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Waste minimization in construction using lean six sigma

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ABSTRACT

In India, the construction industry is one of the largest industries after agriculture industry. It produces a large quantity of waste and consumes more resources, which makes construction a troubling task. The application of a new technology, Lean Six Sigma concept is likely to be effective for improving the efficiency of construction industry. It aims to eliminate all defects and also to minimize the wastage of materials, time and effort in order to generate the maximum possible amount of value. The aim of this study is to evaluate, Lean six sigma as a process improvement method to improve the construction process by, understanding and analysing the factors affecting the formation of construction wastes. It is not possible to implement a lean philosophy into a company, without understanding the basics and purpose for which they were introduced. Practical part of the article is devoted to a detailed analysis construction process using the well-known Six Sigma cycle DMAIC - an abbreviation of the words: Define - Measure - Analyze - Improve - Control. The analysis was carried out on the basis of net study and interviews with the construction management and employees of subcontracting companies present at the construction site. The set of 45 potential factors which contribute most to waste generation was identified. Questionnaire survey was developed and sent to architects, contractors and project managers involved with on-site construction activities. It can be said that using quality management tools (Lean and Sig Sigma principles) it is possible to visibly improve building processes and it is likely to achieve waste minimization before and during construction works.

Keywords: *Six sigma, Lean, Waste minimization, Construction.*

1. INTRODUCTION

The construction industry in India is increasing rapidly. It has been growing annually at the rate of 10 per cent over the last 10 years as against the world average of 5.5 per cent and is already at 10% of the GDP. The built-up area is expected to surge almost five times from 21 billion sq. ft in 2005 to approximately 104 billion sq. ft. by 2030. The Union ministry of forests and environment (MoEF) has acknowledged that there is no systematic database on C&D waste. However, we can infer from same data from Technology Information, Forecasting and Assessment Council and Centre for Science and Environment.

Just for year 2013:

- India has constructed 5.75 billion sq. m of new additional floor space from 2005 with almost one billion sq. m.
- Approximately 50 kg per sq. m of waste is generated during construction. India must have generated 50 million tonnes (MT) of C&D waste.

A total of about 530 MT of C&D waste was generated in India from buildings in 2013 alone. This was 44 times higher than the official estimate. This waste is being used illegally to fill up water bodies and wetlands around urban centers for real estate development and rest is just being dumped into rivers and open spaces. In addition, money, time, and resources are also wasted as a result of inefficient or poorly managed construction projects. Improving the efficiency and management of construction projects, then, can result in savings related to resources, energy, and cost.

While previous construction related studies have focused on the reduction of waste, increase of productivity, or minimization of environmental impacts, to date, limited research has been done to combine all three efforts. This research integrates two methods: lean to reduce waste and Six-Sigma to improve quality and productivity, in the belief that these methods together could help minimize all of the above-mentioned impacts generated by construction activities.

2. METHODOLOGY

Six Sigma was created in the 1980's by Bill Smith at the Motorola Corporation, and seeks to reduce errors and defects by applying the DMAIC (Define, Measure, Analyze, Improve, and Control) methodology. Popa et al. (2005) argue that Six Sigma is a highly disciplined process that helps organizations focus on delivering lower-cost products with improved quality and reduced cycle time, where Sigma represents a statistical term that measures the extent to which a given process deviates from perfection and Lean Six Sigma is a methodology of process improvement used in organizations of international standard in order to eliminate waste in the processes and deliver products and services with extreme quality to its clients.

According to Franchetti (2015), Six Sigma can help in developing skills, improving knowledge and employee morale and the ability to use a wide range of tools, techniques and has the following advantages over total quality management: Establishing zero defaults targets, creating the DMAIC process improvement cycle, and intensive use of statistics and data to make managerial decisions and reduce process variation. The main difference between Lean and DMAIC is that Lean projects can use qualitative and quantitative analysis of root cause analysis, such as the five whys, cause and effect diagrams, Failure mode and effects analysis (FMEA) (Voehl et al. 2010). However, by focusing on process improvement and variability reduction, Six Sigma programs do not guarantee a sustainable competitive advantage, and mechanisms need to be developed that address innovation and product differentiation, the pattern of change in the customer base, and uncertainty Environmental, while improving organizational processes, considering radical changes and the formation of new markets and / or customers (Parast 2011). George (2002), states that it is essential to merge the two methodologies to reduce cost and complexity. Just as Lean cannot statistically control a process, Six Sigma alone cannot dramatically improve process speed or reduce invested capital (George 2003).

