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INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS

THESIS NO: 080/MSCoM/024

**Evaluating the Applicability of DUDBC Norms for Quantity Estimation:
A Case Study of 9-inch-thick Brick Masonry Works in Kathmandu Valley**

by

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A THESIS

**SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER OF SCIENCE IN CONSTRUCTION MANAGEMENT**

DEPARTMENT OF CIVIL ENGINEERING

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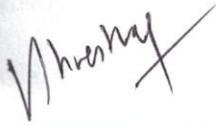
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DECLARATION

I hereby declare that the thesis entitled “**Evaluating the Applicability of DUBBC Norms for Quantity Estimation: A Case Study of 9-inch-thick Brick Masonry Works in Kathmandu Valley**” submitted to the Department of Civil Engineering in partial fulfilment of the requirement for the degree of Master of Science in Construction Management, is a record of an original work done under the guidance of Thesis Supervisor Asst. Prof. Mahendra Raj Dhital, Institute of Engineering, Pulchowk Campus. This thesis contains only work completed by me except for the consulted material which has been duly referenced and acknowledged.



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ABSTRACT

Construction industry is one of the most resource intensive sectors and plays a key role in development activities. Reliable cost estimation is essential for effective planning and control of construction projects. Quantity estimation forms the basis of cost estimation, and in Nepal, this process is guided by norms developed by DUDBC. However, discrepancies are often observed between quantities prescribed by norms and actual usage. This study evaluates the applicability of DUDBC norms for quantity estimation of 9-inch-thick brick masonry works in Kathmandu Valley, and investigates the causes of deviation and potential interventions to improve their applicability in real site conditions. A mixed-method approach was adopted using 89 observations from 15 construction sites, combined with expert consultation. Statistical tools, including descriptive analysis, one-sample t-test, one-sample Wilcoxon signed-rank test, and SPC, were used to analyze the observed data, while the Delphi method was applied to analyze expert responses. The results show statistically significant deviations between DUDBC norms and actual site practices for all resources ($p < 0.05$). Brick quantity and labour usage were lower than standard values, whereas cement and sand consumption were higher. SPC analysis indicated stable variability, but inconsistent process means. Key factors contributing to deviations include brick size variation, mortar thickness, mason skill, and management practices. The study concludes that DUDBC norms require periodic updates along with improvements in site practices to enhance applicability under real construction conditions.

Keywords: DUDBC norms, brick masonry, quantity estimation, descriptive statistics, inferential statistics, statistical process control, Delphi method

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TABLE OF CONTENTS

COPYRIGHT	II
DECLARATION	III
CERTIFICATE OF THESIS APPROVAL	IV
ABSTRACT	V
ACKNOWLEDGEMENT	VI
LIST OF TABLES	X
LIST OF FIGURES	XI
LIST OF PHOTOGRAPHS	XII
LIST OF SYMBOLS & ABBREVIATIONS	XIII
CHAPTER 1: INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement	2
1.3 Research Questions	2
1.4 Objectives	3
1.5 Significance of the Study	3
1.6 Scope and Limitations of the Study	3
CHAPTER 2: LITERATURE REVIEW	5
2.1 Theoretical Framework.....	5
2.1.1 Cost estimation.....	5
2.1.2 Quantity estimation.....	5
2.1.3 Cost estimation norms.....	6
2.1.4 DUDBC norms.....	6
2.1.5 Nepal Building Code (NBC).....	7
2.1.6 Prevalent issues of cost estimation in the construction industry.....	7
2.1.7 Brick masonry	8
2.1.8 Components of brick masonry work.....	9
2.1.9 Manpower requirement in brick masonry works	11
2.1.10 Relevance of brick masonry in contemporary times.....	12
2.1.11 Impacts of brick masonry works on construction cost.....	12
2.1.12 Cross-sectional research.....	12
2.1.13 Inferential statistics	12
2.1.14 Statistical process control	13

2.1.15 Use of SPC in construction projects	17
2.1.16 Delphi method.....	17
2.2 Review of Relevant Studies	18
CHAPTER 3: METHODOLOGY	20
3.1 Research Approach	20
3.2 Research Design.....	20
3.2.1 Research Methodology	20
3.2.2 Research Framework	22
3.3 Study Area	23
3.4 Population, Sampling Technique and Site Selection	24
3.5 Data Collection Methods	25
3.5.1 Data from observations at construction sites	25
3.5.2 Survey Delphi Method.....	30
3.5.3 Secondary Data	30
3.6 Data Analysis Techniques.....	31
3.6.1 Data from site observations	31
3.6.1.1 Quantitative analysis for data from field observations	31
3.6.2 Data from expert consultation.....	34
3.6.2.1 Qualitative analysis.....	34
3.6.2.2 Quantitative analysis for expert responses.....	34
3.7 Reliability and Validity.....	35
3.8 Research Matrix	36
3.9 Ethical Considerations	37
CHAPTER 4: RESULTS	38
4.1 Assess and analyze the applicability of DUDBC norms by comparing standard values with observed field data.....	38
4.1.1 Comparative analysis with standard values	38
4.1.2 Descriptive statistics	39
4.1.3 Inferential statistics	40
4.1.4 Frequency distribution analysis	43
4.1.5 Statistical process control analysis.....	48
4.2 Factors contributing to deviations between DUDBC norms and actual site data..	57
4.3 Potential interventions for improving the applicability of DUDBC norms.....	63
CHAPTER 5: CONCLUSION AND RECOMMENDATIONS	71

5.1 Conclusions.....	71
5.2 Recommendations.....	73
REFERENCES.....	75
APPENDIX 1: DATA COLLECTED FROM OBSERVATIONS	79
APPENDIX 2: SITE MEASUREMENT COLLECTION FORMAT.....	81
APPENDIX 3: STATISTICAL CALCULATIONS	82
APPENDIX 4: DELPHI FORM ROUND 1 AND 2.....	91
APPENDIX 5: DELPHI, RESPONSE FROM EXPERTS	101
APPENDIX 6: EXPERTS SELECTED FOR DELPHI AND SITE IN CHARGE FROM OBSERVED CONSTRUCTION SITES	106
APPENDIX 7: PHOTOGRAPHS	107
APPENDIX 8: ACCEPTANCE E-MAIL FOR 18TH IOE GRADUATE CONFERENCE.....	116
APPENDIX 9: ORIGINALITY REPORT	117

LIST OF TABLES

Table 3.1: Research matrix	36
Table 4.1: Comparison between observed and standard values	38
Table 4.2: Statistical summary of resource consumption	39
Table 4.3: Shapiro-Wilk test of normality	40
Table 4.4 Results of one sample t-test	41
Table 4.5: Results of one-sample Wilcoxon signed rank test.....	41
Table 4.6 Validated factors causing deviation in resources.....	58
Table 4.7 Potential interventions for enhancing applicability of norms.....	63
Table 4.8 Results of Delphi analysis for factors affecting deviation in resource utilization	59
Table 4.9: Ranking of identified factors	62
Table 4.10 Results of Delphi analysis on potential interventions for applicability of norms.....	65
Table 4.11: Ranking of identified potential interventions	67

LIST OF FIGURES

Figure 3.1: Research flowchart	21
Figure 3.2: Research Framework.....	23
Figure 4.1 Frequency distribution of brick consumption per cubic meter.....	43
Figure 4.2 Frequency distribution of cement consumption per cubic meter	44
Figure 4.3 Frequency distribution of sand consumption per cubic meter.....	45
Figure 4.4 Frequency distribution of skilled manpower usage per cubic meter	46
Figure 4.5 Frequency distribution of unskilled manpower usage per cubic meter	47
Figure 4.6 X-bar chart for brick usage.....	48
Figure 4.7 R-chart for brick usage	49
Figure 4.8 X-bar chart for cement usage	50
Figure 4.9 R chart for cement usage	51
Figure 4.10: X-bar for sand usage.....	51
Figure 4.11 R chart for sand usage	52
Figure 4.12 X-bar chart for skilled manpower usage	53
Figure 4.13 R chart for skilled manpower usage	54
Figure 4.14 X-bar chart for unskilled manpower usage	55
Figure 4.15 R chart for unskilled manpower usage	56

LIST OF PHOTOGRAPHS

Photograph 3.1: Measurement of standard box	26
Photograph 3.2: Material measurement using standard box selected for study.....	26
Photograph 3.3: Material measurement using standard box available on site.....	27
Photograph 3.4: Brickwork on selected construction sites	28
Photograph A7. 0.1: Photograph at site S1	107
Photograph A7. 0.2: Photograph at site S2	107
Photograph A7. 0.3 : Photograph at site S3	108
Photograph A7. 0.4: Photograph at site S4	108
Photograph A7. 0.5: Photograph at site S5	109
Photograph A7. 0.6: Photograph at site S6	109
Photograph A7. 0.7 : Photograph at site S7	110
Photograph A7. 0.8: Photograph at site S8	110
Photograph A7. 0.9 :Photograph at site S9	111
Photograph A7. 0.10 : Photograph at site S10	111
Photograph A7. 0.11 : Photograph at site S11	112
Photograph A7. 0.12 : Photograph at site S12	112
Photograph A7. 0.13 : Photograph at site S13	113
Photograph A7. 0.14 : Photograph at site S14	113
Photograph A7. 0.15 : Photograph at site S15	114
Photograph A7. 0.16 : Site raw data collection	115

LIST OF SYMBOLS & ABBREVIATIONS

NBC	: National Building Code
DUDBC	: Department of Urban Development and Building Construction
RUD	: Ready to Use Detailing
CV	: Coefficient of Variance
SPC	: Statistical Process Control
UCL	: Upper Control Limit
CL	: Centre Line
LCL	: Lower Control Limit
X-bar chart	: Mean chart
R chart	: Range chart
IQR	: Inter Quartile Range
Q1	: First Quartile
Q2	: Second Quartile

CHAPTER 1: INTRODUCTION

1.1 Background

Construction is one of the foundational activities of human civilization. It reflects the evolution of society, with built structures representing social values, organization, and technological progress (Courrier & Rosaz, 2026). Construction projects are inherently resource intensive and at the same time play a pivotal role for driving development endeavours. The construction industry is one of the most capital-intensive sectors globally, contributing significantly to economic growth, infrastructure development, and urban transformation (James, 2026)

In Nepal, construction sector is growing rapidly, especially in urban areas like Kathmandu Valley. With rapid growth in such a resource intensive field, proper planning for budget and resources management is essential to lead a balanced multi-sectoral development of the country.

One of the fundamental steps in planning a construction project is to develop a reliable cost estimate that reflects the budgetary requirements of the project. Accurate cost estimation supports effective budgeting, efficient allocation of resources, informed decision making and cost control throughout the execution phase. (Blessing & Ifeanyi, 2025)

Diving deeper in this line of thought, at roots of cost estimation process lies estimates of quantity of work items which when matched with prevalent rates of items gives desired cost estimation. The quantity of work item directly correlates with unit material usage, equipment usage and productivity of labour.

In context of Nepal, Department of Urban Development and Building Construction (DUDBC) provides standardized norms for material consumption, labour productivity, and equipment usage for various construction work items in building projects. These norms are the basis for rate analysis which is used for building construction projects throughout Nepal's construction industry. (DUDBC, 2041) However, actual site conditions affected by variations in workmanship, changing building practices and contextual constraints often lead to discrepancies between prescribed norms and real resource utilization.

Despite widespread usage of DUDBC norms, limited empirical research has tested their applicability under real construction site conditions. This research aims to address that gap by evaluating the reliability of DUDBC norms for 9-inch-thick brick masonry works; one of the most popular and material/ labour intensive work item focusing on construction sites in Kathmandu Valley. By comparing prescribed standards with measured on-site data, the research aims to identify discrepancies and recommend adjustments for more reliable and context-relevant estimation practices.

1.2 Problem Statement

Substantial gaps persist between prescribed unit quantities for brick, cement, sand, and labour as per DUDBC norms and actual resource utilization on construction sites. Such mismatch between standard norms and actual site usage can result in cost overruns, disputes, and even impact quality and schedule aspects due to inefficiency in work progress. (Mulyanto & Prabowo, 2024)

Informal discussions regarding the relevance of norms due to changes in construction practices, workforce behaviour, and the need to update the norms themselves are prevalent within the industry workforce. But very few studies have been conducted to identify such discrepancies and the significance of their impact. Hence, a systematic study is needed to:

- Quantify discrepancies between DUDBC norms and on-site data
- Identify underlying causes for deviation
- Identify evidence-based interventions to improve the applicability of standards

1.3 Research Questions

The study addresses the following research questions:

- i. To what extent do DUDBC norms reflect actual resource utilization on site, and what is the magnitude of deviation from observed site data?
- ii. What are the key factors causing deviation between DUDBC norms and actual site practices?

- iii. What interventions can enhance the applicability of DUDBC norms under actual site conditions?

1.4 Objectives

The primary objective of this study is to evaluate the applicability of DUDBC norms for estimating material usage and labour productivity in 9-inch-thick brick masonry works under actual site conditions. To achieve this aim, the study is guided by the following specific objectives:

- i. To assess and analyze the applicability of DUDBC norms for 9-inch-thick brick masonry work by comparing standard values with observed field data.
- ii. To identify and analyze the factors contributing to deviations between DUDBC norms and actual site data using expert consensus through the Delphi method.
- iii. To identify and prioritize potential interventions for improving the applicability of DUDBC norms using expert consensus through the Delphi method.

1.5 Significance of the Study

The study addresses a major gap in the empirical validation of DUDBC norms for brick masonry work. Brick masonry is a dominant and resource-intensive construction material in Kathmandu valley. Due to extensive use of brick masonry work, reliable estimation of materials consumption and labour productivity is very essential, and it directly affects budgeting, resource allocation, and overall performance of the project.

The findings of this study will help to identify and fill the existing research gap by identifying any significant discrepancies, their underlying causes, and providing evidence-based recommendations to improve norms, which will enhance reliability and relevance for actual use.

1.6 Scope and Limitations of the Study

The scope of this study includes field-based measurement and data collection to determine the actual usage of materials and manpower in 9-inch-thick brick masonry work across construction sites within Kathmandu Valley. The study also seeks to identify the key factors contributing to these variations and potential interventions that can improve the applicability of norms under real site conditions.

However, the study is also subjected to certain limitations. The findings are based on observations from a specific geographic region, which may restrict their generalizability to other regions with different construction conditions. Data collection was conducted over a limited time frame; therefore, seasonal variations such as monsoon effects and festival-related labour shortages are not fully captured. Measurement of water usage was excluded due to its relatively minor contribution to the overall construction cost. Additionally, workers who were involved during observations were trained to follow a predefined method statement, which may affect actual productivity and resource usage. Despite efforts to minimize observer effect, the workers' behaviour may have been influenced during the observation period. Additionally, sand bulking due to moisture variation may have affected volumetric measurements. Minor discrepancies may also have arisen due to unquantified, very small brick fragments during measurement.

CHAPTER 2: LITERATURE REVIEW

The literature review section presents an elaborate study of relevant theories and past studies that support and set the direction for the research. The chapter is organised into two main components. The first part discusses the theoretical framework that establishes the fundamental concepts and definitions relevant to the study based on existing theories. The second part focuses on a review of past studies and published papers that highlight the findings of similar studies and provide a basis for the development of current study.

2.1 Theoretical Framework

The theoretical framework outlines main concepts, models, definitions, and established theories which forms the base of the study. It supports the analysis of relationships among variables and guides the interpretation of results. By linking the study to established knowledge, the framework provides a structured approach for analyzing the research gap and explaining observed outcomes within a broader theoretical context. (Kavitha et al., 2025)

2.1.1 Cost estimation

Cost estimation is simply a process of determining the expected expenditure of a project, program or goods by calculating all the resources needed, which includes labour, material and overheads. Cost estimation plays a critical role in project management of any kind. It helps the management body to create budget plans, make informed financial decisions and also practice effective cost control measures without compromising on desired quality. In construction projects, accurate cost estimation is essential for effective resource allocation, decision making, and maintaining financial control. (Bozorgmehr Nia et al., 2023).

2.1.2 Quantity estimation

Quantity Estimation is a vital sub-step involved in cost estimation process. It calculates the amounts of specific work items involved in a project. For a building construction project, the items are brickwork, PCC, rebar works, plastering etc. Total quantity of

such work items is ascertained in standard units of measurement. Accurate quantity estimation is the heart of precise cost estimates.

2.1.3 Cost estimation norms

Cost estimation norms are established standards which are based on industry benchmarks and standardized processes that gives estimates for labour, materials and equipment for specific work item. This translates to number of skilled and unskilled manpower needed, materials and equipment needed for a standardized volume of work. Eg, number of skilled and unskilled manpower, bricks, weight of cement, volume of sand and water needed for one cubic meter of brick masonry work.

2.1.4 DUDBC norms

DUDBC norms are the standardized estimates for the usage of resources and equipment for a unit work item of building construction work intended for use in Nepal. Ideally, these norms represent the basis for the quantity estimation of work items for all building construction works within Nepal.

The norms for rate analysis were initially developed in 2041 B.S. under the Ministry of Housing and Physical Planning and later amended by Ministry of Water Resources in 2050 B.S. Currently, these norms are maintained and implemented by the Department of Urban Development and Building Construction (DUDBC) and are widely used as the standard reference for construction estimation in Nepal.

Each work item has a specific standard consumption rate which specifies the amount of material and labour required for one unit of work. As per DUDBC norms (DUDBC, 2041); 1 cubic meter of brick masonry work in 1:6 cement sand mortar consumes;

- 560 nos. of bricks
- 0.07 metric ton of cement
- 0.3 cubic meters of sand
- 100 liters of water
- 2.2 number of skilled manpower
- 1.5 number of unskilled manpower

These standards when combined with approved district rate for the fiscal year become the base for establishing rate analysis of each building work items and subsequently aid in accurate construction cost estimation of the entire project.

Here, unit number of manpower refers to 8 hours of worktime including prescribed breaktimes as per Nepal Labour Act.(Nepal Labour Act, 2017)

2.1.5 Nepal Building Code (NBC)

In context of Nepal, NBC provides a comprehensive set of guidelines and standards developed to regulate building construction activities, ensuring safety, health, accessibility, and sustainability in the built environment. (DUDBC, 2024) provides specifications and guidelines for burnt brick masonry construction under NBC 205: 2024.

The code specifies that bricks shall be well-burnt, of standard rectangular shape, and may be either hand-moulded or machine-made, with a minimum compressive strength of 3.5 N/mm². The recommended nominal size of mortar joints is approximately 10 mm thick. In terms of construction practices, the code emphasizes proper workmanship, including pre-soaking of bricks, full bedding of mortar, and complete filling of vertical joints with staggered bonding between courses. The wall thickness is specified to range from half-brick (approximately 115 mm) to one-brick thickness (approximately 230 mm or 9 inches). Correspondingly, cement–sand mortar mixes of 1:4 and 1:6 are recommended for half-brick and full-brick walls, respectively. (DUDBC, 2024)

These provisions establish the standard assumptions for brick dimensions, wall configuration, and mortar proportions used in quantity estimation and resource planning. Any deviation from these specifications can significantly influence material consumption, labour productivity, and overall construction performance.

