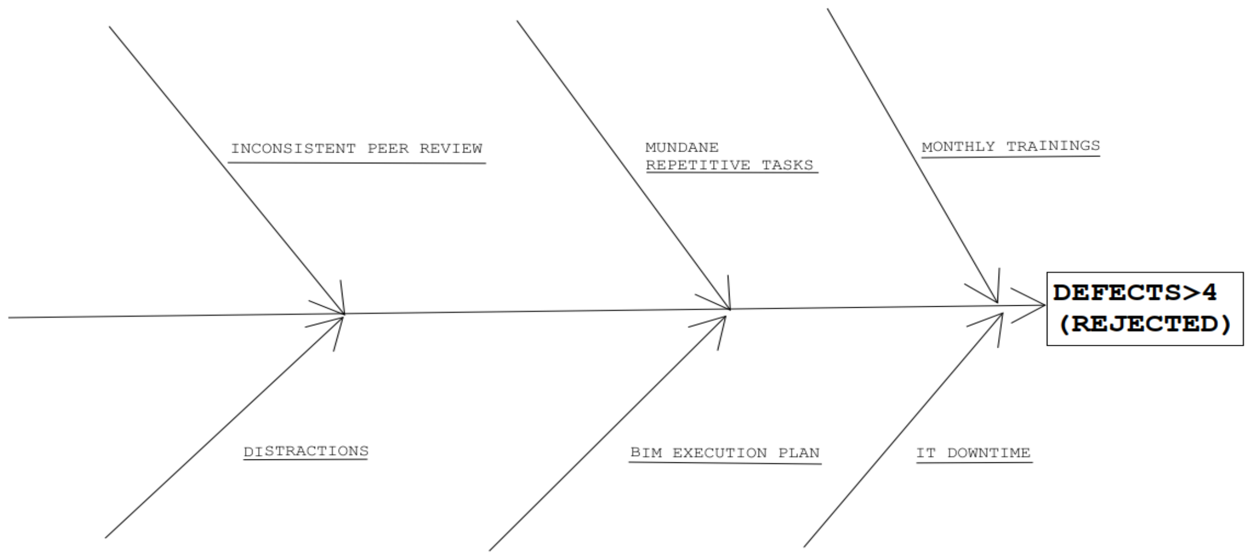

Chart-2: Cause and Effect (Fishbone) Diagram

After identifying the major causes for the defects, a Pareto chart (Chart 3) was created for 20 projects to identify the most important and repetitive reasons for the defects. The Pareto chart helped to prioritize the addressing of the root problems.

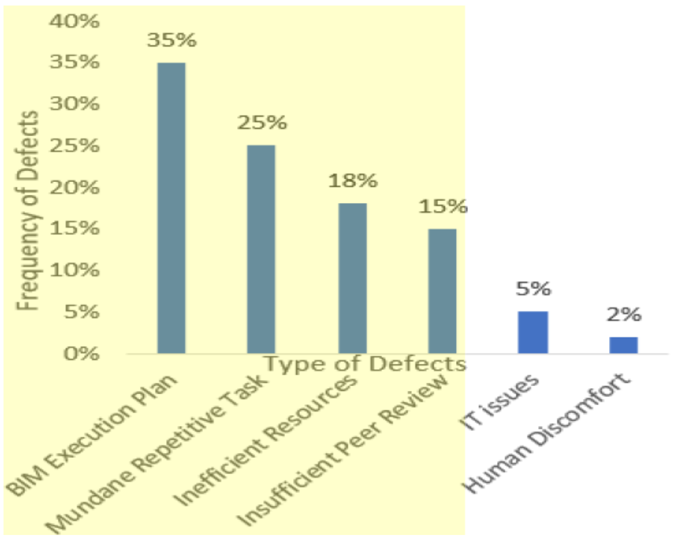

Chart 3: Pareto Chart for Root Cause Identification (Yellow being the major causes)

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As highlighted in the Pareto chart, BIM execution plan, Mundane Repetitive Task, In-efficient Resources & Insufficient Peer Review constitutes 93 % of the reasons for the defects which helped to identify the key issues and prepare an action plan. The detailed action plans are elaborated under the Control section of the paper.