3. CASE STUDY

3.1 Define Phase

Typology: Shopping complex, Thiruvanmiyur

Site area: 5200sq.ft

Build up area: 3800sq.ft

A Case study was done to understand waste generation during construction phase. The ongoing work was foundation and basement of a shopping complex project under Tamil Nadu Horticulture Department. The purpose of this shopping complex is to sell horticulture related products. The project was started on February 2020 and estimated to be finished by October 2020. Due to corona lockdown restrictions the project was delayed for 2 months(May-June). From July 2020 the project continued. In September 2020 before the processing of first bill of foundation work the Government officials from the Horticulture Department came to inspect the site and found that the basement was too high (.7m) so they insisted to reduce the basement to (.3m). Due to delay in sanction of funds the project was put on hold by September end. Still the project is in process.

3.2 Measure Phase

The foundation process consist of marking, 1) Earthwork excavation for footing and grade beam, 2) Sand filling for footing and grade beam, 3) Steel, centering and RCC for footing and grade bream, 4) Basement brick work. The foundation process has been completed; the brickwork for the basement has been estimated for the depth of 0.7 meter and executed. After execution they felt that the height of basement was more and reduced to 0.3meter.

3.3 Estimated Brick work

The depth of the brick work is estimated as 0.70meter.

Sl. No	Description	Nos			L	B	D	Total
10	Brick work in following Cement Mortar using best quality of Second class ground moulded chamber burnt bricks 9"x4-3/8"x2-3/4" for foundation and basement including curing etc, complete complying with standard specification.							
	In cement mortar 1:5							
	For Foundation and Basement							
	For Grade Beam							
	X- Axis							
	Grid A1-A6	1	x	1	18.23	0.23	0.70	2.93
	Grid B1-B6	1	x	1	13.88	0.23	0.70	2.23
	Grid C1-C6	1	x	1	17.62	0.23	0.70	2.84
	Grid b/w CtoD - 3to5	1	x	1	6.10	0.23	0.70	0.98
	Grid D1-D6	1	x	1	18.15	0.23	0.70	2.92
	Grid E1-E6	1	x	1	18.15	0.23	0.70	2.92
	Cantilever Beam	1	x	1	18.90	0.23	0.70	3.04
	Y- Axis							
	Grid 1A-1E	1	x	1	15.76	0.23	0.70	2.54
	Grid 2A-2E	1	x	1	15.69	0.23	0.70	2.53
	Grid b/w 2to3 - AtoB	1	x	1	2.36	0.23	0.70	0.38
	Grid b/w 2to3 - CtoE	1	x	1	12.03	0.23	0.70	1.94
	Grid 3A-3E	1	x	1	15.46	0.23	0.70	2.49
	Grid 4A-4C	1	x	1	4.02	0.23	0.70	0.65
	Grid 5A-5E	1	x	1	16.06	0.23	0.70	2.58
	Grid 6A-6E	1	x	1	15.76	0.23	0.70	2.54
	Add extra							0.49
	Total							**34.00**