2.1.6 Prevalent issues of cost estimation in the construction industry

Managing cost information remains a significant challenge in the construction industry, with inaccurate estimation being one of the key concerns. Cost estimation is affected by a large number of dynamic influencing factors. Large infrastructure projects are often seen to exceed initial budgets due to inaccuracy in estimates, changes in scope,

fluctuations in material prices, labour inefficiencies, and unforeseen site conditions. (James, 2026) In addition to cost overruns, issues such as disputes and compromised project outcomes also may arise.

In the context of Nepal, particularly within the Kathmandu Valley, these issues are further intensified by the rapid urbanization and evolving construction practices. The reliance on standardized norms, such as those provided by the DUDBC, aims to bring consistency to estimation; however, discrepancies between these norms and actual site conditions are common.

Factors such as varying skill levels of labour, inconsistent material quality, logistical constraints, and seasonal labour availability increase estimation inaccuracies. Furthermore, limited empirical validation of existing norms and outdated standards for quantity estimation add to the complexity, often resulting in budgets that do not reflect site realities.

2.1.7 Brick masonry

Brick masonry work is a construction technique in which bricks are laid in a regular pattern and bonded in mortar to build a solid, durable structure capable of bearing loads. Mortar, typically made from cement, sand, and water, binds the bricks together and fills the joints, providing both strength and stability to the structure.

a. Types of brick masonry

- Brickwork in Mud: This type uses mud as a binding material. It is low-cost and suitable for a non-load-bearing wall.
- Brickwork in Cement: This type uses cement-sand mortar (e.g., 1:4 or 1:6 mix ratio), which is stronger, more durable, and commonly used in permanent structures.

b. Brick Bond Patterns

Bricks are arranged in specific bonding patterns to improve strength and aesthetics. Common bond types include (Gupta, 2019):

- Stretcher bond: Bricks are laid with their longer faces parallel to the wall surface.

- Header bond: Bricks laid with their shorter ends facing the wall surface.
- English bond: Bricks are laid with alternate headers and stretchers course.
- Flemish bond: Each course consists of alternating headers and stretchers.

2.1.8 Components of brick masonry work

- **Brick**

Bricks are masonry components typically produced from earthen materials like clay. Burnt clay bricks are extensively used because of their strength, durability, and resistance to environmental and fire related effects.

Bricks can be categorized into different types based on their composition, appearance and application, including burnt clay, sand lime, fly ash, and fire clay bricks, as well as solid and perforated forms. (Gupta, 2019, pp. 103-122)

Brick is one of the most widely used masonry units and is often preferred when locally available in acceptable quality and strength. It offers desirable properties such as strength, durability, dimensional stability, thermal efficiency, good fire rating, and cost-effectiveness.(Bureau of Indian Standards, 1991, pp. 108)

- **Cement**

Cement is a finely ground binding material that, when mixed with water, undergoes hydration and hardens to form a solid mass capable of binding other construction materials such as sand and aggregates.

- **Sand**

Sand is a granular material consisting of finely divided rock and mineral particles. In construction, sand acts as a fine aggregate in mortar and concrete mixes. It provides bulk, stability, and improves the workability and strength of the mortar used in brick masonry.

- **Water**

Water is a vital component in mortar and concrete preparation. It reacts chemically with cement in a process called hydration, causing the mixture to harden and gain strength. The right amount of water ensures proper workability and durability of the mortar in brick masonry.

- **Mortar**

Mortar is an workable mixture of binding materials, such as cement or lime, and fine aggregates such as sand or surkhi. (Bureau of Indian Standards, 1991, pp. 7) It's mix proportion and volume play a significant role in determining material consumption in brick masonry.

- **Quantity estimation of water**

Water is a vital component in brick masonry work with regard to strength and workability. However, cost aspect of water required for brick masonry work is very low compared to brick, cement, sand and labour. Subsequently, it doesn't have a notable impact on total project cost.

Additionally, construction sites use borewells, municipal lines for water and even mortar mix are done without measurement logs unlike cement, brick and sand. This makes water usage data very hard to quantify and validate.

Hence, water usage is omitted for most of the cost driven analysis and studies. Cost of water is found to be calculated as percentage of total material and labour cost rather than from separate volume in several practices. (Dutta, 2016, pp. 492) uses 1.5% water charges addition on material and labour cost for brickwork with 1:6 cement: sand mortar. (Central Public Works Department, 2023, pp. 325, 327) uses 1% water charges addition on material and labour cost for same mortar mix.

- **Bulking of sand**

Bulking of sand occurs due to the presence of moisture, where a thin film of water forms around sand particles and keeps them apart due to surface tension. This results in an increase in the apparent volume of sand. Bulking effect increases with moisture

content up to a certain limit and then decreases and comes down to zero when the sand becomes fully saturated. For fine sand, bulking can be significant and may reach up to about 40% for 5% moisture content, whereas for coarse sand it is relatively lower. (Gupta, 2019, pp. 113)

2.1.9 Manpower requirement in brick masonry works

Manpower required in brick masonry work is a combination of skilled masons and unskilled helpers, as categorized by DUDBC norms. The effective coordination between these two groups is essential for achieving the desired quality, productivity, and efficiency in masonry construction.

- **Skilled manpower in brick masonry work**

Skilled manpower in brick masonry work refers to workers who are trained to accurately lay bricks and blocks to construct durable walls and structures. They prepare and apply mortar, cut bricks to fit, and ensure proper alignment and levelling. Skilled masons apply safety protocols while working efficiently. Their expertise directly impacts the quality and strength of masonry work.

- **Unskilled manpower in brick masonry work**

Unskilled manpower in brick masonry work refers to labourers who perform basic manual tasks without specialized training. Their duties include carrying and loading materials, mixing mortar, site preparation, cleaning debris, digging trenches, and assisting skilled masons. Unskilled labourers are crucial for cost-effective project completion and flexible workforce deployment but require supervision and training for safety and efficiency. They handle physically demanding work and contribute to the overall construction process by supporting skilled craftsmen.

- **Labour productivity and its effect**

Labour productivity is a critical determinant of construction cost. Factors such as site conditions, worker skill levels, supervision quality, and material supply affect the production rate for brick masonry work. Labour productivity in brick masonry work is highly variable and difficult to predict, which makes it a major factor that significantly influences construction costs. (Lawaju et al., 2021)

2.1.10 Relevance of brick masonry in contemporary times

Bricks are universal, ecological, and recyclable building material which has been widely used as a construction material for centuries. Brick as a construction material, continues to remain relevant despite advancements in the building industry. Its durability, resistance to weather conditions, aesthetic value, and properties such as being non-toxic, fire-resistant, and recyclable make it a sustainable material for long-term use. (Fiala et al., 2020)

Masonry structures comprise a major portion of buildings worldwide and is expected to continue for centuries due to socio-economic factors, cultural preferences, economic viability, and resource availability, among others. (Parajuli et al., 2020) These recent studies suggest that brick masonry works remain one of the most widely used and significant construction items in modern practice.

2.1.11 Impacts of brick masonry works on construction cost

Brick masonry works significantly influence construction cost through direct material and labour expenses, labour productivity variations, and the risk of cost overruns due to delays, rework, and resource management challenges. Brick masonry is a major part of building construction; any inaccuracies during estimation or modifications during execution can significantly impact the overall project cost. In addition, rework in brick masonry leads to increased costs due to additional labour, material wastage, and project delays.

2.1.12 Cross-sectional research

A cross-sectional study collects data from a population or sample at a single point in time. It is often used to assess the prevalence of characteristics or outcomes and is typically quick and cost-effective. Cross-sectional studies can be qualitative, quantitative, or mixed-methods.

2.1.13 Inferential statistics

Inferential statistics use sample data to make generalizations or predictions about a population. This involves hypothesis testing, confidence intervals, and estimating

population parameters. Inferential methods help to determine if observed patterns are likely to be true for the whole population or just the collected sample.

Shapiro–Wilk test: This test evaluates whether the sample data follow a normal distribution. Relevant tests are applied based on the result of normality.

One-sample t-test: Mean of the collected sample and a known population mean is compared in this test. It is used when the data are approximately normally distributed. It helps to decide if the collected sample is significantly different from the population. For example, testing if the average brick usage as per data collected from construction sites differs significantly from the DUDBC norm.

One-Sample Wilcoxon Signed-Rank Test: It is a non-parametric alternative to the one-sample t-test. It compares the median of a sample to a hypothesized value and is used when the data do not follow a normal distribution. Instead of using raw values, it ranks the differences between observed values and the hypothesized value. For example, it can be used to test whether the median cement or labour usage differs significantly from the DUDBC norm when the assumption of normality is not satisfied.

2.1.14 Statistical process control

Consistent product quality depends on a controlled process that produces uniform results with minimal fluctuations. Statistical Process Control (SPC) is a collection of statistical tools used to monitor, control, and improve process performance by reducing variability. (Montgomery, 2009)

Statistical process control (SPC) comprises the use of statistical methods to observe and regulate the performance of a process or production system. It gives a deeper insight of process behaviour, detecting sources of variation, and improving overall performance. Among the various SPC tools, control charts are the most widely used, originally introduced by Walter A. Shewhart in the early twentieth century. Control charts are used to track process data over time and identify unusual variations from normal performance. They help distinguish between two types of variation; common cause variation, which is inherent to the process, and special cause variation, which arises from external factors and indicates that the process is out of control. (American Society for Quality)

a. Process variation (chance and assignable causes)

In any process, a certain level of natural variability always exists due to the effect of many small and unavoidable factors. This inherent variability is referred to as chance causes and represents a stable process condition. When a process exhibits only natural variation without the influence of external factors, it is regarded as being in a state of statistical control. However, additional variability may arise due to factors such as improper machine settings, operator errors, or variation in material quality. These are known as assignable causes and typically result in significant deviations from normal process behaviour. The presence of assignable causes indicates that the process is out of statistical control. (Montgomery, 2009)

b. Control charts

A primary objective of SPC is to detect assignable causes of variation beforehand so that preventive actions can be implemented prior to producing a large number of nonconforming outputs. Control charts are commonly used to observe process performance over time. Control charts help distinguish between common (chance) and special (assignable) causes of variation and provide a basis for maintaining process stability. Among various SPC tools, control charts for \bar{X} (mean) and R (range) are widely used to monitor process mean and variability. The \bar{X} chart evaluates changes in the process average, while the R chart is used to assess the variability within sample observations. (Montgomery, 2009)

c. Control chart design

Control charts are typically developed using principles derived from the normal distribution. The vertical axis represents the quality characteristic being measured, while the horizontal axis represents time sequence or sample number. A control chart includes a centre line (CL) showing the process mean, along with upper and lower control limits (UCL and LCL) that define acceptable limits of variation within the process. (Şengöz, 2018)

Control charts are constructed by extending sigma (σ) limits above and below the mean. For a normally distributed process, approximately 99.73% of observations lie within $\pm 3\sigma$, and therefore, control limits are commonly established at $\pm 3\sigma$. These limits are

referred to as action limits, beyond which the process is considered out of statistical control. The selection of control limits involves a trade-off between Type I and Type II errors. Wider limits reduce the probability of false alarms (Type I error), while narrower limits increase sensitivity but also increase the chance of incorrect signals. Three-sigma limits are widely adopted in practice because they provide a reasonable balance between these two types of errors, resulting in a low false alarm probability of approximately 0.0027. (Montgomery, 2009)

- **Warning limit**

In addition to control limits, warning limits are often introduced to improve the sensitivity of control charts. These are typically set at $\pm 2\sigma$ and serve as early indicators of potential process instability. When a point falls between the warning limits and control limits, it suggests that the process may be deviating from stability and requires closer monitoring or increased sampling. (Montgomery, 2009)

According to Şengöz (2018), for larger sample sizes, warning limits can be approximated at about 1.962σ from the mean, while action limits extend to approximately 3.09σ . In the case of smaller samples, these limits are adjusted as $2\sigma/\sqrt{n}$ and $3\sigma/\sqrt{n}$, respectively.

The use of warning limits enhances the ability of the control chart to detect shifts in the process more quickly. However, it also increases the likelihood of false alarms and may introduce some complexity in interpretation. Despite this, warning limits are commonly used in practice to improve the responsiveness of the control chart. (Montgomery, 2009)

d. Control chart formulation

For action limits,

\bar{X} Chart

$$UCL = \bar{X} + A_2\bar{R}$$

$$CL = \bar{X}$$

$$LCL = \bar{X} - A_2\bar{R}$$

R Chart

$$UCL = D_4 \bar{R}$$

$$CL = \bar{R}$$

$$LCL = D_3 \bar{R}$$

For warning limits,

\bar{X} Chart

$$UCL = \bar{X} + \frac{2}{3} * A_2 \bar{R}$$

$$CL = \bar{X}$$

$$LCL = \bar{X} - \frac{2}{3} * A_2 \bar{R}$$

Where;

- \bar{X} represents the average of sample means.
- \bar{R} is the average range of samples.
- UCL (Upper Control Limit) represents the upper boundary of acceptable variation in the process.
- LCL (Lower Control Limit) represents the lower boundary of acceptable variation.
- CL (Center Line) represents the average value of the process.

The constants A_2 , D_3 , and D_4 depend on the sample size and are obtained from standard statistical tables. (Montgomery, 2009)

Warning limits were obtained by proportionally scaling the $\pm 3\sigma$ control limits, where $\pm 2\sigma$ corresponds to (2/3) of the control limit range.

e. Interpretation of control charts

A process is considered to be in statistical control when all observations lie within the control limits, and no systematic pattern is observed. In such cases, only chance causes of variation are present. However, if observations fall outside control limits or show non-random patterns, it indicates the presence of assignable causes, requiring further investigation and corrective action. Points that fall between the warning limits and control limits suggest that the process may be approaching instability. Although the process is not yet out of control, such observations indicate a possible shift and therefore require closer monitoring or additional data collection. (Montgomery, 2009)

In this study, \bar{X} and R control charts are adopted to evaluate the stability and variability of brick, cement, sand, skilled labour, and unskilled labour usage. These charts help identify whether observed variations are due to inherent process variability or external influencing factors, thereby assessing the consistency of construction practices.

2.1.15 Use of SPC in construction projects

Toma et al., (2025) proposed the application of Statistical Process Control (SPC) as a method for evaluating the reliability of cost and time estimates in construction projects. The study evaluates estimation accuracy by comparing estimated and actual values, which are used to develop control charts. The results demonstrate that SPC can effectively identify activities with inaccurate estimations and support estimation teams in diagnosing the causes of such deviations. Furthermore, the approach is presented as a practical tool for continuous improvement of estimation performance.

2.1.16 Delphi method

The Delphi method is a systematic approach to structured communication that enables a group of participants to address complex issues collectively.. (Linstone & Turoff, 1975) It is especially useful in situations where informed judgment is required for decision-making. This technique is particularly applicable when experts are geographically dispersed or when it is not feasible to bring them together for face-to-face discussions. It involves multiple rounds of questionnaires administered to selected experts, allowing for iterative feedback and refinement of responses. Through this process, the Delphi technique facilitates the development of consensus on complex

problems, emerging trends, and future projections. It is especially valuable in situations where precise data is unavailable and expert judgment is essential. (Yousuf, 2007)

2.2 Review of Relevant Studies

Mulyanto & Prabowo, (2024) conducted a study at Universitas Serang Raya, Banten, Indonesia, to analyze labour coefficients and labour requirements in brick masonry work by comparing field data with SNI 2022 standards for red brick wall installation in a cigarette depot building project. Primary data was collected through field observations and interviews to gather data on work volume, number of workers, and labour wages. Secondary data included masonry work reports and SNI 2022-unit price analysis. The research calculated labour efficiency based on daily work volume and number of workers, comparing observed labour coefficients with SNI 2022 standards. Labour needs were determined using the SNI 2022 coefficient, and the field-based labour requirements were evaluated against SNI 2022. The study found differences in labour coefficients, and labour needs between field data and SNI 2022. The foreman's labour coefficient in the field was lower than SNI 2022, while the head handyman's coefficient was higher. The labour needs of the foreman were the same as SNI, but there were differences in the number of head handymen, masons, and handyman helpers required in the field compared to SNI.

Pramesti et al., (2024) carried out a study at a construction site in Yogyakarta, Indonesia, to evaluate labour productivity in brick masonry work. The research compared the actual on-site productivity of installing red brick walls with the standards prescribed by the Ministry of Public Works and Public Housing regulations. The study employed a multi method approach to evaluate labour productivity in installing red brick walls. It involved direct observation at a construction site in Yogyakarta over seven days, with observations conducted three times daily to record worker activities. The primary data collection used the Work Sampling Method, which involves random observations to assess how workers allocate their time and activities. The study also analysed labour productivity based on regulations from the Ministry of Public Works and Public Housing (PUPR), comparing these benchmarks with actual on-site performance. Statistical tools, including linear regression analysis, were used to develop predictive models for productivity trends over time. The overall approach integrated field data collection, regulatory comparison, and forecasting to evaluate

productivity. The research found that the workforce's on-site productivity in installing red brick walls surpassed regulatory benchmarks. Specifically, the actual labour coefficient (person-days/m²) and productivity rate (m²/person-day) were significantly better than the standards, indicating a highly efficient team. The productivity tended to improve over time, with the linear regression model predicting an upward trend ($y = 0.2828x + 5.5273$). Daily productivity showed fluctuations but generally indicated a positive trajectory, suggesting ongoing efficiency improvements. These results demonstrated that field practices, management, and techniques are leading to superior performance compared to existing regulations. However, the study also highlighted the need for verification to ascertain data accuracy and to avoid potential under-reporting.

These studies indicate that discrepancies are seen when comparing standard estimation norms with onsite realities. This strongly supports the need to evaluate the DUDBC quantity estimation norms against current site realities. Such an assessment is essential to evaluate the relevance and applicability of these norms in today's construction context, ensuring they reflect contemporary practices, materials, labour productivity, and technological advancements in construction processes.

CHAPTER 3: METHODOLOGY

This chapter outlines the research methodology adopted in the study and describes the procedures followed to achieve the research objectives. It covers key aspects including the research design and methodology, study area, population size, sample size determination, statistical tools and tests, data collection techniques, data analysis procedures, and the research matrix.

3.1 Research Approach

This study adopts a mixed-method research approach combining both quantitative and qualitative techniques. The focus of the quantitative part is to evaluate the applicability of DUDBC norms for resource estimation in 9-inch-thick (full brick) masonry walls by comparing standardized norms against site-based data from multiple construction sites within Kathmandu valley. The qualitative part of the study aims consultations with industry experts combined with synthesis of literature review to explore causes of observed deviation and suggest recommendations for improvement of existing estimation norms from DUDBC. The insights from expert consultations are further quantified and refined using Delphi technique to achieve consensus and draw reliable conclusions.

3.2 Research Design

The research design of this study is structured to systematically investigate the variation between standard norms and actual practices in 9-inch-thick brick masonry work. It integrates field-based data collection with statistical analysis and expert consultation to ensure practical relevance of findings. The design follows a logical sequence from problem identification to data interpretation, enabling a comprehensive understanding of material and labour consumption patterns under real construction conditions.

3.2.1 Research Methodology

The research methodology adopted in this study follows a structured and systematic approach to achieve the defined objectives. Initially, the research problem was identified based on observed discrepancies between standard norms and actual practices in 9-inch-thick brick masonry work. This led to the formulation of research objectives

and research questions, which defined the scope and direction of the study. A research flow was developed to serve as a roadmap, outlining the procedures for data collection and analysis as shown in figure 3.1. An extensive review of relevant literature related to material consumption, labour productivity, and standard norms in brick masonry work was conducted to establish a strong theoretical basis and support the research design.