Some surprising findings related to CCV and SCV reasons were revealed during the audit of various projects. Since modelling is an entirely human intervention (with software interface), CCVs (Common Cause Variation) (Common Cause Variation) cannot be ruled out but can be minimized but SCVs (Special Cause Variation) can be mitigated by timely intervention. These findings are listed below:

Factors leading to Common Cause Variations (Chance Factor)

a) Inability to check one's own work with eagle eyes.
b) Ingrained casualness due to repetitive work or mundane tasks.
c) Less time for self-check due to tight project timelines.
d) Insufficient time to spend on learning of regulatory codes.
e) Lack of awareness of BIM execution plan.
f) Inconsistent peer review.

Factors leading to Special Cause Variations (Assignable special causes)

a) Work delivery by a new member in the team especially fresher or juniors without sufficient training.
b) Attrition causing brain drain from the organization.
c) Improper kick-off of the project leading to mismatch in expectations.
d) New tools or software e.g., a person working on Revit assigned to work on Micro-station without enough training.
e) Projects of a new country with new language or new country specific regulations.
f) Architectural changes not communicated in time.

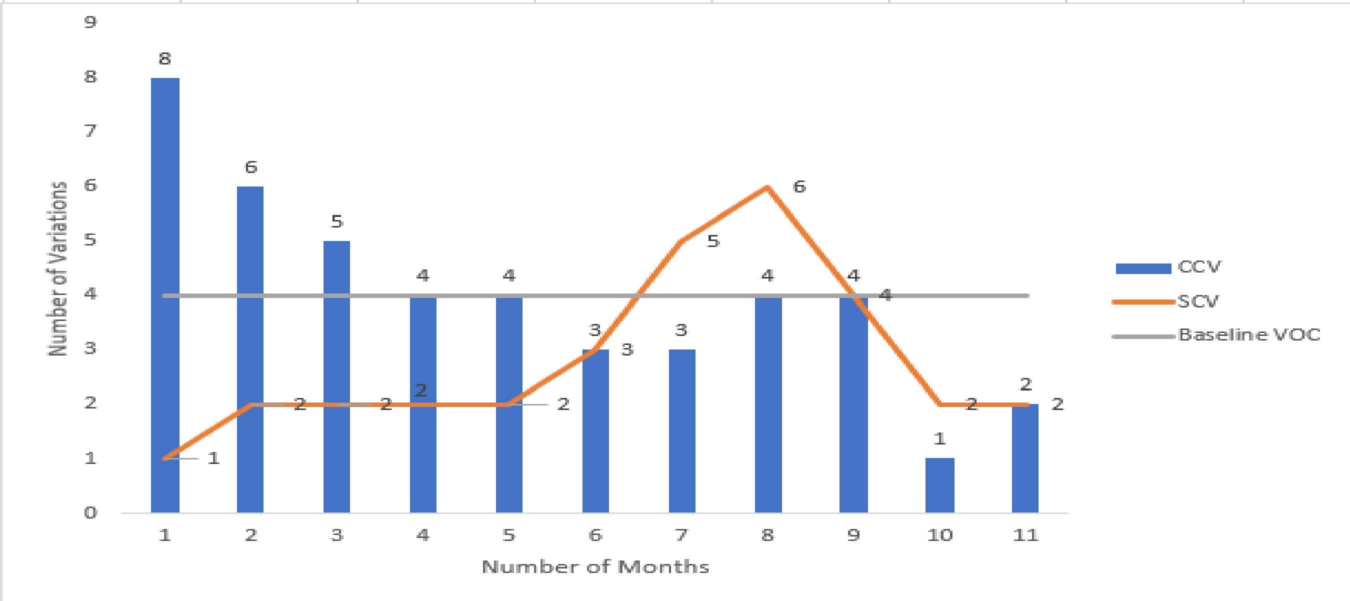

Chart 4: SCV & CCV Analysis

A graphical representation (Chart 4) of improvement in SCV and CCV leads to a better understanding of process taking shape. It is clear from the graph that there is a gradual decrease in the common cause variation from 1st month to 11th month of the study after implementing the action plan. The first month variations were exceeding the allowed variation i.e., 4 but as soon as these causes were identified, and corrective measures were taken this number reduced to 2 by the end of 11th month. There is a sudden increase in the special cause variations in 7th & 8th month due to addition of a lot of new members in the team who were not aware of the complete process. This SCV was taken as a learning for future and within 2 months this variation was reduced from 6 to 2 which is suggestive of the quick improvement action for the new recruits.