3.4 Bill of quantity for the brick work

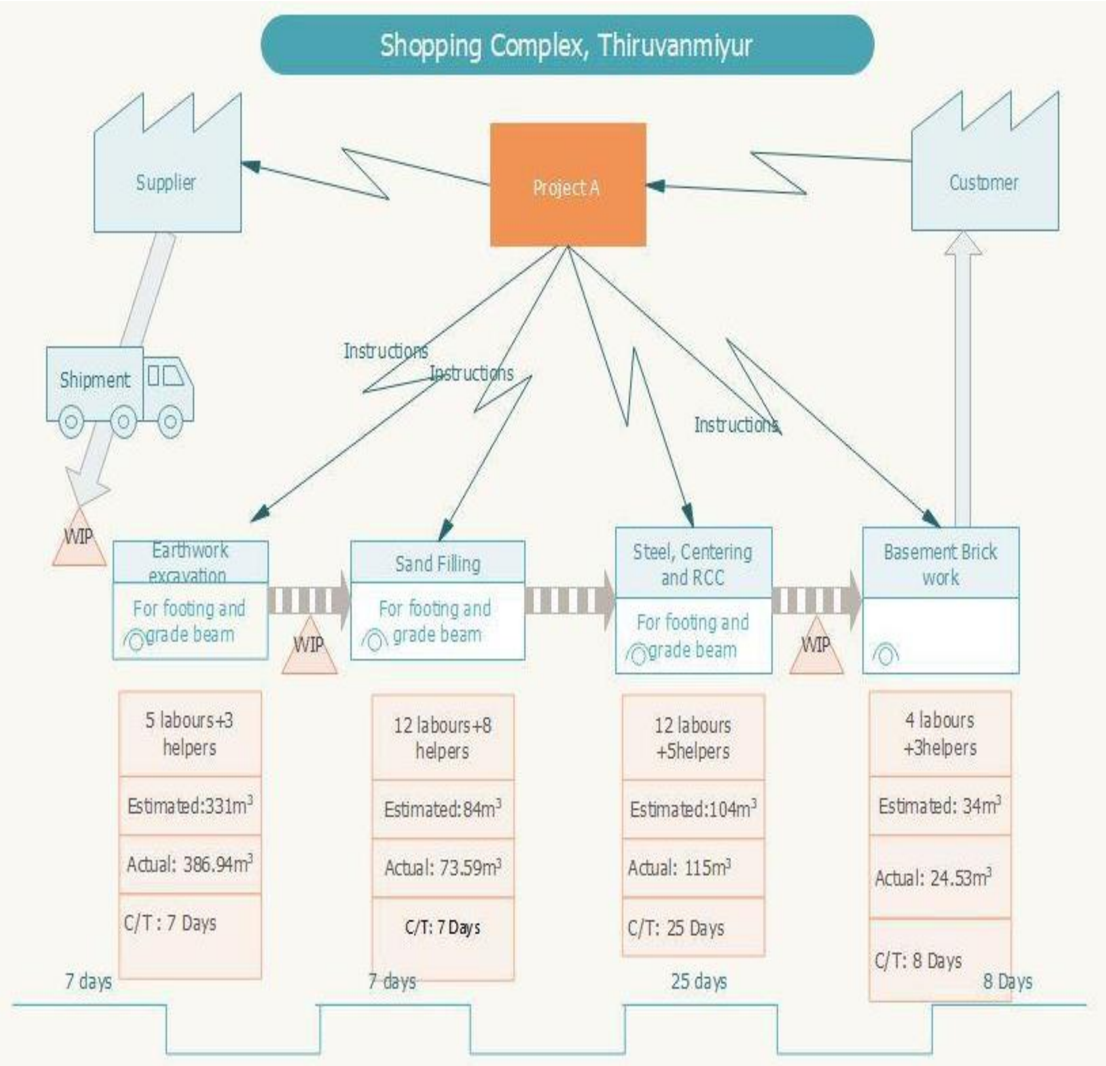
Actual amount spent was Rs.1,47,587. The basement brickwork was broken to a depth of 0.30meter. Wasted amount approx.Rs.74,357.