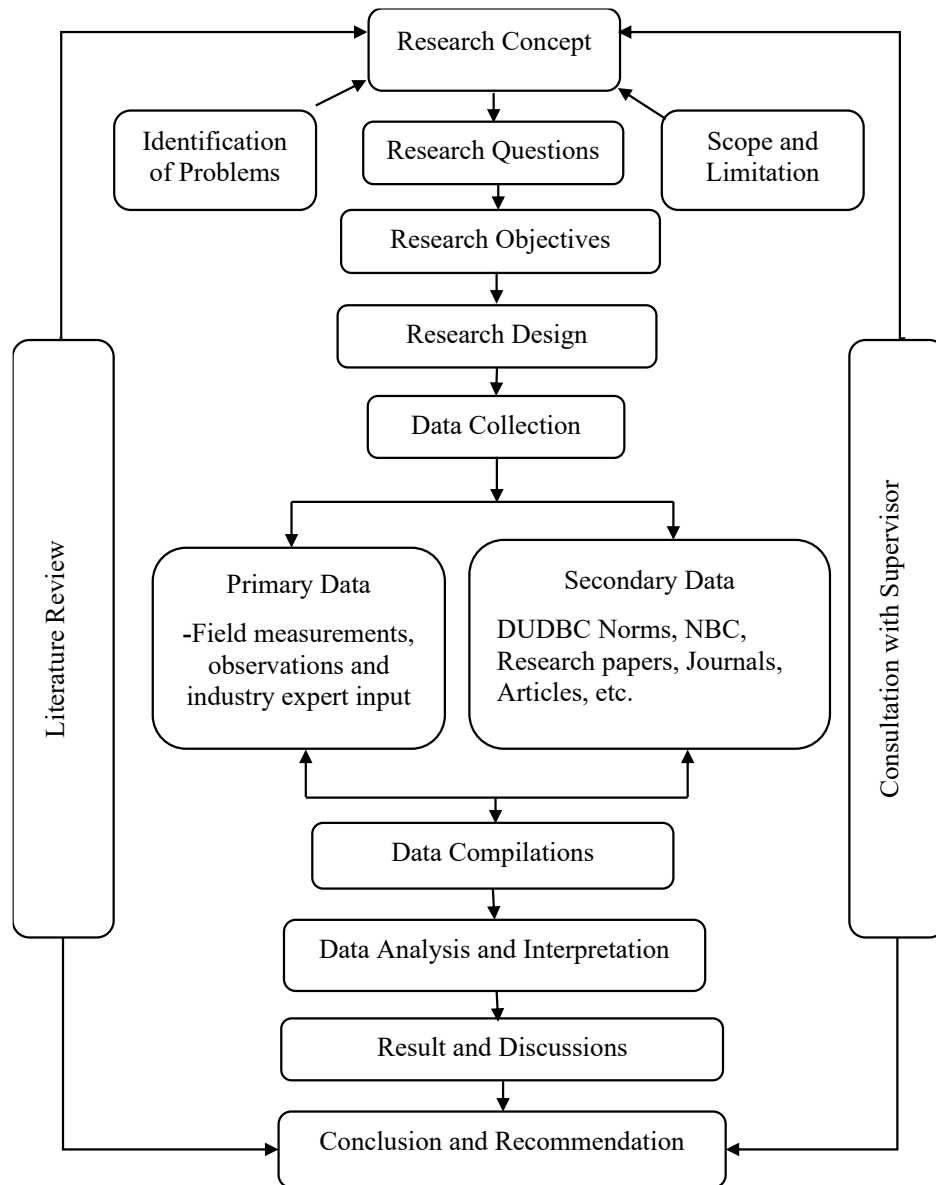


Figure 3.1: Research flowchart

The study primarily relies on field-based data collection, where actual measurements of material usage and manpower were recorded for 9-inch-thick brick masonry work at selected construction sites within Kathmandu Valley. The collected data were

systematically compiled and analysed using descriptive and statistical methods to identify variations and assess deviations from standard norms. In addition to field observations, expert consultations were carried out with industry experts to gain insights into the factors influencing discrepancies between standard and actual practices. The findings from both quantitative analysis and expert input were interpreted to ensure their practical relevance and validity.

Finally, the study concludes with a summary of key findings and provides recommendations aimed at improving the applicability and reliability of standard norms in real construction conditions. Literature review and expert input were integrated throughout the research process to enhance the credibility and usefulness of the study.

3.2.2 Research Framework

The research framework presents the overall process followed in the study and shows how different components are connected to achieve the research objectives, as shown in figure 3.2. It helps in understanding the sequence of steps involved, from data collection to analysis and final outcomes. Developing the research framework before conducting the study is important as it acts as a guide for selecting appropriate methods and ensuring that all necessary information is collected systematically. (Kavitha et al., 2025) The figure below illustrates the research framework adopted in this study.

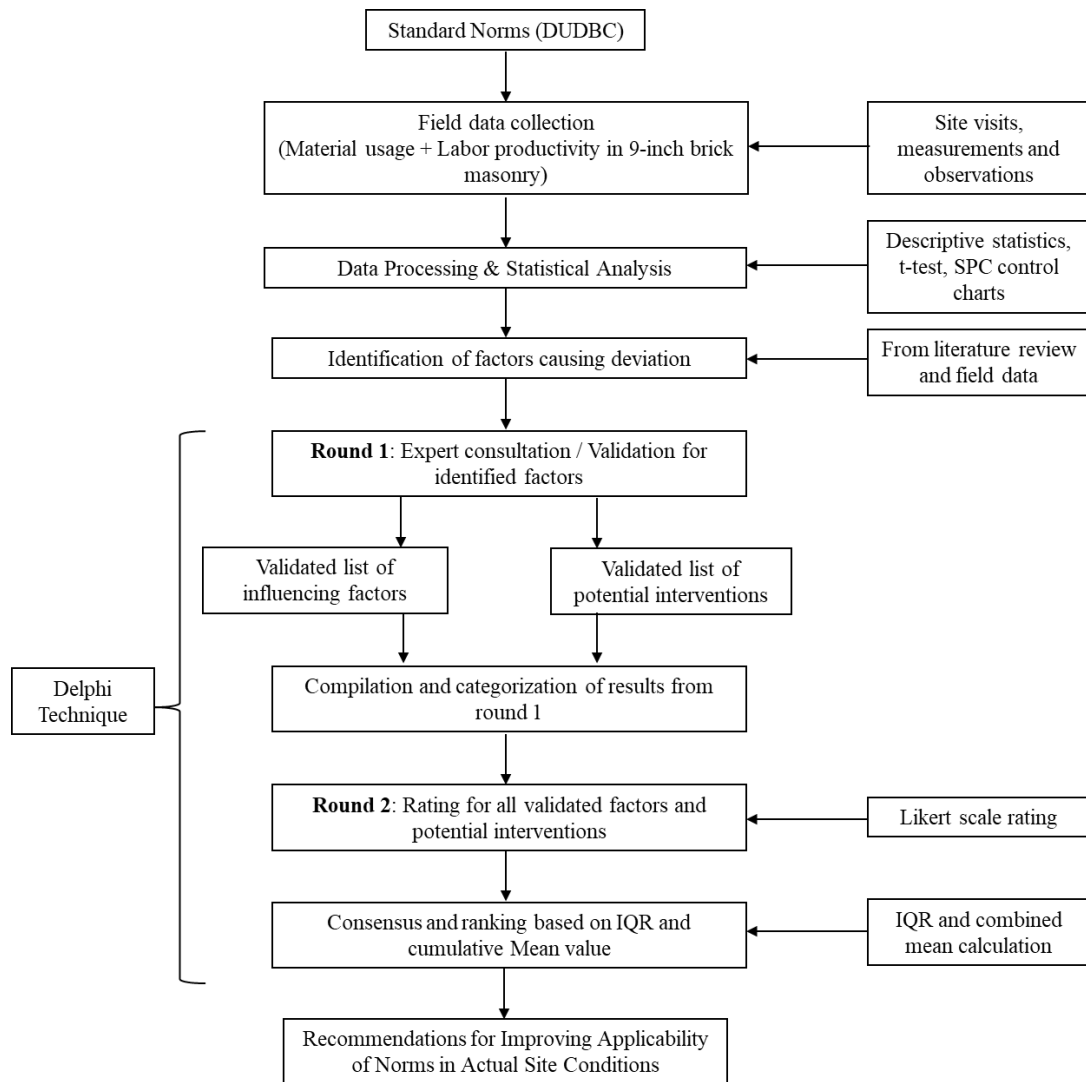


Figure 3.2: Research Framework

3.3 Study Area

The study was conducted in selected construction sites within Kathmandu Valley. The selected sites included residential, office, and commercial building projects where 9-inch-thick brick masonry work using 1:6 cement–sand mortar was actively being carried out. These sites were considered representative of common brick masonry work practices in the region.

3.4 Population, Sampling Technique and Site Selection

This section defines the target population, sampling strategy, and selection criteria adopted for data collection and expert consultation in the study.

a. Population

The study involves two different of population groups. The first population comprises observations of brick masonry work collected from construction sites, representing the primary data for analysis of material consumption and labour productivity. The second population consists of industry experts engaged for the Delphi consultation, providing professional insights on factors contributing to deviations and potential intervention measures.

b. Site selection

Site selection was done using a purposive sampling approach, considering criteria such as ongoing brick masonry works, accessibility of observation, and willingness of site personnel to cooperate. This checklist ensured smooth and reliable collection of data. Within the selected sites, the sampling unit comprised of full brick wall segments constructed using a 1:6 cement-sand mortar ratio.

The sample population required for observation was applying Cochran's formula for estimating sample size in large populations (Cochran, 1963),

$$n_0 = \frac{Z^2 \cdot p \cdot (1 - p)}{e^2}$$

Where;

z = standard normal value at 90% confidence level (1.645),

p = estimated proportion of the population (0.5 for maximum variability),

e = margin of error (0.1).

Substituting the values, we get,

$$n = 67.5 \approx 68$$

Thus, a minimum of 68 observations was required to ensure statistically reliable results.

A total of 95 observations were initially collected from 18 construction sites. Among the collected data, 6 observations from 3 sites were excluded due to inconsistencies as outliers. Final data set consisted of 89 valid observations from 15 construction sites, which were used for further analysis.

The dataset exhibits acceptable consistency and variability across observations, supporting the validity of statistical inference at the selected confidence level.

c. Expert selection

Experts were selected using a purposive sampling method, with selection criteria requiring a minimum of 10 years of professional experience in the construction industry. Participants included both public sector officials and private sector professionals. This ensured a balanced perspective relevant to the study.

A total of five experts were selected, comprising two public sector officials, two private sector project managers, and one retired public sector official currently working as a freelance engineer. This composition ensured the inclusion of experienced, multisectoral respondents with practical knowledge regarding construction practices and estimation norms.

3.5 Data Collection Methods

Primary data for this study were collected through field observations at construction sites and expert input obtained within the framework of the Delphi method.

3.5.1 Data from observations at construction sites

Primary data were collected from selected construction sites within Kathmandu Valley. Field measurements were conducted under controlled conditions where workers followed a predefined method statement to ensure consistency in batching and execution.

Data was recorded using standardized formats to maintain uniformity across sites. Data collection process followed these protocols;

a. Calibration and measurement:

A standard box was prepared which was calibrated and measured for its actual volume before start of the observation as shown in photograph 3.1. In cases where similar standard measuring box was present at site, the device was measured.



Photograph 3.1: Measurement of standard box

b. Material measurement

The volume of one fresh bag of cement was measured with the help of the standard measuring box, as shown in figure 3.2. Sand to be used for the mortar mix, i.e., six parts sand for one part cement, was measured in correct proportion with the help of the same dye as shown in photographs 3.2 and 3.3. In case a different device was used on-site, such a device was calibrated for 1 bag of cement. The aim was to ensure that the mix ratio is consistent throughout the observation.



Photograph 3.2: Material measurement using standard box selected for study



Photograph 3.3: Material measurement using standard box available on site

c. Site personnel training

The supervisor in charge, and workers were briefed and instructed to use same mixing process for every batch throughout the observation period. The target was that cement: sand ratio is maintained at ratio of 1:6. (Department of Urban Development and Building Construction (DUDBC), 2024, pp. 12)

d. Minimizing observer effect

After the brief and training the observer recorded the starting time of the observation and left the site with an intention to minimize observer bias. This was done to reduce the influence of Hawthorne effect (Dickson & Roethlisberger, 1966) and thus ensure natural workflow and collection of real uninfluenced data.

e. End of day recording

The observer returned at the end of the day to record the observation end time, work progress and material/ manpower usage status.

f. Site photographs

Photographic records of the observed sections of brickwork were taken. These records were systematically archived to facilitate cross checking and validation.



Photograph 3.4: Brickwork on selected construction sites

g. Collection of Observed Data

One full observation lasted a single working day. Data collection included the following:

- Volume of brick masonry completed during the observation period, by direct measurement
- Number of bricks used during the observation period, by direct counting
- Cement bags used, by counting bags and from the supervisor's record
- Volume of sand consumed from the supervisor's record and cross-verified by calculation, i.e., sand volume = cement volume x 6
- Number of skilled manpower utilized, by counting and site records
- Number of unskilled manpower utilized, by counting and site records
- Start time and end time for each observation
- Dimensions of bricks (80 bricks per site)

The collected data were used to calculate the following:

- Number of bricks used for one cubic meter of brick masonry work in 1:6 mortar

- Weight of cement in Tons used for one cubic meter of brick masonry work in 1:6 mortar
- Volume of sand in cubic meter used for one cubic meter of brick masonry work in 1:6 mortar
- Number of skilled manpower utilized for one cubic meter of brick masonry work in 1:6 mortar
- Number of unskilled manpower utilized for one cubic meter of brick masonry work in 1:6 mortar

During pilot surveys, it was observed that an average bricklaying team consisting of two masons and one helper used between 600-800 bricks per day depending on wall geometry and location. This number spread over seven meters in length and one meter in height of masonry work, which made manual count manageable.

h. Brick counting method

This study employs manual counting for daily brick usage measurement. Although automated systems and digital image-based counting tools are available. (Hui & Brilakis, 2013) This approach was selected based on practical feasibility and observational reliability within the research context.

Additionally, construction sites lacked proper lighting and setup, especially in the evening essential for an image-based counting system. The financial and logistical demands associated with deploying automated systems were also disproportionate to the scope of daily measurements needed. Therefore, manual counting provided a reliable, straightforward, and resource-efficient approach that ensured data accuracy without disrupting site operations or imposing undue burden on the research process.

i. Brick size measurement

Brick size was measured brick by brick by determining the dimensions at the centre of each brick and subsequently calculating the average size for each construction site. Bulk measurement methods, involving a fixed number of randomly selected bricks to determine average dimensions, are also recommended in standards such as BS 3921:1985 (Specification for Clay Bricks). However, previous studies have shown that such simplified approaches can introduce significant inaccuracies due to irregularities

in brick shape and surface conditions. For instance, Abeysekera, (2012) demonstrated that bulk measurement approaches may overestimate brick dimensions, with variations ranging from 2% to 20%, thereby justifying the need for more precise, unit-based measurement techniques.

j. Data collection platform

Data was collected in a structured format from the site on a digital device, which was later transferred to Microsoft Excel in a suitable format for data analysis.

3.5.2 Survey Delphi Method

Data from selected industry experts was collected using the Delphi method. A total of two Delphi rounds were conducted to achieve consensus on the key deviation factors affecting brick masonry work and to identify potential interventions for improvement.

The ground work for first round involved creating a list of factors that cause deviations in material usage and labour productivity from existing literature and field observations. The identified factors were grouped into six main categories. In the first round, experts were requested to validate the relevance of identified factors and state additional factors based on their professional experience. For interventive measures, the questionnaire was kept open ended to allow experts to freely propose potential improvement strategies. The responses were compiled by integrating duplicated opinions and organizing additional inputs into logical categories. A final refined list of factors and potential interventions was produced.

Second round form was developed using the compiled results from the first round. The form also included explanatory notes informing the experts about integration and structuring of responses from first round. In this round, experts were asked to rate each factor and intervention using a Likert scale. The responses from all five experts were recorded and compiled in MS excel format file for quantification and statistical analysis.

3.5.3 Secondary Data

Secondary data for the study were obtained from a range of sources including academic literature, government publications, standards, textbooks, and research articles. Key

sources included the norms and guidelines published by the Department of Urban Development and Building Construction (DUDBC) and the Nepal Building Code, which provided the standard values for material consumption and labour requirements in brick masonry work.

In addition, textbooks were referred, for fundamental definitions and theoretical concepts related to construction materials, masonry practices, and labour productivity. Peer-reviewed journal articles and previous research studies were reviewed to understand factors influencing material usage, labour productivity, and variations in construction practices.

These secondary sources helped establish the theoretical base of the study, supported the development of the research framework, and provided a basis for deeper analysis and interpretation of the primary data, collected from field observations and expert responses.

3.6 Data Analysis Techniques

This section presents the analysis techniques adopted to interpret and evaluate the data collected for the study.

3.6.1 Data from site observations

Recorded data was transferred to MS Excel with proper formatting. Data cleaning was done, including the transformation of collected data to per cubic meter metrics. Analysis was carried out by following methods:

3.6.1.1 Quantitative analysis for data from field observations

Quantitative analysis was conducted using appropriate statistical techniques to examine material consumption and labour productivity in brick masonry work.

- **Descriptive statistics:**

Mean, maximum, minimum, standard deviation, Coefficient of Variance was calculated and tabulated for

- Bricks, cement, and sand usage per cubic meter of brickwork as per observed data.

- Labour productivity per cubic meter of brickwork as per observed data.
- **Comparative tables**

Comparative table showing deviations between standard values and observed values for brick, cement, sand, and labour productivity was developed. Percentage deviations were also calculated to quantify the extent of variation.

- **Inferential statistics**

Shapiro Wilk Test: The Shapiro Wilk test was performed to assess the normality of the observed dataset and to determine whether parametric or non-parametric statistical tests should be applied.

One-sample t-test: This test was performed to compare the observed mean values with standard values provided by norms. This test was used to determine statistical significance of the observed deviations under the assumption of normal distribution

One-sample Wilcoxon signed rank test: This test was done to compare the observed median values with standard values provided by norms. This test was done to determine statistical significance of the observed deviations when the assumption of normality was not satisfied.

The selection of appropriate statistical tests was based on the results of the normality test.

- **Statistical process control (SPC) analysis**

Statistical Process Control (SPC) techniques were applied to assess the variability and stability of material consumption and labour productivity in brick masonry work. Control charts, like \bar{X} (mean) and R (range) charts, were developed for selected parameters, including bricks, cement, sand, and labour productivity.