iv. IMPROVE

Once the factors leading to CCV and SCV are identified, it was time to brainstorm solutions without going in too much depth of it. The idea is to work on the easiest solution called low hanging fruit and prepare action plan around it. The outcome of this study identified the area where any individual or process fell short of expectations.

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Since there were several categories of defects and each required specific training, a severity case was developed by assigning Risk Priority Number (RPN) against each reason by using Failure Mode and Effect Analysis (FMEA) tool causing CCV or SCV (Table 3). The RPN was derived as below:

RPN = Severity of error * Likelihood of Occurrence * Likelihood of detection

(Scale: 1-10; 1 being least severe and 10 being most severe)

The RPN, thus gives an indication on the level of priority to be assigned to each cause and planning measures around it. The MEASURE and IMPROVE phase progressed side-by-side indicating how much improvement has taken place by the action plan so implemented.

Improve Phase										
Name of Employee	What needs to be controlled	How frequently measure	When to act	What action	Who will act	When to stop the process of monitoring	Severity (a)	Likelihood of occurrence (b)	Likelihood of detection (c)	Risk priority Number (RPN)
							Scale 1 -10 (1 - Least severe, 10 Most severe)			a*b*c
Mr/ Ms XYZ	1. Sheet Annotation	Fortnightly	defects >2	1. Training in concepts	1. Name of Trainer	defects <2	7	10	9	630
	2. Fixture Placement	Weekly	Defects >0	2. Training in XYZ	2. Team Leader	Defects =0	5	5	10	250
	3. Worksheet Set up	Fortnightly	Defects >3	3. Facilitation of Infrastructure/ software	3. XYZ	Defects <3	10	9	6	540

Table 3- Failure Mode and Effect Analysis (FMEA)

Based on RPN calculation (Table 3), the priority action for Improvement phase was decided in the following order:

1. Sheet Annotation (RPN 630)
2. Worksheet Set Up (RPN 540)
3. Fixture Placement (RPN 250)

The following solutions were implemented in the order of RPN score:

a. **Skill Improvement Plan:** The analysis of the project also revealed that employees needed eagle eyes to check annotation work, understand various BIM processes like Worksheet Set Up etc thus, making it the best case to be improved. An extensive up-skilling program was instituted where the experienced engineers and modellers provided classroom training and examination, followed by honing of skills on dummy projects.
While the above two steps in themselves constituted enough improvement, the enjoyment and improvement of skills helped the organization to control attrition thus retaining the skilled employees within organization.

b. **Automation:** It was observed that mundane task is one of the most principal elements which causes errors in BIM design. It was noted that if there are 500 rooms in a hotel project and the modeller must fix same type of electrical fixture, switch sockets in all rooms day in and day out, it is very much likely to breed boredom resulting in errors. One solution was to automate the process. A software plugin was prepared for Revit that helped to place all such repetitive fixtures at appropriate and pre-defined coordinates at the click of mouse in all 500 rooms together. Similar automation was done to define sizes of HVAC (Heating, Ventilation and Air Conditioning) ducts, pipes and other elements, their nomenclature and this took care of majority of annotation errors in addition to saving of efforts and increase profit.

c. **Peer review:** It was observed that to bring the quality of submission to an elevated level, it was necessary to get the project reviewed by a peer before client submission. BIM being human centric process, there are all the chances that the modellers who are primarily responsible for the project cannot look at their errors holistically. Another person was tagged with them for peer review and by spending some efforts, the quality improved significantly. However, this method may be possible only during the beginning of DMAIC process improvement to supplement training and skill enhancement but over time budget constraints may not allow peer review efforts.