10			Brick work in following Cement Mortar using best quality of Second class ground moulded chamber burnt bricks 9"x43/8"x2-3/4" forfoundation and basement including curing etc, complete complying with standard specification.		
10a	M^3	24.53	For Foundation and Basement	6016.60	147587.20

3.5 Wastage calculated for basement brick work

Materials	Used	Wasted	Rate/unit
Brick	7500e/a	3000e/a	6.82
Cement bags	45 bags	15 bags	380
M. Sand	8 units	3 units	4500

3.6 Value Stream Mapping



Done using Edraw max software

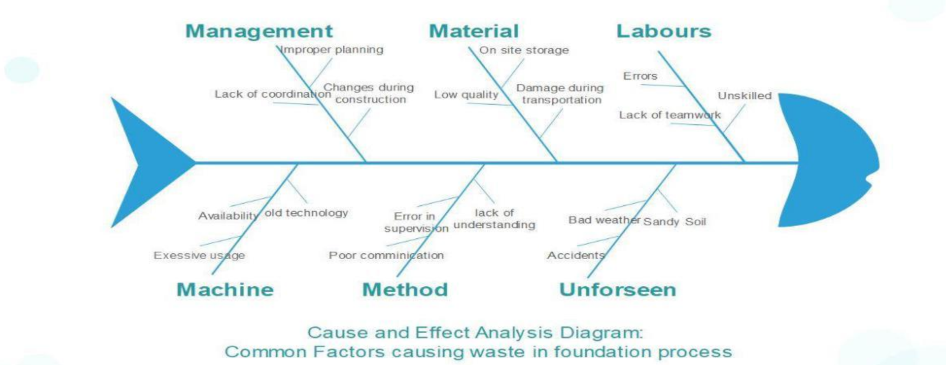
Value Stream Map (VSM) was developed in order to identify, for each step of the foundation process, where waste may occur. A VSM systematically illustrates the relationships between the process, data flows, and logistics. For this study, the VSM organized the four major process involved in the foundation that are the 1) Earthwork excavation for footing and grade beam, 2) Sand filling, 3) Steel, centring and RCC, 4) Basement brick work.

One notable feature of the VSM is the data table, which can be used to organize process-related data, such as time, money, and materials used. In this case study, the information recorded in the data table includes number of labours, estimated area, actual area, and cycle time.

3.7 Analysis Phase

To Analyse, the Six-sigma process improvement method was implemented, with a Cause and Effect Diagram being used to analyse the root causes of the generated waste. The Cause and Effect Diagram helped to identify the root causes of waste under several categories: Unforeseen events, Materials, Labour, Machines, Methods, and Management

3.8 Cause and effect diagram



3.9 Improve Phase

Based on the results from the previous phase, the project group proposed to the Project Manager the following changes in the functioning of the construction process:

- Employment or transfer from another construction of at least one person from the general supervision of the contractor.
- A decision was made to accept one more person from the engineering team. The given person will support the team in terms of inter-branch coordination, checking the correctness of the works carried out and quality control during the works performed.
- Introduction to the schedule of weekly meting with the bricklaying company together with the installation subcontractor.

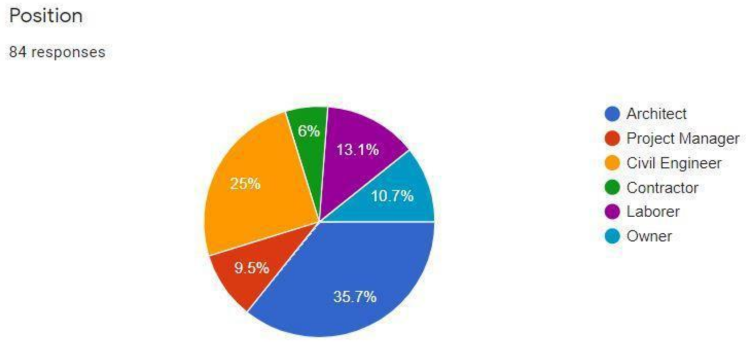
Meetings, held once a week, will allow construction supervision and subcontractors to better communicate, establish a daily work schedule and better synchronization of fronts of both companies. In addition, a note from the meeting will contain a table in which will be marked places ready to brick up. Additionally, in order to minimize problems related to communication, it was decided to introduce the principle of informing each other also via e-mail. The messages will also be sent to the construction manager, which will help solve possible problems in a wider circle. The team leader, i.e. the Project Manager, also decided to organize the integration trip of supervisory staff to improve communication in the team.