The \bar{X} chart was used to observe the process mean, while the R chart was used to evaluate the variability within subgroups. Control limits were established using standard SPC formulas based on sample means and ranges. These formulas are derived from (Montgomery, 2009)

$$UCL_{\bar{X}} = \bar{X} + A_2\bar{R}$$

$$LCL_{\bar{X}} = \bar{X} - A_2\bar{R}$$

$$UCL_R = D_4\bar{R}$$

$$LCL_R = D_3\bar{R}$$

Where:

\bar{X} = process mean; \bar{R} = average range; A_2, D_3, D_4 = control chart constants based on subgroup size

For SPC analysis, observations were organized into subgroups of five observations. A subgroup size of five is commonly used in \bar{X} -R control charts for small sample sizes and allows reliable estimation of process variability using the range (R). (Şengöz, 2018) Additionally, the availability of established control chart constants (A_2, D_3, D_4) for $n = 5$ supports accurate computation of control limits. Considering the total sample size of 89 observations, this subgroup size also ensured an adequate number of subgroups for meaningful analysis.

For a subgroup size of $n=5$, the control chart constants are

$A_2=0.577, D_3=0, D_4=2.114$.

$$UCL_{\bar{X}} = \bar{X} + 0.577\bar{R}$$

$$LCL_{\bar{X}} = \bar{X} - 0.577\bar{R}$$

$$UCL_R = 2.114\bar{R}$$

$$LCL_R = 0$$

For the construction of \bar{X} and R control charts, a subgroup size of five observations was adopted.

Furthermore, warning limits were also established for process mean at interval of $\bar{x} \pm 2\sigma$ and $\bar{R} \pm 2\sigma$, which can be computed using aforementioned formula derived from $\bar{x} \pm 3\sigma$ and $\bar{R} \pm 3\sigma$ by simple arithmetic process:

$$\text{Control limits for } \pm 3\sigma = \bar{x} \pm A_2\bar{R}$$

$$\text{Control limits for } \pm 2\sigma = \bar{x} \pm 2/3 * A_2\bar{R}$$

For a subgroup size of $n=5$, the control chart constants are

$A_2=0.577$, $D_3=0$, $D_4=2.114$.

$$UCL_{\bar{X}} = \bar{X} + .384\bar{R}$$

$$LCL_{\bar{X}} = \bar{X} - .384\bar{R}$$

Control charts were used to assess whether the construction processes were stable and consistent. Observations falling outside control limits or showing systematic patterns were considered indications of non-random variation caused by identifiable factors such as improper material handling, labour inefficiencies, or site conditions.

3.6.2 Data from expert consultation

Data collected from expert consultations were analyzed using a combination of qualitative and quantitative methods to interpret expert opinions and establish consensus.

3.6.2.1 Qualitative analysis

Responses obtained from the first-round Delphi consultation were qualitatively analysed and synthesized into a refined list of deviation factors and interventive measures. Similar responses were grouped and organized into appropriate categories.

3.6.2.2 Quantitative analysis for expert responses

Responses obtained from Likert scale ratings from the second round of the Delphi method were transferred to Microsoft Excel. Statistical measures, including mean, first quartile (Q1), median (Q2), third quartile (Q3), and interquartile range (IQR), were calculated. An IQR value of ≤ 1 was considered to indicate consensus among experts.

The mean values were used to rank the identified factors and intervention strategies as high, moderate, or low in significance.

3.7 Reliability and Validity

Reliability and validity are essential to ensure the credibility of the data collected in the study. Appropriate measures were adopted during data collection and analysis to enhance both reliability and validity.

a. Reliability:

Following efforts were made improve reliability of data collected:

- Pilot observations and data collection was done which tested tools and method for observation.
- Calibration of measuring box was done to ensure uniformity in volume measurement.
- Workers and supervisors were briefed and trained in advance to follow a standardized procedure during the observation period.
- Observer bias was minimized by leaving the site during active work periods to reduce the influence of the Hawthorne effect.

b. Validity:

All site observations were verified by the site in charge responsible for the construction management.

3.8 Research Matrix

The research matrix developed for the study is shown in the table below:

Table 3.1: Research matrix

S.N.	Objectives	Data Required	Data Collection Methods	Analysis Tools	Outcomes
1.	To assess the applicability of DUDBC norms for the estimation of material usage and labour productivity in brick masonry works based on field observations.	Standard data from DUDBC norms Actual resource consumption on site	DUDBC Norms review Direct measurements and observation on site Photographic documentation	Comparative tables One-sample t-test Descriptive statistics SPC (X-bar and R control charts)	Quantified deviation between DUDBC norms and observed data Statistical validation of deviations Identification of variability patterns and process stability
2.	To identify the factors contributing to such deviations	Identified factors from literature / field observation Validated factors from experts Expert ratings (Likert scale)	Literature review, field observations Structured questionnaire survey (Delphi rounds)	Delphi technique	Expert validated and ranked factors influencing deviation
3.	To identify potential strategies for enhancing DUDBC norms' applicability based on research findings.	List of potential intervention measures from experts Expert ratings (Likert scale)	Structured questionnaire survey (Delphi rounds)	Delphi technique	Expert validated and ranked intervention measures

3.9 Ethical Considerations

Consent from the site in charge was obtained after providing a detailed explanation about the research prior to starting observation. Confidentiality of the construction site and participant identities is maintained by presenting the results in an aggregated form of data without direct reference to a particular project or contractor.

Similarly, consent was obtained from all participating experts prior to distributing forms for the Delphi study. The purpose of the study and expected outcomes were clearly communicated. The participant identities are maintained by presenting the results in an aggregated form of data without direct reference to a particular expert.

CHAPTER 4: RESULTS

This chapter describes the outcomes of field observations and expert consultations, along with their subsequent discussion. The results are organized into two main sections:

- Analysis of primary data collected from construction sites
- Analysis of expert opinions obtained through the Delphi method.

The findings are then integrated to identify key deviation factors and practical intervention strategies.

4.1 Assess and analyze the applicability of DUDBC norms by comparing standard values with observed field data

The first objective of this study was to assess the applicability of DUDBC norms by comparing standard values with observed field data. The analysis of observed data evaluates the extent of deviation under actual site conditions and examines the consistency of process behaviour in material consumption and labour utilization.

4.1.1 Comparative analysis with standard values

Observed values were compared with values prescribed by standard norms to reflect the degree of deviation.

Table 4.1: Comparison between observed and standard values

Resource	DUDBC Norm/ Population Mean (μ)	Observed Sample Mean (\bar{x})	Deviation (%)	Remarks
Bricks (Nos)	560	499.103	-10.87	Under used
Cement (Ton)	0.07	0.103	46.90	Over used
Sand (m3)	0.3	0.444	48.15	Over used
Skilled Manpower (Days)	1.5	1.359	-9.40	Under used
Unskilled Manpower (Days)	2.2	1.321	-39.94	Under used

Brick consumption is 10.87% lower than the standard (560 bricks/m³) value, indicating underutilization of bricks compared to prescribed values in norms. Cement consumption is seen 46.90% higher than the standard (0.07 tons/m³), indicating significant overuse of cement. Sand consumption is 48.15% higher than the standard (0.3 m³/m³), which aligns with increased cement usage due to the fixed mix ratio. Skilled manpower is 9.40% lower, while unskilled manpower was 39.94% lower than standard values, indicating high labour productivity per unit volume.

The comparative table indicates suggests increased mortar volume usage, which may be attributed to thicker mortar joints. Whereas, labour productivity appears to be higher than assumed in DUDBC norms.

4.1.2 Descriptive statistics

Descriptive statistical analysis was done for material consumption and labour productivity per cubic meter (m³) of brick masonry work.

Table 4.2: Statistical summary of resource consumption

Resource	Mean (\bar{x})	Std Dev (s)	Min	Max	CV (SD/Mean)
Bricks (Nos)	499.103	21.565	443.839	548.025	4.321%
Cement (Ton)	0.103	0.025	0.056	0.171	24.071%
Sand (m3)	0.444	0.110	0.214	0.75	24.646%
Skilled Manpower (Days)	1.359	0.512	0.493	2.618	37.652%
Unskilled Manpower (Days)	1.321	0.597	0.235	2.202	45.200%
Wet Mortar Volume Calculated	0.339	0.034	0.26	0.414	10.100%

Mean brick consumption is found to be 499.103 bricks/m³, with a standard deviation of 21.656 and CV of 4.321%, indicating low variability and relatively consistent brick usage across observed sites.

Cement consumption has a mean value of 0.103 tons/m³ with a standard deviation of 0.025 and a CV of 24.071%, indicating moderate variability. Similarly, sand

consumption showed a mean of 0.444 m³/m³, standard deviation of 0.110, and CV of 24.646%, suggesting significant variation in mortar usage practices.

Labour productivity exhibits higher variability compared to materials. Skilled manpower had a mean of 1.359 days/m³ with a CV of 37.652%, while unskilled manpower had a mean of 1.321 days/m³ with a CV of 45.200%, indicating high inconsistency in labour utilization across sites.

The calculated wet mortar volume has a mean of 0.339 m³ and a CV of 10.100%, suggesting relatively controlled mortar volume despite variations in material proportions.

4.1.3 Inferential statistics

This section describes the inferential statistical analysis performed to determine whether the observed differences between standard and field values are statistically significant. A test of normality was first conducted to determine the appropriate statistical methods, followed by the application of relevant tests.

a. Shapiro-Wilk test of normality

The test was performed to assess the normality of observed data sets.

Table 4.3: Shapiro-Wilk test of normality

Resource	Statistic	df	Sig.
Bricks (Nos)	0.993	89	0.909
Cement (Ton)	0.957	89	0.005
Sand (m3)	0.981	89	0.214
Skilled Manpower (Days)	0.972	89	0.053
Unskilled Manpower (Days)	0.961	89	0.009

The results indicate that bricks ($p = 0.909$), sand ($p = 0.214$), and skilled manpower ($p = 0.053$) follow a normal distribution, as their significance values are greater than 0.05. In contrast, cement ($p = 0.005$) and unskilled manpower ($p = 0.009$) deviate from normality, as their p-values are less than 0.05.

Based on these findings, parametric test (one-sample t-test) was applied for normally distributed variables, while non-parametric test (one-sample Wilcoxon signed-rank test) was used for variables that did not satisfy the normality assumption.

b. One sample t-test and one-sample Wilcoxon signed rank test

The t-test was conducted to compare the observed sample means of brick, sand and skilled manpower usage with the corresponding standard values prescribed in norms. The null hypothesis assumed that there is no significant difference between the sample mean and the standard mean, while the alternative hypothesis stated that a significant difference exists.

For variables that did not satisfy the normality assumption, the one-sample Wilcoxon signed rank test was applied to compare the sample median with the standard value.

Table 4.4 Results of one sample t-test

Resource	t-value	p-value	Mean difference	95% confidence interval		Remarks
				Lower bound	Upper bound	
Bricks	-26.641	<0.001	-60.89	-65.43	-60.90	Statistically Significant
Sand	12.441	<0.001	+0.144	0.1214	0.1675	Statistically Significant
Skilled	-2.600	<0.01	-0.1410	-0.2488	-0.0332	Statistically Significant

Table 4.5: Results of one-sample Wilcoxon signed rank test

Resource	Test Statistic (W)	Z-value	p-value	Sample Median	Median Difference	Remarks
Cement	3873.000	7.969	<0.001	0.0980	+0.028	Statistically Significant
Unskilled	107.000	-7.755	<0.001	1.2560	-0.944	Statistically Significant

The results indicate that all resources show statistically significant differences between observed and standard values ($p < 0.05$).

For brick usage, which was analyzed using a one-sample t-test, the sample mean is significantly lower than the standard value, with a large negative mean difference and a high negative t-value of -26.641. This suggests that brick consumption is considerably lower than expected standards, possibly due to efficient usage or overestimation of requirements.

In contrast, sand consumption evaluated using a one-sample t-test shows a positive mean difference, indicating that the observed values exceed the standard norms. Cement consumption, analysed using the one-Sample Wilcoxon signed-rank test, also shows a statistically significant positive median difference, indicating higher usage than the prescribed norm. This further supports the observation of increased mortar consumption indicated by the comparative study. These results suggest overconsumption of these materials, which may be attributed to thicker mortar joints, wastage, improper mix proportions, or inefficient handling practices.

For labour resources, both skilled and unskilled manpower exhibit significant negative differences compared to DUDBC norms. Skilled labour shows a lower mean value than the standard, while unskilled labour shows a substantial negative median difference. This indicates that labour requirements in actual site conditions are lower than those assumed in the norms, suggesting higher labour productivity or differences in work organization.

Overall, the aforementioned statistical test results confirm that there are statistically significant differences between observed and standard values for all resources. This highlights inconsistencies in resource utilization and indicates the need for strategies that align standard prescriptions and actual site practices to acceptable limits.

4.1.4 Frequency distribution analysis

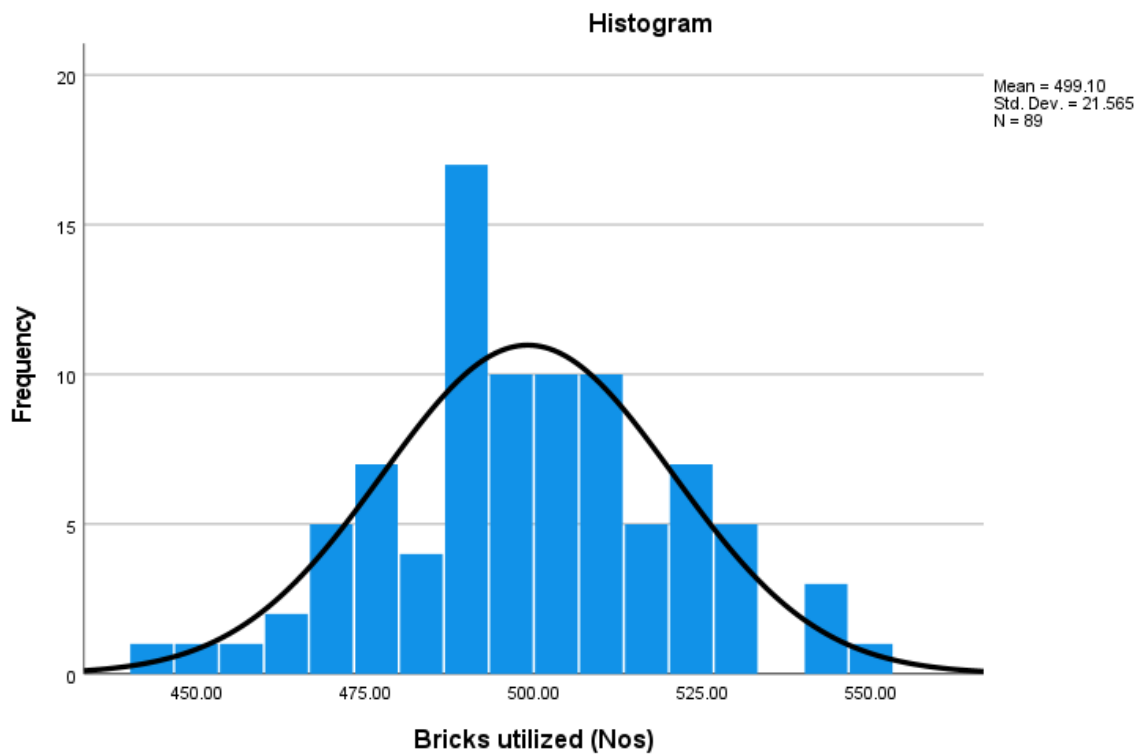


Figure 4.1 Frequency distribution of brick consumption per cubic meter

The histogram of brick consumption per cubic meter shows an approximately normal distribution, indicating a consistent pattern across the observed sites. The mean lies near the centre of the distribution, with most observations clustered within a narrow range and only minimal presence of extreme values. This suggests low variability and relatively stable brick usage practices, which is consistent with the low coefficient of variation observed.

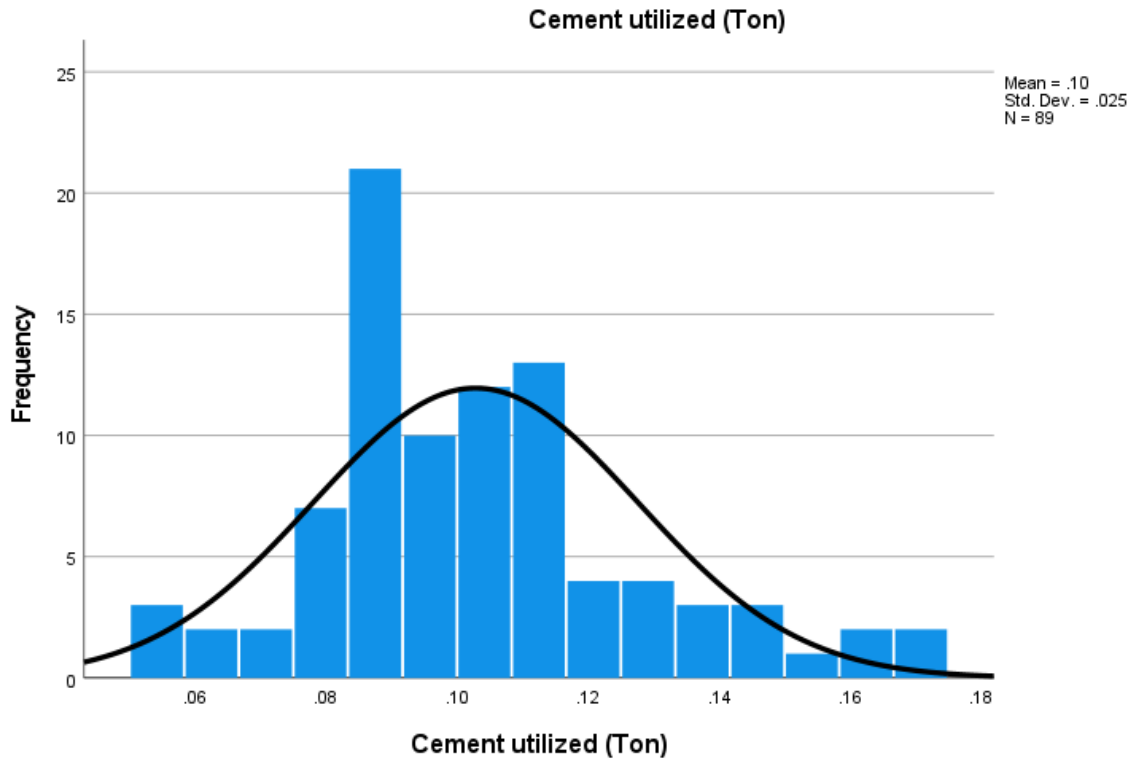


Figure 4.2 Frequency distribution of cement consumption per cubic meter

The distribution of cement consumption shows a slight right skew, as a few observations extend toward higher values. The mean value is 0.10 tons, with most observations concentrated between approximately 0.08 and 0.12 tons. The standard deviation of 0.025 indicates moderate variability in cement consumption compared to brick usage. The presence of a few higher-value observations suggests occasional over consumption, which could be due to factors like variations in mortar mix proportions or site practices. However, the overall distribution remains fairly consistent, indicating that cement usage generally follows a stable pattern across the observed sites.