d. **BIM Execution Plan** was given to all the team members and regular weekly meetings were scheduled to discuss and to ensure that progress has been made on the execution as well as implementation of the same in the project. There were nominated mentors for the doubt solving sessions along with a monthly knowledge transfer meeting for the same. This helped the team members to be aware of the possible defects and the methods to minimize their

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mistakes. It was observed that gradually the number for this type of error was reduced which resulted in improvement of the quality of deliverables.

v. **CONTROL**

Improve phase will become worthless if performance level is not sustained. Thus, developing controls around the processes is especially important. Statistical process charts help supervisor or the workers to observe the performance. Since, this case required discrete data measurement (number of defects not defectives), the C-type control chart was used for this last step (Chart 5). The following indicators helped supervisor or the modeller to attend to the process if any of the following happened (Chua, n.d.) as if variation were random, it is highly unlikely that any of these conditions will be present but if it exists, this will mean process is out of control and need attention:

a) A point outside control limits.
b) Nine points in a row on the same side of centre line.
c) Six points in a row all increasing or decreasing.
d) Fourteen points in a row alternately going up and down.
e) Two out of three points more than two sigma limit from the centre line on the same side.
f) Four out of five points more than one-sigma from the centre line on the same side.

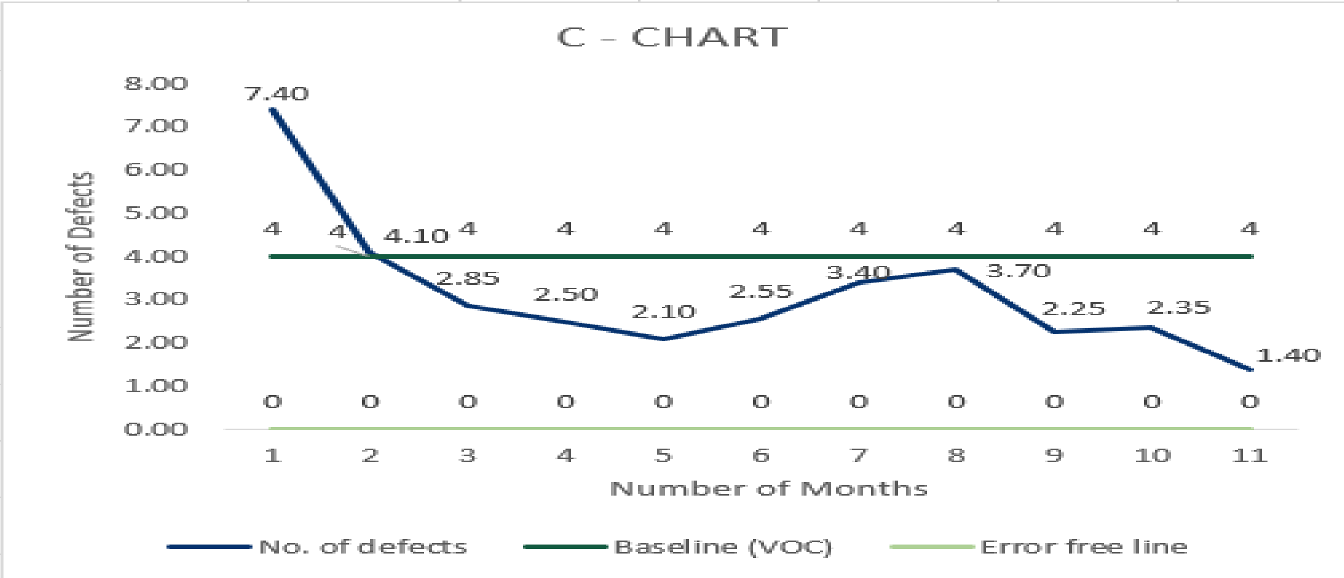

Chart-5: C-Chart for discrete sampling of error data (monthly data)

The C-chart was analysed continuously month by month and none of the above conditions were present thereby meaning that the process is under control.