3.10 Control Phase

Implementation of improvements to the process aimed at reducing waste ran from Jan to March. As part of the inspection, during the works on the building the measurements of the walls were made together with the calculation of the waste generated. If too much non-reusable material was found, the supervision was to conduct a special coordination meeting. The solutions introduced, proposed in the IMPROVE phase, did not force supervision to organize such a meeting. As a result waste was decreased by almost half. Common factors that contribute to the generation of waste in construction were identified for each stage. Then a Pareto chart is used to explore how to improve the most commonly occurring waste causes. First, the Cause and Effect Diagram helped to identify the root causes of wastes. Factors most likely to affect the generation of waste, under these categories were listed such as:

1. Planning and Design phase
2. Operation phase
3. Material Handling
4. Procurement
5. Questions for Causes of waste in construction

The set of 45 potential factors which contribute most to waste generation was identified. A questionnaire was developed and sent to architects, contractors and project managers involved with on-site construction activities. All 84 responses were returned within 4 weeks.

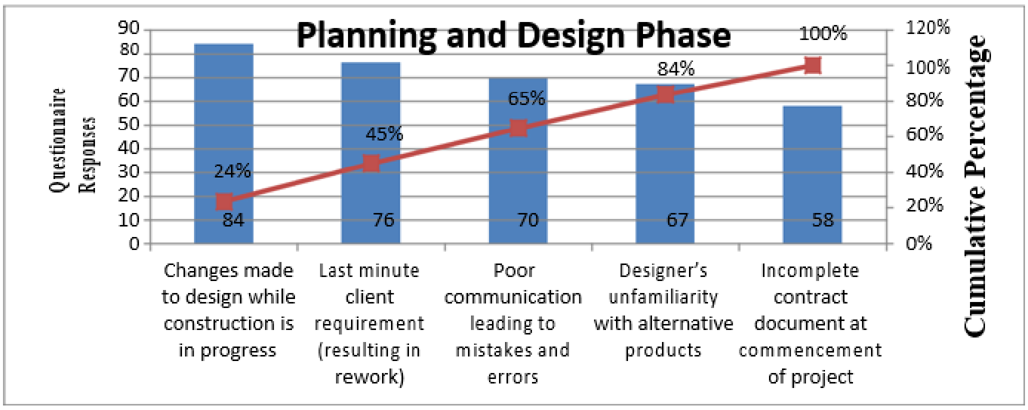


3.11 Questionnaire Survey

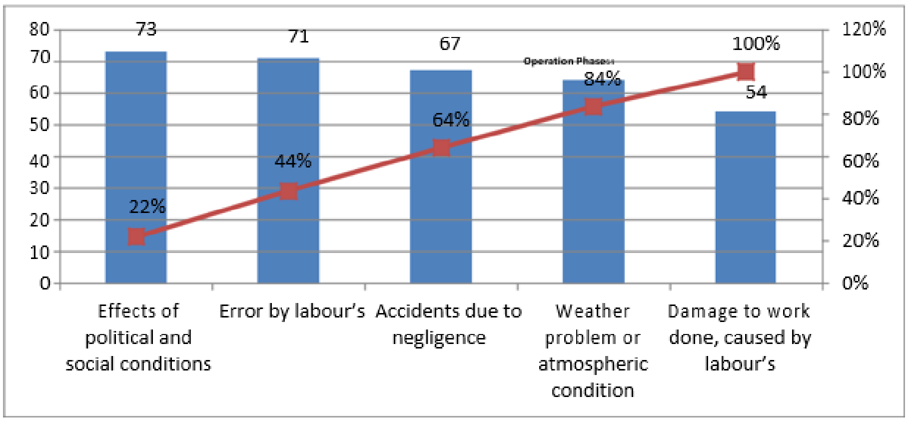
Category	Factors affecting generation of construction waste	Relative Index	Ranking by category
1. Planning and Design Phase	1. Changes made to design while construction is in progress	0.119596	1
	2. Lack of attention paid to standard sizes available in the market.	0.079067	7
	3. Designer's unfamiliarity with alternative products	0.094852	4
	4.Complexity of detailing in drawing	0.0812	6
	5. Lack of information in the drawing	0.072241	8
	6. Error in contract document	0.067691	10
	7. Incomplete contract document at commencement of project	0.082622	5
	8. Selection of low-quality product	0.061007	12
	9. Designer's inexperience in method and sequence of construction.	0.06186	11
	10. Last minute client requirement (resulting in rework)	0.108362	2
	11. Poor communication leading to mistakes and errors	0.099261	3
	12. Lack of knowledge about construction techniques during design activities	0.072241	9
2. Operation Phase	1. Error by labor's	0.122807	2
	2. Accidents due to negligence	0.114723	3
	3. Damage to work done, caused by labor's	0.092879	5
	4. Use of incorrect material	0.087375	9
	5. Method adopted and sequence of construction	0.087375	8
	6. Delaying in passing the information to the contractor on type of product to be used	0.090127	6