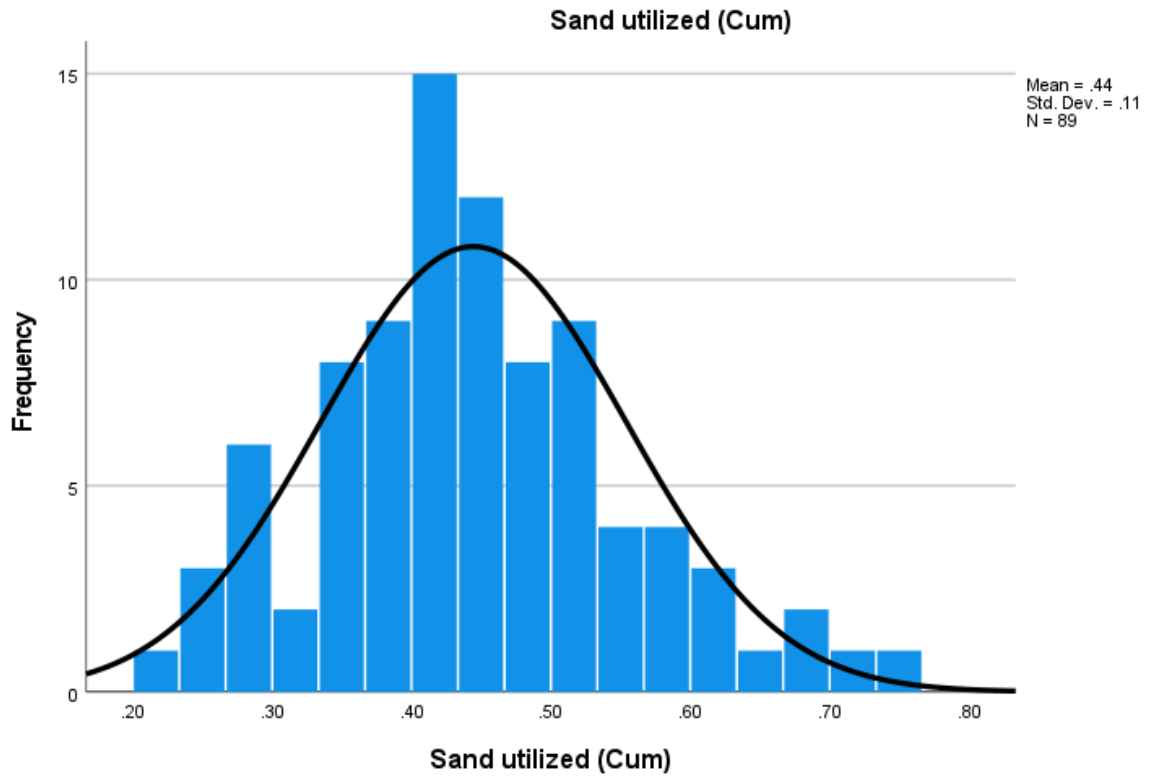


Figure 4.3 Frequency distribution of sand consumption per cubic meter

The histogram for sand consumption shows an approximately normal distribution with a slight right skew, as some observations extend toward higher values. The mean value is 0.44 cubic meters, with most observations concentrated between approximately 0.35 and 0.55 cubic meters. The standard deviation of 0.11 indicates relatively higher variability compared to brick and cement consumption. The wider spread and presence of higher-value observations suggest that sand usage could be more influenced by site-specific factors, such as mortar proportioning, workmanship, and material handling practices. Despite this variability, the overall distribution follows a general normal pattern, indicating that sand consumption is broadly consistent but less controlled compared to other materials.

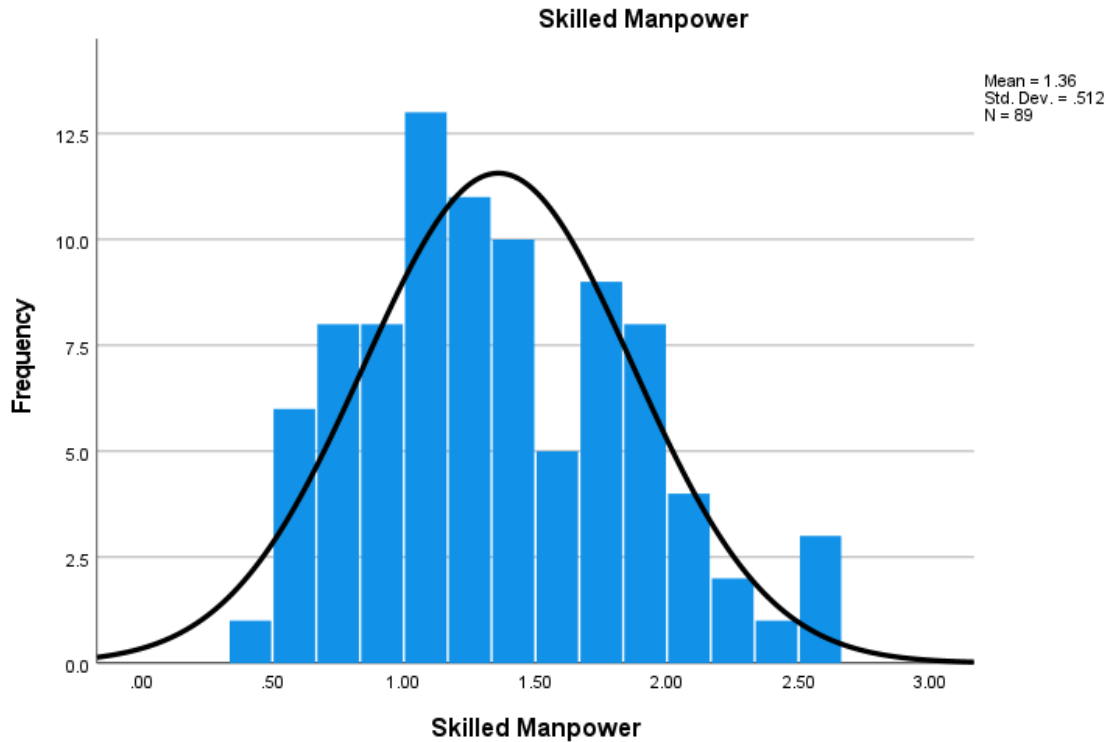


Figure 4.4 Frequency distribution of skilled manpower usage per cubic meter

The distribution of skilled manpower usage shows an approximately normal distribution with a slight right skew, as a few observations extend toward higher values. The mean value is 1.36, with most observations concentrated between approximately 0.8 and 1.8. The standard deviation of 0.512 indicates relatively higher variability compared to material usage. The wider spread and presence of higher values suggest that skilled labour deployment varies significantly across sites. This variation could be attributed to differences in work complexity, crew organization, and site management practices. Although the overall distribution follows a general normal pattern, the variability indicates that skilled manpower usage is less consistent and more dependent on site-specific conditions.

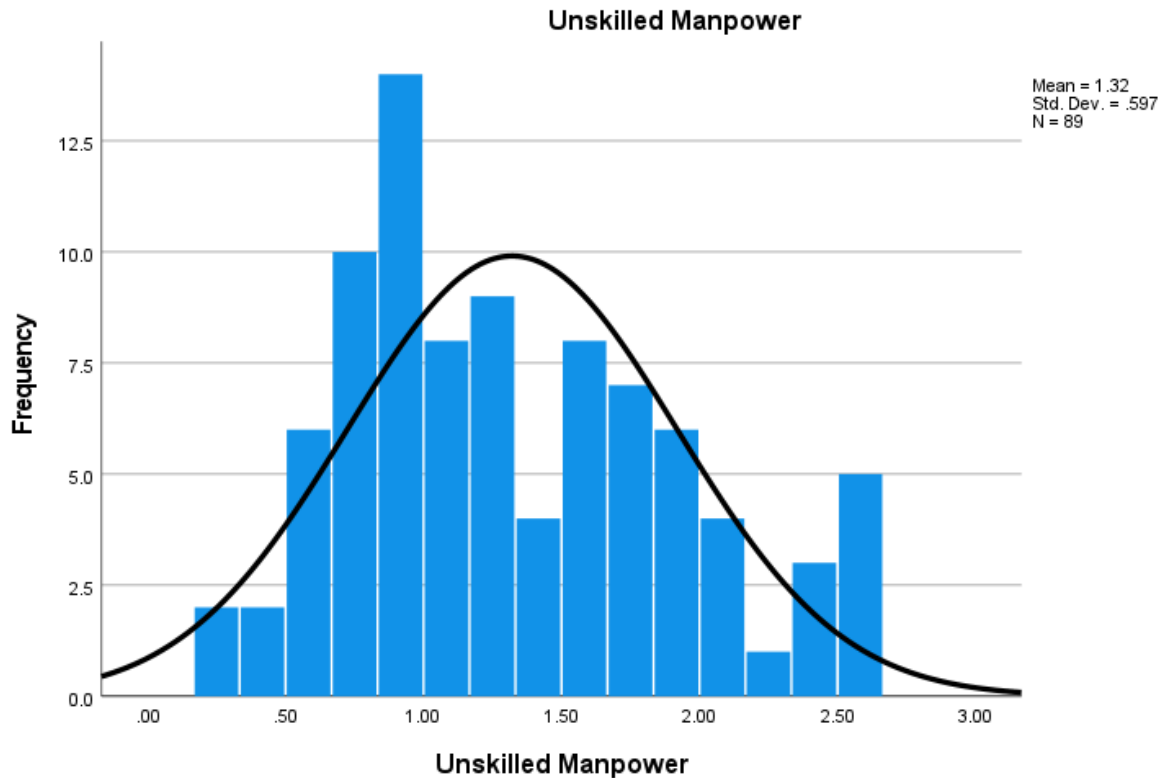


Figure 4.5 Frequency distribution of unskilled manpower usage per cubic meter

The histogram of unskilled manpower usage shows a slight right skew, as some observations extend toward higher values. Although the distribution follows a general bell-shaped pattern, the presence of a right-side tail indicates positive skewness. The mean value is 1.32, with most observations concentrated between approximately 0.8 and 1.8. The standard deviation of 0.597 indicates relatively high variability, slightly greater than that observed for skilled manpower. The wider spread and presence of higher values suggest that unskilled labour deployment varies considerably across sites. This variation may be influenced by differences in site organization, labour availability, and the nature of supporting tasks involved in construction activities. Although the overall distribution follows a general normal pattern, the higher variability indicates that unskilled manpower usage is less consistent and more dependent on site-specific conditions.

Overall, the histogram analysis reveals that material consumption tends to follow relatively consistent patterns with moderate skewness, whereas labour productivity exhibits higher variability across construction sites. This highlights the influence of site-specific and human factors on productivity.

4.1.5 Statistical process control analysis

Statistical Process Control (SPC) techniques were applied using X-bar and R control charts to ascertain the consistency and stability of resource consumption and labour productivity across observed construction sites. The control charts assist in distinguishing between random variation (common causes) and assignable causes of variation (special causes).

Brick consumption

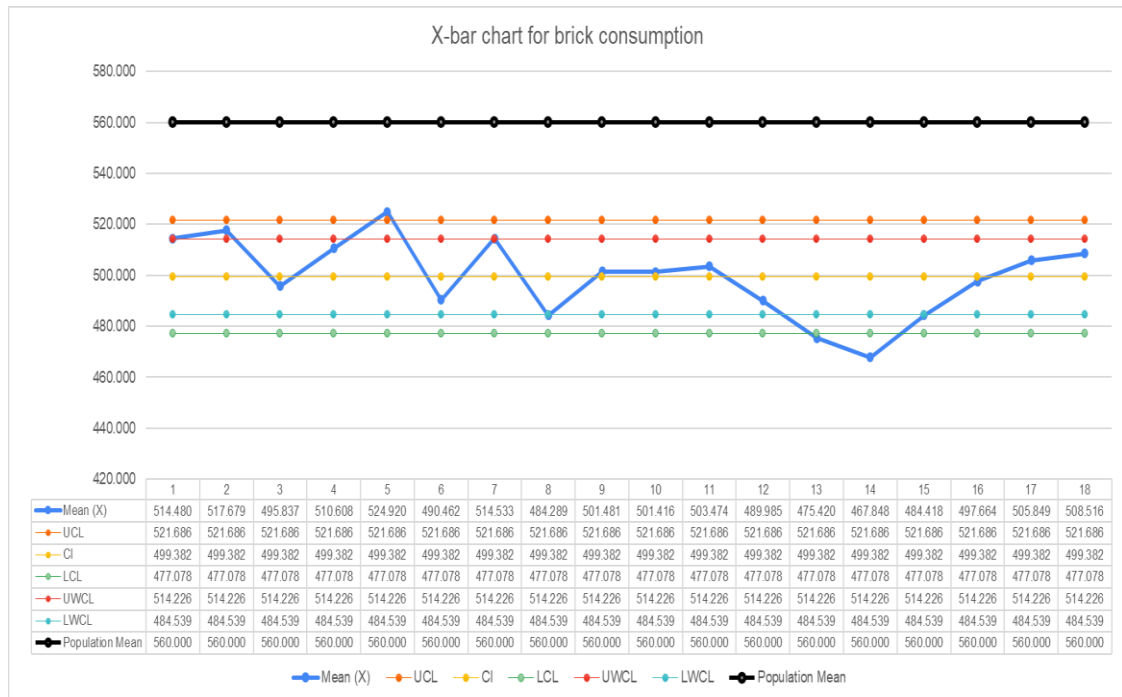


Figure 4.6 X-bar chart for brick usage

The \bar{X} chart for brick consumption shows that most sample means fall within the control limits, suggesting that the process is stable in general. However, sample 5 exceeds the upper control limit, while sample 14 falls below the lower control limit, indicating the presence of assignable causes. In addition, a downward shift in the process mean is observed between samples 11 and 14, followed by recovery to normal range. This pattern suggests a temporary disturbance in the process rather than purely random variation.

Additionally, sample 2 lies above the upper warning limit, while samples 7 and 8 fall on the warning limit, indicating periods where brick consumption is relatively high and

approaching the upper boundary of acceptable variation. These points act as early warning signals and suggest potential unstable variability.

Overall, while the process is mostly within control limits, the presence of a point beyond the control limit and several points near or on the warning limits suggests that the process mean is not in full statistical control. This indicated occasional variations that may be influenced by site conditions, workmanship, or material handling practices. These instances should be investigated to ensure consistent brick usage.

The observed sample means are significantly lower than the population mean, indicating that the actual brick consumption is generally lower than the standard (DUDBC) value.

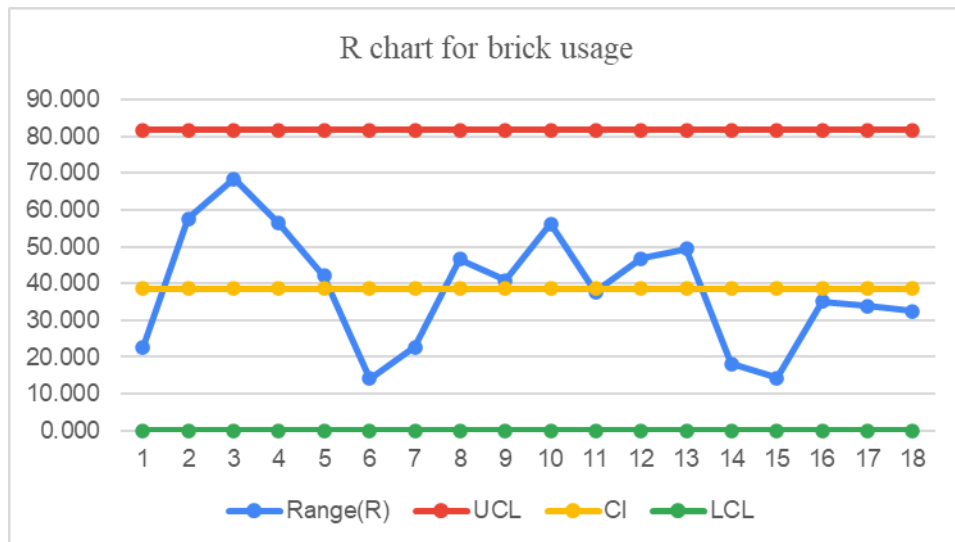


Figure 4.7 R-chart for brick usage

The R chart for brick usage shows that all sample range values lie within the control limits. There are no points exceeding the upper control limit. Although some fluctuations in range are visible (e.g., higher variability around samples 2–4 and 10–13, and lower variability around samples 6, 14, and 15), these variations remain within acceptable statistical limits. Since all points are within the control limits and exhibit random behavior, the variability in brick usage can be considered stable and under statistical control. This indicates that only common cause variation is present, and no assignable causes are affecting dispersion.

Cement consumption

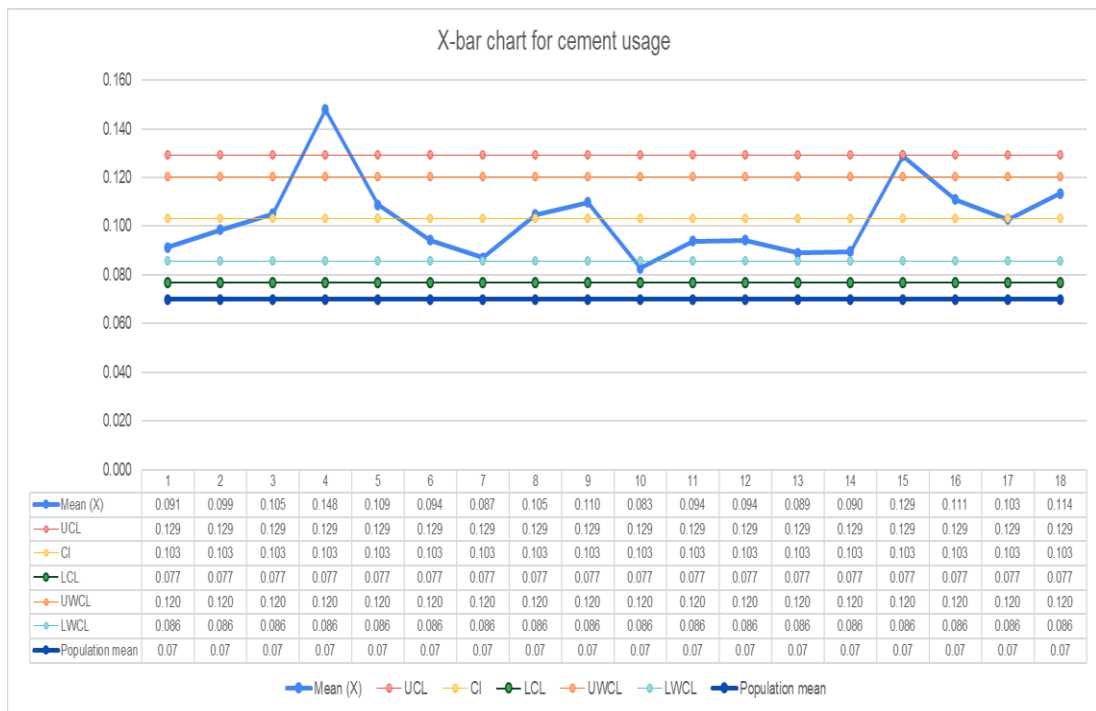


Figure 4.8 X-bar chart for cement usage

X-bar chart for cement consumption reveals that sample 4 exceeds the upper control limit, indicating that the process is out of statistical control at this point due to a special cause of variation. Additionally, sample 15 is observed to be very close to the upper control limit, suggesting an increase in cement consumption. Although it does not exceed the limit, such points near the control boundary may act as early warning signals of potential process instability. Further, sample 10 crosses the upper warning control limit, which serves as an early warning signal of possible process variation. Although it does not exceed the control limit, such behavior indicates the need for closer monitoring.