The results of the Pareto Chart suggested that there were 4 major causes of the defects arising in the project. The control plan for the same was prepared as below:

a. BIM execution plan was to be followed compulsorily. At the onset of project, a team was nominated to explain the plan to all team members.
b. Plugins made integral for all projects.
c. One model training calendar for 21-days training was prepared that helped new employees to understand procedures and quality parameters, BIM plan and above all importance of quality.
d. Peer review support provided to new employees for one month.
e. Data collection to be continued on monthly basis.

IV. RESULT SUMMARY

The output of this study was successful implementation of Six-Sigma approach to improve the BIM design process in construction industry. The statistical model predicted and confirmed the accuracy of outcome and probability of deviation from the hypothesized values in future. The statistical outputs were based on hypothesized error rate of less than 4 (four) per project (minimum 500 man-hour). A consistent number of projects were selected every month (Table 4) and the selection was made to include gender, seniority and projects of different geographies having different language, culture, and way of working to align with the discrete sampling technique process of statistics. The P-value and Z-value were calculated in the table shown below. The result was a consistent improvement of P-value and constant reduction of DPMO.

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Statistical Analysis of BIM Projects											
	Month-1	Month-2	Month-3	Month-4	Month-5	Month-6	Month-7	Month-8	Month-9	Month-10	Month-11
Count of projects	20	20	20	20	20	20	20	20	20	20	20
Mean	7.40	4.10	2.85	2.50	2.10	2.55	3.40	3.70	2.25	2.35	1.40
Standard Deviation (S.D.)	4.13	2.81	3.03	1.96	2.13	2.68	2.74	5.50	2.20	2.87	1.76
Hypothesized Error (less than value)	4	4	4	4	4	4	4	4	4	4	4
P-value	0.0008	0.438	0.947	0.999	1.000	0.987	0.830	0.595	0.999	0.991	1.000
Z-value achieved	-3.156	-0.157	1.616	2.983	3.364	2.227	0.954	0.241	3.078	2.351	4.706
Statistical Hypothesis H0<=4, Ha>4	Reject	Reject	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept
DPMO	61667	34167	23750	20833	17500	21250	28333	30833	18750	19583	11667
Sigma Level	3.05	3.32	3.48	3.54	3.61	3.53	3.40	3.37	3.58	3.56	3.77

Table-4: Statistical Analysis of BIM Project

V. CONCLUSION

As construction industry aspire to move from in-situ construction practices to mass production, the onus of producing high quality and error-free product has shifted from contractor to design teams. The objective of this study was to assess if Six-Sigma quality programs can be implemented in BIM industry producing accurate designs to achieve this objective. This case study developed methodology wherein the BIM quality can be defined, measured, analysed, and improved upon in continuous loop in terms of Sigma level of quality. The modern BIM processes despite being carried out with the help of advanced software are utterly human dependent also. During this study, this human dependence was analysed, and steps were taken to improve upon them by identifying areas of concern in a statistical way by upskilling. Similarly, the interface between humans and software was improved by developing several plugins which helped reduce the mundane repetitive tasks performed by humans which was found to be another major cause of costly mistakes. The results of this study were analysed by developing a statistical model. The statistical model helped understand the probability of finding a BIM model with number of defects higher than the hypothesized number of defects (considered 4). It was observed that P-value (at 95% confidence level that defect will not appear) was 0.0008 in the first month indicating there was a high possibility of getting defects more than four in a project (P-value should be more than 0.05 to consider process is in control).

However, during application of DMAIC methodology, the P-value kept on increasing month-by month signifying improvement in process and very less probability of getting more than four defects on average per project. It is evident that the DPMO value reduced from 61667 to 11667 which itself is a stark improvement.

The results of improvement were also analysed in C-chart to identify the variation in process. There were Special Cause Variations (SCV) which resulted in lower sigma level in the 7^{th} and 8^{th} months but overall, it was concluded that the quality measure defined in terms of sigma level continued to increase from 3.05 sigma in the first month to 3.77 sigma at the end of study period. Since there are no machines involved and there is a dependency on humans; it is important that a significant focus is laid on automation, audits, trainings, and identification of individual’s needs for development as part of IMPROVE and CONTROL plan.

This study will help to lay the foundation for further improvement in BIM quality levels as more research in implementation of DMAIC methodology is needed as the construction industry slowly moves towards mass production of constituent elements.

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