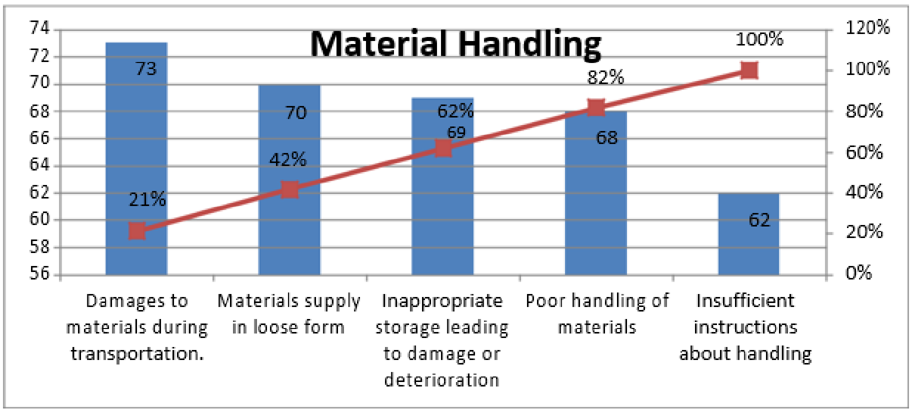
	7. Equipment malfunctioning	0.081871	10
	8. Weather problem or atmospheric condition	0.109219	4
	9. Difficulties in obtaining work permits	0.088751	7
	10. Effects of political and social conditions	0.124871	1
3. Material Handling	1. Damages to materials during transportation.	0.124871	1
	2. Required quantity unclear due to improper planning	0.117533	9
	3. Inappropriate storage leading to damage or deterioration	0.086943	3
	4. Materials supply in loose form	0.111737	2
	5. Unfriendly attitude of project team and labour	0.112381	8
	6. Theft	0.08179	10
	7. Manufacturing defects	0.09451	6
	8. Insufficient instructions about handling	0.099662	5
	9. Using excessive quantities of materials than required	0.093544	7
	10. Poor handling of materials	0.109966	4
4. Procurement	1. Ordering errors(eg., ordering significantly more or less)	0.266258	2
	2. Lack of possibility of order of small quantities	0.240082	3
	3. Purchased product that do not comply with specification	0.220859	4
	4. Changes in material prices	0.272802	1
5. Causes of waste in construction	1. Waste minimization enhances the productivity in Construction activity?	0.05314	8
	2. Complexity of detailing in the drawings	0.132664	4
	3. Selection of low-quality products also one of the reason for increasing waste?	0.132664	5
	4. Poor technology will decrease the productivity?	0.100334	7
	5. Waste produced due to over ordering & over production	0.120959	6
	6. Waste due to re-work	0.16518	1
	7. Insufficient instructions about handling generate waste	0.153475	2
	9. Effects of political and social conditions create an impact	0.141583	3