All remaining data points lie within the warning control limits and are distributed around the central line (mean), indicating that the process is generally stable with only normal variations. However, the presence of points beyond control limits and near or above warning limits indicates occasional deviations that may be due to site-specific factors and should be investigated to maintain process control.

The observed sample means are consistently higher than the population mean, indicating that the actual cement consumption is generally greater than the standard (DUDBC) value.

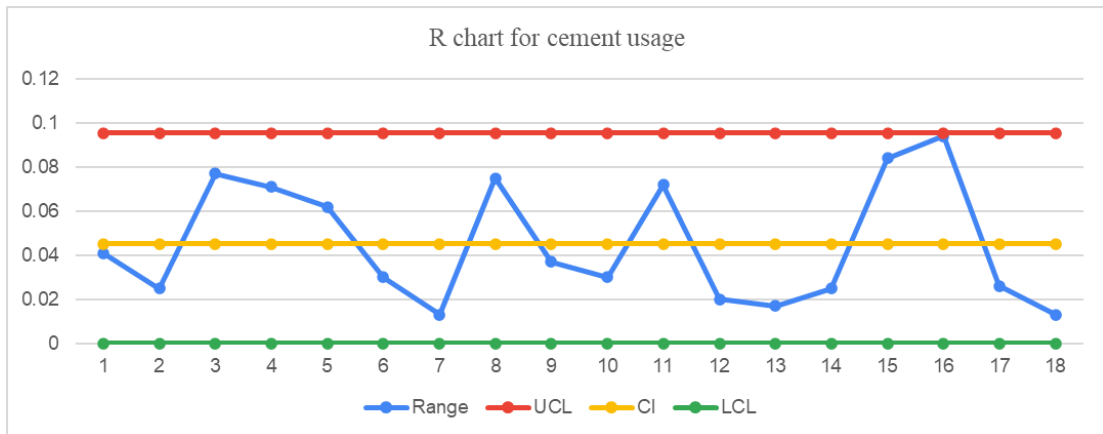


Figure 4.9 R chart for cement usage

The R chart for cement consumption indicates that all observed range values lie within the established control limits. It is observed that samples 15 and 16 approach the upper control limit, with sample 16 reaching the UCL. However, none of the points exceed the control limits. These higher values indicate moments of increased variability, but since they remain within acceptable bounds, the process variability is considered statistically in control. No systematic patterns such as trends or cycles are observed, confirming that the variation is due to common causes.

Sand consumption

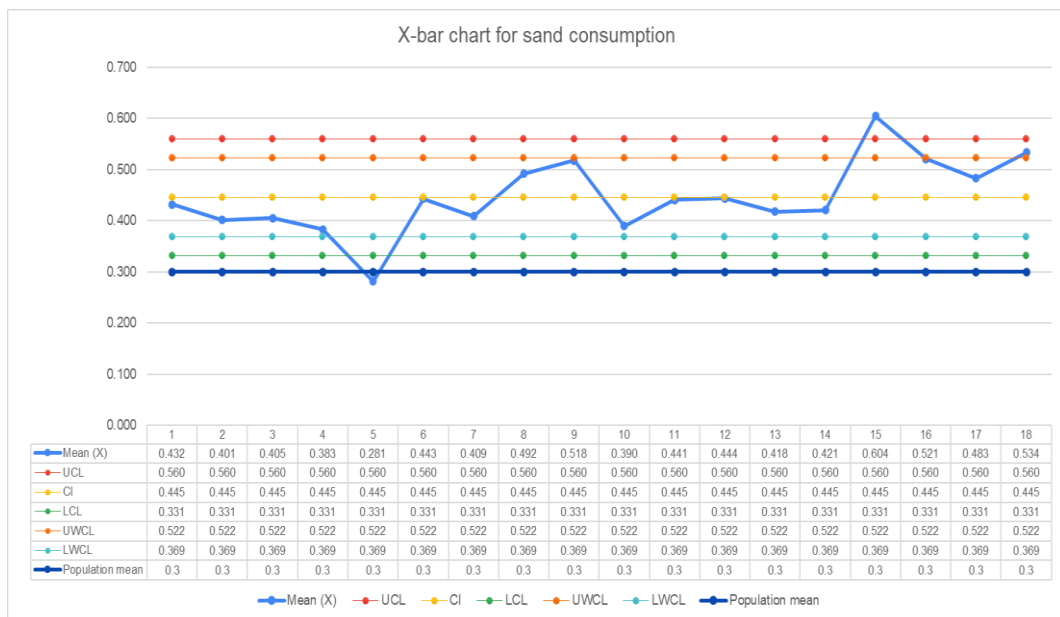


Figure 4.10: X-bar for sand usage

The X-bar chart for sand usage shows that most sample means fall within the control limits. However, sample 15 exceeds the upper control limit, indicating a significant shift in the process mean due to an assignable cause. In addition, sample 5 falls below the lower control limit, suggesting a temporary reduction in sand usage. The presence of a point beyond the control limit confirms that the process mean is not in statistical control.

Additionally, several points such as samples 8, 9, 16, and 18 lie close to or above the upper warning limit, indicating periods where sand consumption is relatively high and approaching the upper boundary of acceptable variation. These points act as early warning signals of potential process variability.

Apart from these points, the remaining values are randomly distributed around the centre line, with no strong evidence of trends or cycles. Overall, while the process is largely within control limits, the presence of points beyond the control limits and multiple observations near or above the warning limit indicates occasional variability influenced by site conditions, material handling, or workmanship. These deviations should be investigated to ensure consistent and controlled sand usage.

Furthermore, the sample means are consistently above the population mean, suggesting that actual sand consumption is higher than the standard (DUDBC) value.

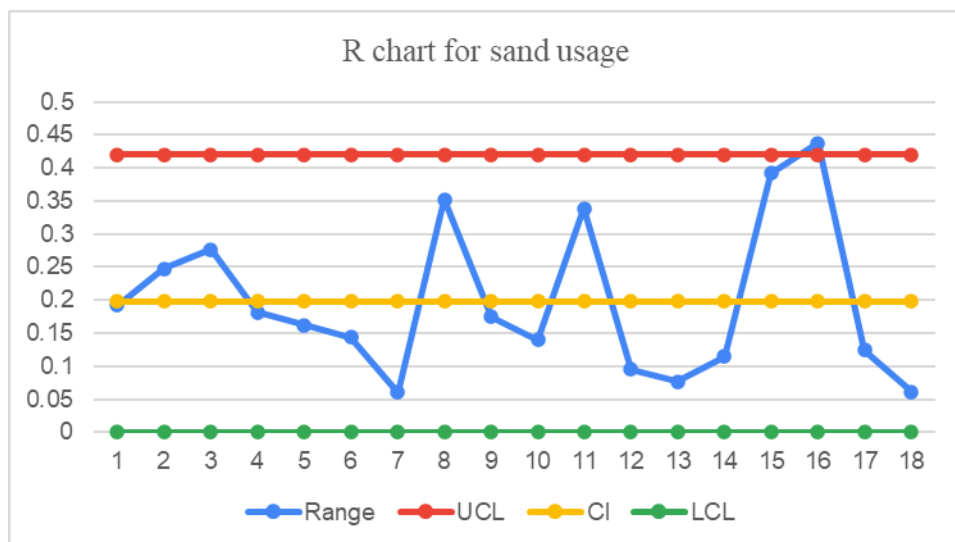


Figure 4.11 R chart for sand usage

The R chart for sand usage indicates that most of the range values lie within the control limits. However, sample 16 slightly exceeds the upper control limit, indicating the

presence of an assignable cause affecting process variability at that point. Additionally, samples 15 and 16 are very close to the UCL, showing a sudden increase in variability compared to earlier samples. The remaining points fluctuate randomly within the limits without any consistent trend or pattern. The presence of a point beyond the control limit suggests that the variability in sand consumption is not fully in statistical control.

Skilled manpower usage

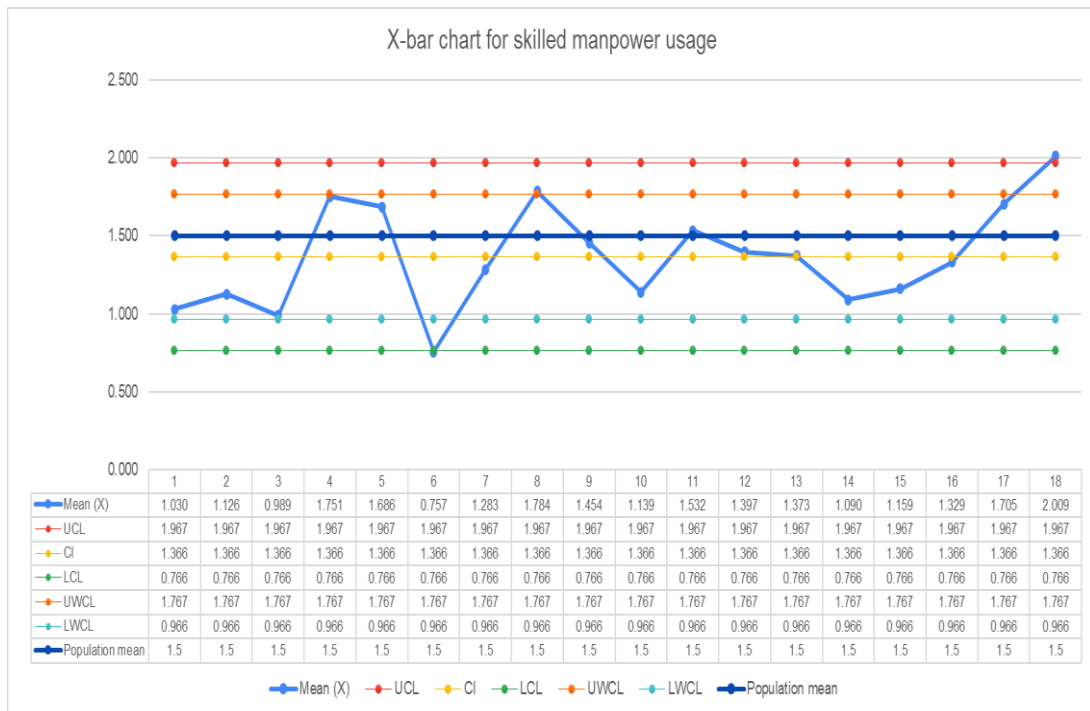


Figure 4.12 X-bar chart for skilled manpower usage

The \bar{X} chart for skilled manpower usage shows that most sample means fall within the control limits, indicating overall process stability. However, sample 18 slightly exceeds the upper control limit, suggesting a possible assignable cause and a temporary increase in skilled labour usage at this point. On the lower side, sample 6 shows a relatively low value near the lower control limit, indicating temporary reduced manpower usage, although it remains within acceptable bounds.

Additionally, samples 4 and 8 lie on or near the upper warning limit, indicating periods where manpower usage is relatively high and approaching the upper boundary of

acceptable variation. These points act as early warning signals and suggest potential instability in variation.

While the remaining sample means lie within the control limits and are randomly distributed around the centre line, the presence of this single point beyond the control limit indicates that the process is not in statistical control. These variations may be influenced by factors such as labour availability, site management, experience, crew composition or work efficiency, and should be investigated to ensure consistent manpower utilization.

While the overall mean of observations remains below the population mean, the individual sample (group of 5) means fluctuate around it, with values both above and below the standard, indicating inconsistency and variability in meeting the standard manpower requirement.

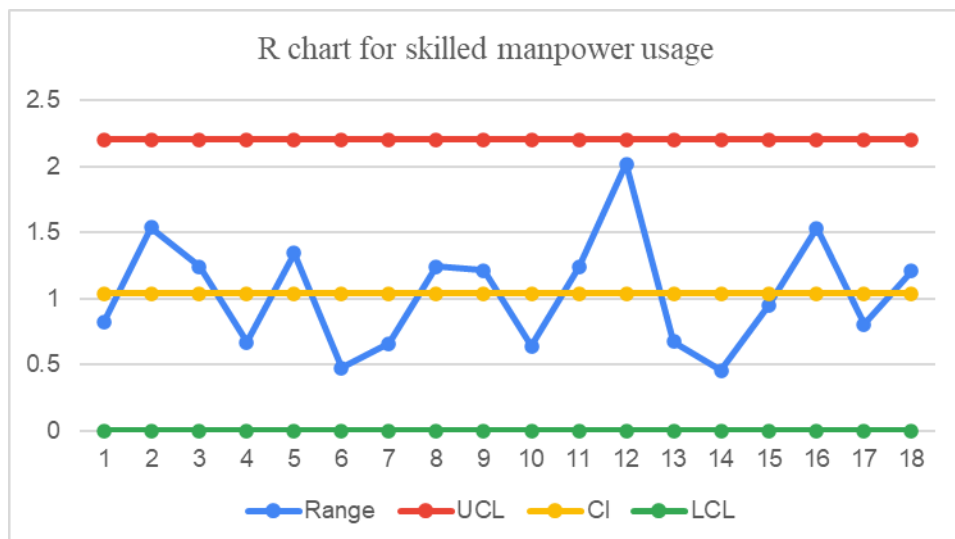


Figure 4.13 R chart for skilled manpower usage

The R chart for skilled manpower usage shows that all range values lie within the control limits. Although some fluctuations in variability are observed, particularly around samples 2, 5, 12, and 16, none of the points exceed the control limits. The values are randomly distributed without any systematic trends or unusual patterns. This indicates that the variability in skilled manpower usage is stable and under statistical control, governed by common cause variation.

Unskilled Manpower Usage

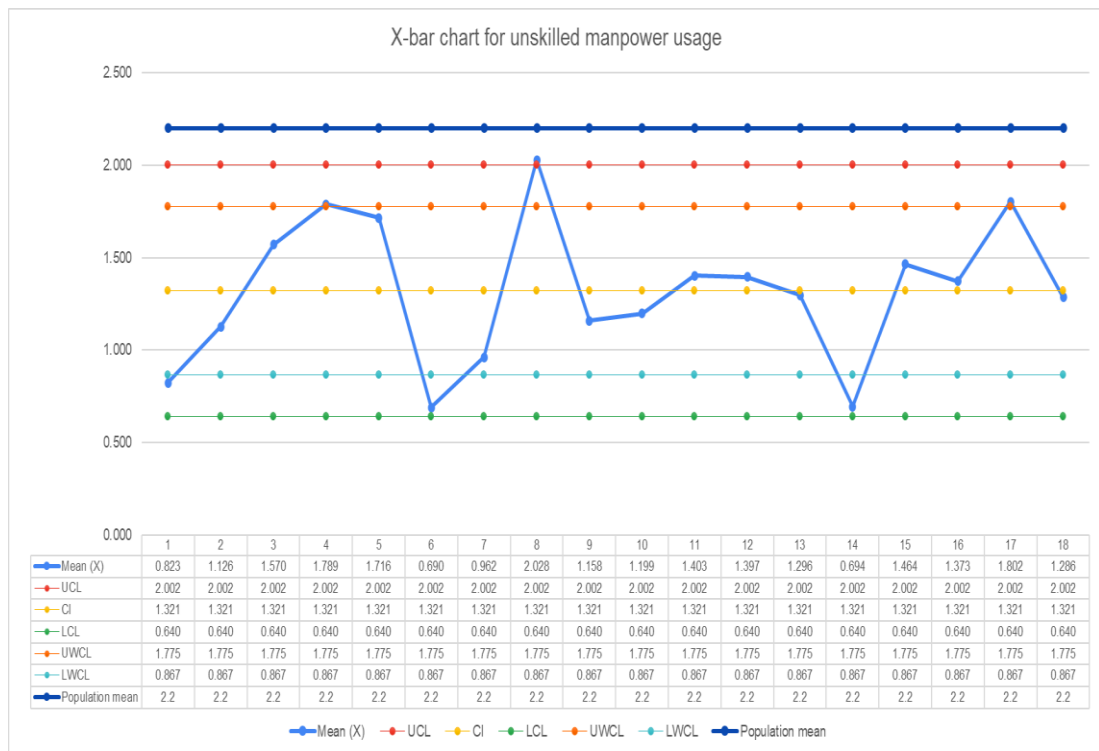


Figure 4.14 X-bar chart for unskilled manpower usage

The X bar chart for unskilled manpower usage shows that most of the sample means fall within the control limits. However, sample 8 reaches the upper control limit, indicating a peak in manpower usage during that period. While this point does not exceed the control limit, it represents the maximum observed value and suggests a temporary increase in unskilled labour deployment. On the lower side, samples 6 and 14 shows a value close to the lower control limit, indicating a temporary reduction in manpower usage. The remaining points are randomly distributed around the centre line, and no strong non-random patterns such as trends or cycles are observed.

Additionally, samples 4 and 17 lie on or near the upper warning limit, indicating periods of relatively higher unskilled labour usage. These points act as early warning signals of increased variability in manpower deployment. The remaining observations are distributed within the control and warning limits without any strong systematic pattern. Overall, while the process remains within control limits, the fluctuations around the warning limits and the consistent deviation from the population mean indicate variability in manpower utilization. These variations may be influenced by site-specific conditions, labour management practices, or differences in work execution, and should be further examined to ensure alignment with standard requirements.

All sample means lie significantly below the population mean, suggesting that actual unskilled manpower usage is consistently lower than the standard requirement.

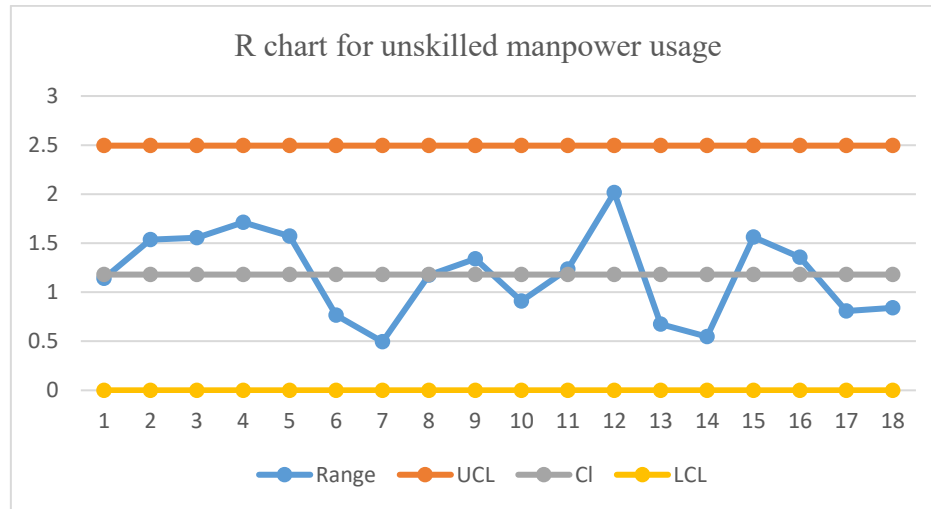


Figure 4.15 R chart for unskilled manpower usage

The R chart for unskilled manpower usage indicates that all range values lie within the control limits. Although fluctuations in variability are observed across the samples, particularly a relatively higher range at sample 12, none of the points exceed the control limits. The values appear randomly distributed without any systematic trends or patterns. This suggests that the variability in unskilled manpower usage is stable and under statistical control, governed by common cause variation.

The SPC analysis reveals varying levels of process control among the different resources, indicating differences in how each resource is managed and utilized on site.

Brick usage charts suggest that although the variability in brick usage is consistent, the average consumption is affected by assignable causes. Such variation can be attributed to factors such as inconsistencies in brick supply, handling practices, or workmanship. Similarly, cement usage patterns point out that while usage is generally consistent, occasional deviations occur, possibly due to batching errors, material wastage, or changes in mix proportions. Sand consumption is the most unstable among the resources analyzed, with both process mean and variability affected by assignable causes. Such instability may result from inconsistent material handling, wastage, or lack of standardized measurement practices.

For skilled manpower, the charts suggest that workforce allocation is generally consistent, however there are instances of abnormal increases in skilled labour deployment, possibly due to sudden changes in work requirements, task complexity, or scheduling adjustments. On the other hand, unskilled manpower usage demonstrated stable behavior in both the R and X bar charts, with all points lying within control limits. This indicates that unskilled labour usage is the most stable and predictable among all resources, likely due to its flexible and easily adjustable nature on construction sites.

Overall, the comparative analysis indicates that material resources (brick, cement, and sand) exhibit greater instability compared to labour resources. Among all resources, sand consumption shows the highest level of variability and lack of control, while unskilled manpower demonstrates the most stable performance. The findings highlight the need for improved material management practices, including better measurement, handling, and supervision, to reduce variability and achieve process control. In contrast, labour management appears relatively more consistent, though attention is still required to address occasional deviations in skilled manpower usage.

4.2 Factors contributing to deviations between DUDBC norms and actual site data

The Delphi method was employed to identify and prioritize; key factors affecting construction resource variability of DUDBC norms against actual site practices, through expert consensus. A panel of experts participated in two rounds of validation, and rating various factors based on their significance.

The first round of the Delphi resulted in following validated factors.

Table 4.6 Validated factors causing deviation in resources

Category	Factors
Material related Factors	1. Brick size variation
	2. Variable sand grading (variable water requirement for same workability)
	3. Bulking of sand
	4. Variation in material quality due to source differences (sand origin, brick kiln)
Execution related Factors	1. Mixing Method (machine/manual)
	2. Variation in mortar Thickness
	3. Wastage during loading, unloading and handling (Brick, Cement, Sand, Mortar loss)
	4. Use of dry bricks without soaking
	5. Use of machinery (transporting materials, mixing)
Worker related Factors	1. Mason Skill
	2. Crew Composition
	3. Experience
	4. Social harmony and physio-psychological condition of workers
Site related Factors	1. Wall type variation (Partition, exterior, toe walls etc.)
	2. Working height (Scaffolding vs floor)
	3. Environmental conditions (weather)
	4. Haulage distance of material from work place within site
	5. Co-ordination with other site activities
	6. Design Complexity (e.g. curved walls, large frequent openings, slanted walls, and other architectural features)
Management related Factors	1. Quality control
	2. Site management plan

	3. Improper Scheduling (Work plan and manpower allocation)
	4. Lack of training (Work procedure training, toolbox talks)
	5. Mode of contract (measurement basis vs daily wages)
	6. Motivation and expectation management
Norms related Factors	1. Deviation between DUDBC norm assumptions and actual site practices and conditions.
	2. Regional productivity variation

The second round Delphi comprised of 5-point Likert scale rating to these validated factors and. Ratings collected from experts were compiled and analysed using mean and inter quartile range calculation.

Table 4.7 Results of Delphi analysis for factors affecting deviation in resource utilization

Factors		Mean	Q1	Median	Q3	IQR	Remarks
Material Related Factors	1. Brick size variation	4.8	5	5	5	0	Consensus Achieved
	2. Variable sand grading (variable water requirement for same workability)	3.4	3	3	4	1	Consensus Achieved
	3. Bulking of sand	3.6	3	4	4	1	Consensus Achieved
	4. Variation in material quality due to source differences (sand origin, brick kiln)	3.6	3	4	4	1	Consensus Achieved
	1. Mixing Method (machine/manual)	3.6	3	4	4	1	Consensus Achieved

Execution Related Factors	2. Variation in mortar Thickness	4.6	5	5	5	0	Consensus Achieved
	3. Wastage during loading, unloading and handling (Brick, Cement, Sand, Mortar loss)	4	4	4	4	0	Consensus Achieved
	4. Use of dry bricks without soaking	3.8	3	4	4	1	Consensus Achieved
	5. Use of machinery (transporting materials, mixing)	4	4	4	4	0	Consensus Achieved
Worker Related Factors	1. Mason Skill	4.4	4	4	5	1	Consensus Achieved
	2. Crew Composition	4.4	4	4	5	1	Consensus Achieved
	3. Experience	4.2	4	4	4	0	Consensus Achieved
	4. Social harmony and physio-psychological condition of workers	4	4	4	4	0	Consensus Achieved
Site Related Factors	1. Wall type variation (Partition, exterior, toe walls etc.)	3.8	4	4	4	0	Consensus Achieved
	2. Working height (Scaffolding vs floor)	3.8	4	4	4	0	Consensus Achieved

	3. Environmental conditions (weather)	3.8	4	4	4	0	Consensus Achieved
	4. Haulage distance of material from work place within site	3.6	3	3	4	1	Consensus Achieved
	5. Co-ordination with other site activities	3.4	3	3	4	1	Consensus Achieved
	6. Design Complexity (e.g. curved walls, large frequent openings, slanted walls, and other architectural features)	3.8	3	4	4	1	Consensus Achieved
Management Related Factors	1. Quality control	4	4	4	4	0	Consensus Achieved
	2. Site management plan	4	4	4	4	0	Consensus Achieved
	3. Improper Scheduling (Work plan and manpower allocation)	3.8	4	4	4	0	Consensus Achieved
	4. Lack of training (Work procedure training, toolbox talks)	4	4	4	4	0	Consensus Achieved
	5. Mode of contract (measurement basis vs daily wages)	4.4	4	5	5	1	Consensus Achieved

	6. Motivation and expectation management	3.6	4	4	4	0	Consensus Achieved
							Consensus Achieved
Norms Related Factors	1. Deviation between DUDBC norm assumptions and actual site practices and conditions.	4	4	4	4	0	Consensus Achieved
	2. Regional productivity variation	3.4	3	4	4	1	Consensus Achieved

Top factors with high mean value across all categories are

Table 4.8: Ranking of identified factors

Rank	Factor	Mean	IQR
1	Brick size variation	4.8	0
2	Variation in mortar thickness	4.6	0
3	Mason skill	4.4	1
4	Crew composition	4.4	1
5	Mode of contract	4.4	1
6	Experience of workers	4.2	0

The Delphi analysis identified twenty-seven validated factors across six categories, with strong expert consensus achieved for all factors ($IQR \leq 1$). The ranking of these factors provides clear insight into the root causes of the deviations observed in Objective 1.

Brick size variation emerged as the most critical factor (mean = 4.8, IQR = 0), achieving complete consensus among experts. Variation in mortar thickness (mean = 4.6, IQR = 0) was ranked as the second most critical factor. The combined effect of these factors directly relates to the observed underconsumption of bricks (-10.87%) and overconsumption of cement (+46.90%) and sand (+48.15%). Use of thicker mortar

joints is also reflected in the top ranked labour related factors like mason skill (mean = 4.4, IQR=1), and worker experience (mean = 4.2, IQR=0). Less skilled or inexperienced workers tend to apply thicker, uneven mortar joints, leading to increased material consumption.

In addition, labour related factors, including mason skill (mean = 4.4, IQR=1), crew composition (mean = 4.4), and worker experience (mean = 4.2, IQR=0), also explain the observed higher skilled manpower (-9.4%) and unskilled manpower (-39.94%) productivity. Skilled and experienced masons can complete brick masonry work faster and with better quality, reducing the required person-days per cubic meter. The high variability in labour usage (CV of 37.652% for skilled and 45.2% for unskilled) across sites can also be because of variations in skill levels and crew compositions.

Mode of contract (mean = 4.4, IQR=1) emerged as an important management-related factor. Sites operating on a measurement basis (payment per cubic meter completed) typically exhibit higher productivity compared to daily wage contracts. Such conditions can also cause significant variation in labour productivity despite similar skill level and experience.

Overall, the Delphi analysis confirms that construction resource variability is influenced by a combination of material, execution, manpower, site, and management related factors. The high level of consensus among experts strengthens the reliability of these findings.

4.3 Potential interventions for improving the applicability of DUDBC norms

The Delphi method was employed to identify and prioritize potential interventions to enhance applicability of DUDBC norms against actual site practices, through expert consensus. A panel of experts participated in two rounds of validation, and rating various factors based on their significance.

The first round of the Delphi resulted in following validated interventive measures.

Table 4.9 Potential interventions for enhancing applicability of norms

Categories	Potential interventions
Quality Control Measures	1.Maintain required water volume for mortar preparation and ensure adequate soaking of bricks

	2. Control mortar joint thickness within acceptable limits as per norms (10–12 mm)
	3. Use trained manpower for batching and brick laying
	4. Enforce strict quality control practices
	5. Ensure materials procured on site meet standard grade before use on site
	6. Use of appropriate tools and equipment for accuracy (mortar mixer, laser level for accuracy)
Norms Update and Standardization	7. Periodic review and update of wastage factors in norms
	8. Periodic review and update of manpower efficiency norms based on field data
	9. Incorporate machinery usage (e.g., vertical transport equipment) into norms
	10. Modify norms to account for complex designs and difficult site conditions
	11. Define separate manpower requirements for substructure and superstructure works
	12. Consider variability in worker productivity across regions
	13. Conduct further region-specific studies across Nepal to refine norms
Manufacturing and Procurement Control	14. Standardize nominal brick size in norms and regulate manufacturing practices through regulatory authorities (e.g., Nepal Bureau of Standards and Metrology)
	15. Enforce quality control standards via regulatory bodies (DUDBC, DoR)

The second round Delphi comprised of 5-point Likert scale rating to these validated interventive measures. Ratings collected from experts were compiled and analysed using mean and inter quartile range calculation.

Table 4.10 Results of Delphi analysis on potential interventions for applicability of norms

Experts			Me an	Q 1	Me dian	Q 3	IQ R	Remarks
Potential Interventions								
Quality Control Measures	1	Maintain required water volume for mortar preparation and ensure adequate soaking of bricks	4	4	4	4	0	Consensus Achieved
	2	Control mortar joint thickness within acceptable limits as per norms (10–12 mm)	4.4	4	4	5	1	Consensus Achieved
	3	Use trained manpower for batching and brick laying	4.2	4	4	4	0	Consensus Achieved
	4	Enforce strict quality control practices	4	4	4	4	0	Consensus Achieved
	5	Ensure materials procured on site meet standard grade before use on site	4.2	4	4	4	0	Consensus Achieved
	6	Use of appropriate tools and equipment for accuracy (mortar mixer, laser level for accuracy)	4	4	4	4	0	Consensus Achieved

Norms Update and Standardization	7	Periodic review and update of wastage factors in norms	4	4	4	4	0	Consensus Achieved
	8	Periodic review and update of manpower efficiency norms based on field data	4.2	4	4	4	0	Consensus Achieved
	9	Incorporate machinery usage (e.g., vertical transport equipment) into norms	4.2	4	4	4	0	Consensus Achieved
	10	Modify norms to account for complex designs and difficult site conditions	4	4	4	4	0	Consensus Achieved
	11	Define separate manpower requirements for substructure and superstructure works	3.6	3	3	4	1	Consensus Achieved
	12	Consider variability in worker productivity across regions	4	4	4	4	0	Consensus Achieved
	13	Conduct further region-specific	3.6	3	4	4	1	Consensus Achieved

		studies across Nepal to refine norms						
Manufacturing and Procurement Control	14	Standardize nominal brick size in norms and regulate manufacturing practices through regulatory authorities (e.g., Nepal Bureau of Standards and Metrology)	4	4	4	4	0	Consensus Achieved
	15	Enforce quality control standards via regulatory bodies (DUDBC, DoR)	3.4	3	3	4	1	Consensus Achieved

Top potential interventions with high mean value across all categories are

Table 4.11: Ranking of identified potential interventions

Rank	Intervention	Mean	IQR
1	Control mortar joint thickness within acceptable limits	4.4	1
2	Use trained manpower for batching and brick laying	4.2	0
3	Ensure materials meet standard quality before use	4.2	0
4	Periodic review of manpower efficiency norms	4.2	0
5	Incorporation of machinery usage into norms	4.2	0

The Delphi analysis identified fifteen validated interventions across three categories, with expert consensus achieved for all measures ($IQR \leq 1$). The ranking of these interventions provides a practical roadmap for addressing the deviations and causes identified in Objectives 1 and 2.

Control of mortar joint thickness (mean = 4.4, IQR=1) was ranked as the most critical intervention. This directly addresses the second-ranked factor causing deviation (variation in mortar thickness). Implementing strict control over joint thickness within the recommended 10-12 mm range would significantly reduce cement and sand overconsumption.

Use of trained manpower for batching and brick laying (mean = 4.2, IQR=0) addresses the highly ranked labour-related factors (mason skill, crew composition, experience). Training workers on correct batching procedures, mortar preparation, and brick laying techniques would improve execution accuracy, reduce material wastage, and enhance productivity. This intervention is particularly important given the high variability in labour productivity observed across sites.

Ensuring materials meet standard quality before use (mean = 4.2, IQR=0) directly addresses brick size variation, the top-ranked factor. By enforcing quality control at the procurement stage and regulating brick manufacturing through authorities such as the Nepal Bureau of Standards and Metrology, the variability in brick dimensions can be minimized, bringing actual consumption closer to normative assumptions.

Periodic review of manpower efficiency norms (mean = 4.2, IQR=0) and incorporation of machinery usage into norms (mean = 4.2, IQR=0) address the systematic overestimation of labour requirements observed in the site data. The findings suggest that DUDBC norms currently underestimate labour productivity. Periodic updates based on field data would ensure that norms reflect actual site conditions. Additionally, norms should account for the use of machinery (e.g., mortar mixers, mechanical hoists) which improves productivity but is not currently recognized in standard labour coefficients. Use of such devices can significantly deviate actual manpower productivity from values assumed in norms.

Overall, the Delphi analysis confirms that the applicability of DUDBC norms can be enhanced through a combination of quality control measures, norms update and standardization, and manufacturing and procurement control interventions. The high level of consensus among experts strengthens the reliability of these measures and provides a practical, data-based roadmap for reducing resource variability, improving estimation accuracy, and aligning standard norms with actual site conditions.

Overall, the results from statistical analysis and expert consultation consistently indicate significant deviations between standard norms and actual construction practices. SPC analysis revealed instability in several resource usage processes, while t-test results confirmed statistically significant differences from prescribed values. The Delphi method further identified the key factors contributing to these deviations and proposed practical intervention strategies. Together, these findings provide a comprehensive understanding of resource variability from prescribed norms, and offer a practical basis for aligning standard norms with actual site practices.

Triangulation and Integration of Findings

The integration of findings from the three research objectives quantitative site observations (Objective 1), expert-validated deviation factors (Objective 2), and recommended interventions (Objective 3) reveals strong convergence that strengthens the study's conclusions.

- **Mortar over consumption**

The quantitative analysis showed that cement and sand consumption exceeded DUDBC standards by 46.90% and 48.15%, respectively. The t-test and Wilcoxon test confirmed these differences as statistically significant ($p < 0.05$). Experts independently identified variation in mortar joint thickness (mean = 4.6) as the one of the most critical factors contributing to this deviation. The top ranked intervention controlling mortar joint thickness (mean = 4.4) directly addresses this root cause.

This convergence across independent data sources (field measurements and expert opinions) provides strong evidence that excessive mortar usage is a real, systematic phenomenon rather than random variation, and that joint thickness control is a key intervention for improving resource efficiency.

- **Brick under consumption**

The site data showed brick consumption was 10.87% lower than the DUDBC standard, with high statistical significance ($t = -26.641$, $p < 0.05$). Experts identified brick size variation as the most critical factor (mean = 4.8, IQR=0), achieving complete consensus (IQR = 0).

This suggests that the DUDBC norm may have assumed a nominal brick size that does not reflect the actual dimensions of bricks commonly available in Kathmandu Valley. The recommended intervention, standardizing nominal brick size and regulating manufacturing (mean = 4.0) addresses this at the source, further reinforcing the alignment between observed deviations and identified measures.

- **Labour productivity**

Both skilled and unskilled manpower usage were significantly lower than DUDBC norms (9.40% and 39.94% respectively). Experts identified mason skill (mean = 4.4), crew composition (mean = 4.4), and mode of contract (mean = 4.4) as key factors. The high coefficients of variation for labour (skilled: 37.65%, unskilled: 45.20%) across sites are consistent with variations in these human factors. The recommended interventions using trained manpower (mean = 4.2) and periodic review of manpower efficiency norms (mean = 4.2) address both the execution quality and the normative assumptions.

This convergence suggests that DUDBC norms may be underestimating labour productivity, particularly under well managed sites with skilled workers and appropriate contract structures.

- **Process stability**

The SPC analysis revealed that sand consumption exhibited the highest process instability, with points beyond control limits, while unskilled manpower showed the most stable performance. Experts identified wastage during handling (mean = 4.0) and lack of standardized measurement practices as contributors to sand variability. In contrast, the relatively stable process mean and variability of unskilled manpower suggest predictable and consistent deployment, likely due to the repetitive nature of unskilled tasks on construction sites.

The convergence across independent data sources, field measurements, SPC analysis, and expert Delphi consultation strengthens the validity and reliability of the study's conclusions. The triangulation confirms that the observed deviations are real and statistically significant, the identified factors are valid, and the proposed interventions are practically relevant.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

This study evaluated the applicability of standard construction norms (DUDBC norms) in comparison with actual site practices for 9-inch-thick brick masonry works, with a focus on material consumption and labour productivity. The analysis was carried out using descriptive statistics, statistical process control (SPC), inferential statistical methods, and the Delphi technique.

Objective 1: The study revealed that deviations exist between quantity prescribed in DUDBC norms and actual resource utilization in brick masonry work under real construction conditions. Significant deviations were observed for all resources. Brick consumption was found to be lower than standard values (-10.87%), while cement (46.90%) and sand consumption (48.15%) were significantly higher. Labour usage, both skilled (-9.40%) and unskilled (-39.94%), was lower than prescribed norms, indicating higher on-site productivity.

The one sample t-test and one sample Wilcoxon signed rank test results confirmed that all observed resource values differ significantly from standard norms, (p -values < 0.05). This statistically validates the deviation between prescribed standards and actual site practices.

The descriptive analysis revealed that material consumption and labour productivity vary across construction sites, with materials showing relatively lower variability compared to labour. Brick consumption exhibited consistent usage patterns with low variability, whereas cement and sand consumption demonstrated moderate to high variability, indicating inconsistencies in material handling and mix practices. Labour productivity showed the highest variability, reflecting differences in workforce efficiency and site management practices.

The SPC analysis indicated that several processes are not fully in statistical control. While variability in most resources remained stable, the process mean for brick, cement, sand, and skilled manpower showed instances of assignable causes such as worker skill, experience, and mortar application inconsistencies. Sand consumption exhibited the

highest instability, with both mean and variability affected. In contrast, unskilled manpower usage was found to be stable and within control limits.