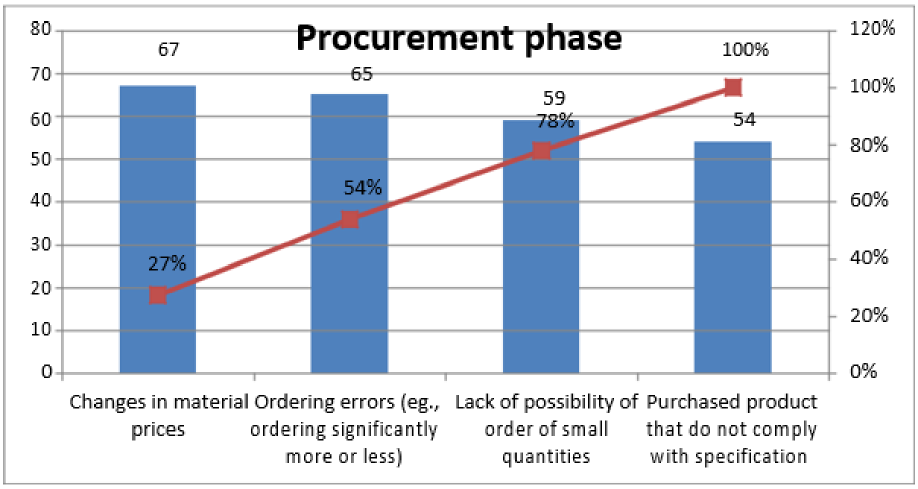
The Pareto chart was used to create a representation of the feedback revealed by the questionnaire results. Applying the Pareto principles, each factor was evaluated based on how it was ranked in the questionnaire. Top 5 factors of each phase of construction were selected for Pareto chart. Pareto Chart Analysis

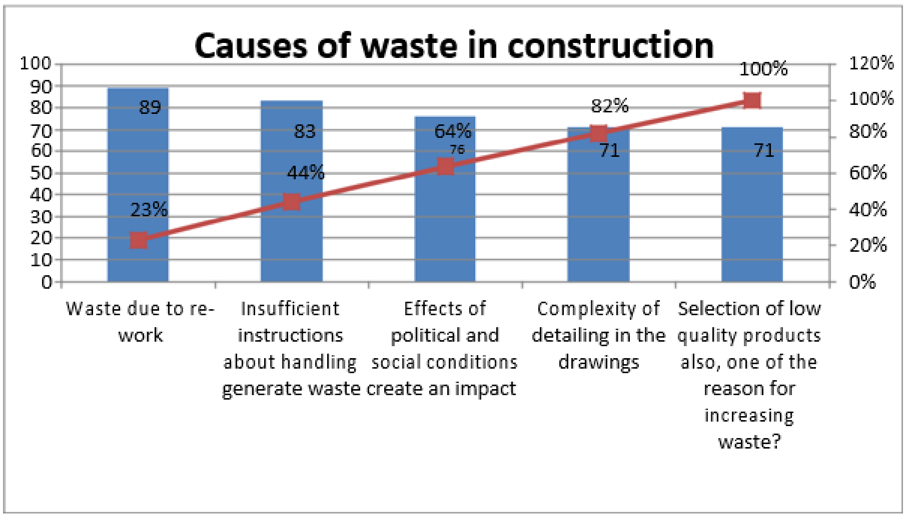


A majority of on-site workers concurred that reducing or eliminating the likelihood of design changes during construction would help increase process performance by reducing waste. This might be achieved through establishing clear communication between involved parties, especially during the early phases of the project. During Planning and Design phase 1) Changes made to design while construction work is in progress, 2) Last minute client requirement, 3) Poor communication leading to mistakes and errors and 4) Designer's unfamiliarity with alternative product, these factors contribute 84% of waste during planning phase.









4. CONCLUSION

Waste due to rework contributes the maximum percentage in the overall factors. Rework can be minimized when proper planning is done and approved by all the stakeholders. Steps to be followed to minimize waste are:

Define- Current problems
Measure - The process and work flow
Analyse- Identify the root cause for the problem
Improve – Create solutions to tackle the root cause
Control – Sustain solution

For future works it is necessary to develop a prospective model incorporating Lean, Green, and Six-sigma tools to prevent waste by diagnosing in advance the planned processes likely to produce waste. Improved planning and enhanced control during the earliest phases of the project have even greater potential to decrease the expense and environmental impacts of waste. Benefits of lean and six sigma provide structured methods of improvement to reduce waste, shorten production time, improving planning and control and ultimately high levels of client satisfaction.

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