The control charts further reveal that the observed process means for material usage and unskilled manpower are significantly displaced from the population mean (DUDBC norms), highlighting a clear deviation from standard values. In contrast, the process mean for skilled manpower tends to fluctuate around the population mean, indicating relatively better alignment with the prescribed norms despite statistically significant differences. This indicates that the norms may need reformation to account for variability in real site conditions.

Objective 2: The study identified multiple interrelated factors contributing to deviations between standard norms and actual site practices based on the Delphi technique. Among these, brick size variation (mean = 4.8, IQR = 0) was ranked as the most significant factor, showing complete consensus among experts and indicating a strong influence on both quantity estimation and material consumption. Variation in mortar thickness (mean = 4.6, IQR = 0) was identified as another key factor, directly affecting cement and sand usage and contributing to their overconsumption. Labour-related factors such as mason skill (mean = 4.4, IQR = 1), crew composition (mean = 4.4, IQR = 1), and experience of workers (mean = 4.2, IQR = 0) were also found to significantly influence productivity and efficiency on site. In addition, management-related factors, particularly mode of contract (mean = 4.4, IQR = 1), play an important role through their impact on worker motivation and work efficiency. Overall, the findings indicate that deviations are not caused by a single factor but arise from a combination of material variability, execution practices, labour efficiency, and management conditions, all of which collectively influence actual resource consumption in brick masonry work.

Objective 3: The study identified several practical interventions through expert consensus to improve the applicability of DUDBC norms in real construction conditions. The most critical interventions include controlling mortar joint thickness within standard limits (mean=4.4, IQR=1), using trained manpower for batching and brick laying (mean = 4.2, IQR = 0), ensuring that materials meet required quality standards before use (mean = 4.2, IQR = 0), periodically revising manpower efficiency norms based on field data (mean = 4.2, IQR = 0), and incorporating machinery usage

into standard norms (mean = 4.2, IQR = 0). These interventions indicate that both technical improvements at the site level and institutional updates in existing norms are necessary to enhance resource efficiency and accuracy in estimation. The findings emphasize that improving construction practices alone is not sufficient unless it is supported by updated, context-specific standards that reflect actual site conditions.

Overall, the study concludes that while standard norms provide a useful baseline, they do not fully capture the variability and complexity of actual construction practices. There is a need for empirical, data-driven refinement of these norms to better reflect site realities and ensure their relevance and practical applicability in contemporary construction practices.

5.2 Recommendations

Based on the findings of this study, the following recommendations are proposed:

- DUDBC norms should be periodically revised using empirical field data to ensure alignment with actual construction practices.
- Standard norms should incorporate flexibility to account for variations in site conditions and construction environments.
- Construction practices should be strengthened through process-based control measures (use of standardized procedures, appropriate tool usage) to reduce variability in material usage.
- Emphasis should be placed on training and skill development of the workforce, efficient crew structuring, and improved work organization to enhance productivity and reduce variability.
- Effective site management systems should be implemented to ensure better coordination, supervision, and quality control.

Recommendations for future research

- Similar studies can be conducted for other construction activities such as 4-inch-thick brick masonry work, PCC, Rebar works, plastering etc.
- Similar studies can be conducted in different regions of Nepal to capture regional variability in material consumption and labour productivity.

- Long-term studies can be carried out incorporating seasonal variations and their impact on construction practices and resource utilization.
- Further research may focus on developing revised or adaptive norm frameworks that incorporate field data and evolving construction practices
- Studies may also explore barriers to updating existing norms, including institutional, technical, and practical challenges in implementation.

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APPENDIX 1: DATA COLLECTED FROM OBSERVATIONS

SN	Site ID	Project Type	Wall Type/ Mix	Work Location	Platform	Work Area	Bricks Used per Cum	Cement(Ton) Used per cum	Sand (Cum) Used per cum	Skilled Manpower	Unskilled Manpower	Calculated Wet Mortar Volume
1	S1	Residence	9"/ 1:6	2nd Floor	Metal Tables	Elevator Duct	510.251	0.095	0.453	1.463	1.463	0.325
2		Residence	9"/ 1:6	3rd Floor	Metal Tables	Elevator Duct	531.325	0.087	0.417	1.256	1.256	0.297
3	S2	Residence	9"/ 1:6	Ground Floor	Floor	Toe Wall	495.154	0.116	0.544	1.085	0.723	0.331
4		Residence	9"/ 1:6	Ground Floor	Floor	Toe Wall	518.834	0.075	0.352	0.701	0.351	0.299
5		Residence	9"/ 1:6	Ground Floor	Floor	Toe Wall	501.125	0.084	0.393	0.643	0.322	0.323
6		Residence	9"/ 1:6	Ground Floor	Floor	Toe Wall	486.934	0.095	0.447	0.666	0.666	0.342
7		Residence	9"/ 1:6	Ground Floor	Floor	Ground Floor	504.053	0.091	0.426	0.792	0.792	0.319
8		Residence	9"/ 1:7	Ground Floor	Floor + Drum	Ground Floor	523.394	0.11	0.517	2.202	2.202	0.293
9	S3	Residence	9"/ 1:6	First Floor	Floor	Exterior Wall	544.477	0.111	0.348	1.112	1.112	0.266
10		Residence	9"/ 1:6	First Floor	Drum	Exterior Wall	529.537	0.086	0.269	0.86	0.86	0.286
11		Residence	9"/ 1:6	Second Floor	Floor	Exterior Wall	443.839	0.108	0.339	0.841	0.841	0.42
12	S4	Residence	9"/ 1:6	First Floor	Floor	Exterior Wall	509.219	0.06	0.286	0.554	1.108	0.318
13		Residence	9"/ 1:6	First Floor	Floor	Exterior Wall	512.239	0.102	0.481	0.762	1.524	0.314
14		Residence	9"/ 1:6	First Floor	Floor	Exterior Wall	510.424	0.119	0.563	0.991	1.983	0.317
15	S5	Office	9"/ 1:6	First Floor	Floor	Exterior Wall	503.466	0.137	0.355	1.797	2.396	0.321
16		Office	9"/ 1:6	First Floor	Floor	Exterior Wall	496.711	0.171	0.442	1.991	2.654	0.33
17		Office	9"/ 1:6	First Floor	Floor	Exterior Wall	516.498	0.159	0.411	2.083	2.083	0.303
18		Office	9"/ 1:6	First Floor	Floor	Exterior Wall	546.259	0.168	0.434	1.76	1.76	0.263
19		Office	9"/ 1:6	First Floor	Floor	Exterior Wall	489.865	0.1	0.26	1.507	1.507	0.339
20		Office	9"/ 1:6	First Floor	Floor	Exterior Wall	503.707	0.141	0.366	1.413	0.942	0.32
21		Office	9"/ 1:6	First Floor	Scaffold	Exterior Wall	510.866	0.116	0.3	1.353	1.353	0.311
22		Office	9"/ 1:6	First Floor	Scaffold	Exterior Wall	548.025	0.109	0.281	1.899	2.532	0.26
23		Office	9"/ 1:6	First Floor	Scaffold	Exterior Wall	542.342	0.145	0.376	2.537	2.537	0.268
24		Office	9"/ 1:6	First Floor	Scaffold	Exterior Wall	517.421	0.083	0.214	1.446	0.964	0.302
25		Office	9"/ 1:6	First Floor	Scaffold	Exterior Wall	505.945	0.091	0.235	1.193	1.193	0.317
26	S6	Residence	9"/ 1:6	Ground Floor	Floor	Toe Wall	490.062	0.096	0.451	0.88	0.88	0.351
27		Residence	9"/ 1:6	Ground Floor	Floor	Toe Wall	489.439	0.085	0.399	0.778	1.038	0.352
28		Residence	9"/ 1:6	Ground Floor	Floor	Toe Wall	496.94	0.115	0.543	0.56	0.747	0.342
29		Residence	9"/ 1:6	Ground Floor	Floor	Exterior Wall	482.704	0.087	0.41	0.545	0.273	0.36
30		Residence	9"/ 1:6	Ground Floor	Floor	Exterior Wall	493.165	0.088	0.412	1.023	0.512	0.347
31	S7	Residence	9"/ 1:6	Ground Floor	Floor	Toe Wall	510.52	0.087	0.408	1.159	0.869	0.331
32		Residence	9"/ 1:6	Ground Floor	Floor	Toe Wall	513.199	0.095	0.447	1.307	0.98	0.327
33		Residence	9"/ 1:6	Ground Floor	Floor	Toe Wall	501.82	0.086	0.403	1.211	0.908	0.342
34		Residence	9"/ 1:6	Ground Floor	Floor	Toe Wall	522.594	0.082	0.387	1.04	0.78	0.315
35		Residence	9"/ 1:6	Ground Floor	Floor	Toe Wall	524.534	0.085	0.399	1.7	1.275	0.312
36	S8	Commercial	9"/ 1:6	First Floor	Floor	Exterior Wall	474.931	0.138	0.649	1.968	2.624	0.381
37		Commercial	9"/ 1:6	First Floor	Floor	Exterior Wall+Zero face	496.17	0.102	0.477	1.451	1.451	0.353
38		Commercial	9"/ 1:6	First Floor	Floor	Exterior Wall	476.596	0.09	0.422	1.124	1.686	0.379
39		Commercial	9"/ 1:6	Second Floor	Floor	Zero face wall	463.61	0.063	0.297	2.367	2.367	0.396
40		Commercial	9"/ 1:6	Second Floor	Floor	Exterior Wall+Zero face	510.138	0.131	0.615	2.01	2.01	0.335
41		Commercial	9"/ 1:6	Second Floor	Floor	Exterior Wall+Zero face	482.664	0.093	0.438	1.707	0.854	0.371

42		Commercial	97:1:6	Second Floor	Floor	Exterior Wall	486.73	0.107	0.504	1.966	1.966	0.366
43		Commercial	97:1:6	Second Floor	Floor	Zero face wall	508.946	0.13	0.613	1.25	0.625	0.337
44		Commercial	97:1:6	Ground Floor	Scaffold	Zero face wall	505.546	0.098	0.462	0.753	0.753	0.341
45		Commercial	97:1:6	Second Floor	Floor	Exterior Wall	523.519	0.121	0.571	1.594	1.594	0.318
46		Commercial	97:1:6	Second Floor	Floor	Exterior Wall	475.843	0.083	0.391	1.041	1.041	0.38
47	S9	Commercial	97:1:6	First Floor	Floor	Partition Wall	530.818	0.1	0.47	1.167	1.75	0.297
48		Commercial	97:1:6	First Floor	Floor	Exterior Wall	486.835	0.075	0.353	1.503	1.503	0.355
49		Commercial	97:1:6	First/ Ground Floor	Floor	Exterior Wall	532.102	0.086	0.404	0.86	0.86	0.295
50		Commercial	97:1:6	First Floor	Floor	Exterior Wall	481.484	0.07	0.33	1.123	0.842	0.362
51		Commercial	97:1:6	Second Floor	Floor	Exterior Wall	496.629	0.058	0.272	0.705	0.705	0.342
52		Commercial	97:1:6	Second Floor	Floor	Exterior Wall	498.882	0.114	0.533	1.915	1.915	0.339
53		Commercial	97:1:6	Ground Floor	Scaffold	Exterior Wall	490.182	0.129	0.608	1.941	1.941	0.351
54		Commercial	97:1:6	Second Floor	Floor	Exterior Wall	527.947	0.057	0.269	1.931	1.287	0.301
55	S10	Residence	97:1:6	Second Floor	Floor	Zero face wall	503.729	0.111	0.521	1.169	1.169	0.337
56		Residence	97:1:6	Second Floor	Floor	Exterior Wall	479.311	0.093	0.438	0.513	0.513	0.369
57		Residence	97:1:6	Second Floor	Scaffold	Exterior Wall	470.623	0.091	0.429	0.83	0.83	0.381
58	S11	Residence	97:1:6	Second Floor	Floor	Exterior Wall	517.441	0.101	0.475	2.529	2.529	0.314
59		Residence	97:1:6	Second Floor	Floor	Exterior Wall	488.614	0.103	0.486	1.725	1.725	0.352
60		Residence	97:1:6	Second Floor	Scaffold	Exterior Wall	493.938	0.083	0.391	1.386	1.386	0.345
61		Residence	97:1:6	Second Floor	Scaffold	Exterior Wall	499.843	0.085	0.399	1.698	1.698	0.337
62	S12	Hostel	97:1:6	Ground Floor	Floor	Toe Wall	470.966	0.086	0.406	1.296	1.296	0.387
63		Hostel	97:1:6	Ground Floor	Floor	Toe Wall	450.404	0.084	0.395	1.025	1.025	0.414
64		Hostel	97:1:6	Ground Floor	Floor	Toe Wall	471.655	0.101	0.472	1.307	1.307	0.386
65		Hostel	97:1:6	Ground Floor	Floor	Toe Wall	484.234	0.089	0.417	1.539	1.154	0.37
66		Hostel	97:1:6	Ground Floor	Floor	Toe Wall	475.675	0.097	0.453	1.336	1.002	0.381
67		Hostel	97:1:6	Ground Floor	Floor	Toe Wall	468.675	0.097	0.455	1.107	0.83	0.39
68		Hostel	97:1:6	Ground Floor	Floor	Toe Wall	472.061	0.072	0.34	0.988	0.593	0.386
69		Hostel	97:1:6	Ground Floor	Floor	Toe Wall	457.482	0.091	0.428	1.139	0.456	0.405
70		Hostel	97:1:6	Ground Floor	Floor	Toe Wall	465.346	0.091	0.429	0.88	0.587	0.395
71	S13	Residence	97:1:6	First Floor	Floor	Zero face wall	475.936	0.114	0.534	1.137	1.516	0.378
72		Residence	97:1:6	First Floor	Floor	Zero face wall	488.543	0.148	0.693	1.77	2.361	0.362
73		Residence	97:1:6	First Floor	Scaffold	Zero face wall	478.226	0.16	0.75	0.997	0.997	0.375
74		Residence	97:1:6	First Floor	Scaffold	Zero face wall	489.083	0.076	0.358	1.067	0.8	0.361
75	S14	Residence	97:1:6	Ground Floor	Floor	Exterior Wall	490.302	0.146	0.687	0.822	1.644	0.351
76		Residence	97:1:6	Ground Floor	Floor	Exterior Wall	488.187	0.056	0.265	0.493	0.985	0.352
77		Residence	97:1:6	Ground Floor	Floor	Exterior Wall	496.997	0.098	0.459	1.343	0.672	0.342
78		Residence	97:1:7	Ground Floor	Floor	Exterior Wall	491.591	0.15	0.703	1.589	1.589	0.366
79		Residence	97:1:8	Ground Floor	Floor	Exterior Wall	488.296	0.127	0.596	2.028	2.028	0.37
80	S15	Office	97:1:6	Second Floor	Scaffold	Exterior Wall	523.25	0.124	0.581	1.192	1.589	0.304
81		Office	97:1:6	Ground Floor	Scaffold	Exterior Wall	492.303	0.087	0.409	1.739	1.739	0.345
82		Office	97:1:6	Second Floor	Scaffold	Exterior Wall	504.81	0.108	0.506	1.455	1.94	0.329
83		Office	97:1:6	Ground Floor	Scaffold	Exterior Wall	514.882	0.1	0.472	1.883	1.883	0.315
84		Office	97:1:6	Second Floor	Scaffold	Exterior Wall	525.592	0.106	0.496	1.319	1.319	0.301
85		Office	97:1:6	First Floor	Scaffold	Partition Wall	491.657	0.113	0.533	2.127	2.127	0.346
86		Office	97:1:6	Second Floor	Scaffold	Exterior Wall	526.382	0.122	0.572	1.781	1.781	0.3
87		Office	97:1:6	First Floor	Scaffold	Partition Wall	507.186	0.109	0.511	1.409	0.939	0.325
88		Office	97:1:6	Ground Floor	Floor	Lift Wall	506.6	0.111	0.524	2.229	1.114	0.326
89		Office	97:1:6	Ground Floor	Scaffold	Lift Wall	493.896	0.112	0.527	2.618	1.309	0.343

APPENDIX 2: SITE MEASUREMENT COLLECTION FORMAT

SN Particulars					Date
9" Brickwork in 1:6					
Work Start Time			WS Time		
Skilled			X Nos		
Unskilled			Y Nos		
Cement Bags			Cb Nos		
Standard Cement Volume					
Full volume on measuring device			a Cum		
Partial volume on measuring device			b Cum		
Total observed volume of 1 bag cement (Co)			a+b Cum		
Cement used (Ct)			Cb*Co cum		
Sand used (S)			Ct*6 cum		
Volume at Start	Length	Breadth	Height	Volume	
Section 1	L1	B1	H1	V1	
Section 2	L2	B2	H2	V2	
Section 3	L3	B3	H3	V3	
Section n	Ln	Bn	Hn	Vn	
Total				V	cum
Volume at End	Length	Breadth	Height	Volume	
Section 1	L1'	B1'	H1'	V1'	
Section 2	L2'	B2'	H2'	V2'	
Section 3	L3'	B3'	H3'	V3'	
Section n	Ln'	Bn'	Hn'	Vn'	
Total				V'	cum
Day Progress (Vt)				V'-V	cum
Bricks Used	Full	Partial	No. of Rows	Total	
Section 1					
Section 2					
Section 3					
Section 4					
Total Bricks Used				Bt	Nos
For 1cum					
Cement Volume in 1 Cum (C1)	Ct/Vt	Ct/ (Vt*Co)	Bags		
Sand Volume in 1 Cum (S1)	S/Vt		Cum		
Work Stop Time		WSt	Time		
Total Work Hours (Wt)		WSt-Ws			
Total Brick used in Wt hours		Bt			
Total work progress in Wt hrs		Vt			
Total work progress in 8 hrs (W8hr)		Vt/Wt*W8h	Cum		
Observed Data in standard unit					
Total Bricks Used in 1 Cum		Bt/Vt	Nos		
Cement in Metric Ton		(C1*50) /1000	Ton		
Sand Volume in 1 Cum		S/Vt	Cum		
Skilled manpower for 1 Cum		W8hr/X	Nos		
Unskilled manpower for 1 Cum		W8hr/Y	Nos		

APPENDIX 3: STATISTICAL CALCULATIONS

a. Mean calculation

The mean value for each resource is calculated as

$$\bar{x} = \Sigma x / n$$

where;

x = observed value of resource consumption per m³

Σx = sum of all observations

n = total number of observations (n = 89)

\bar{x} = mean value of observed data

Using sample data:

$$\bar{x} = (x_1 + x_2 + x_3 + \dots + x_n) / n$$

$$\bar{x} = (\text{Total sum of observations}) / 89$$

b. Standard deviation calculation

Standard deviation is calculated using:

$$s = \sqrt{[\Sigma (x - \bar{x})^2 / (n - 1)]}$$

where,

s = standard deviation

x = observed value of resource consumption per m³

\bar{x} = mean value of observed data

Σ = summation of all values

n = total number of observations (n = 89)

c. Coefficient of variation

The coefficient of variation is calculated using

$$CV = (s / \bar{x}) \times 100$$

where,

CV = coefficient of variation (%)

s = standard deviation

\bar{x} = mean value of observed data

No. of observations (n)=89				
Resource	DUDBC Norm/ Population Mean (μ)	Mean (\bar{x})	Std Dev (s)	CV (SD/Mean)
Bricks	560	499.103	21.565	4.321%
Cement	0.07	0.103	0.025	24.071%
Sand	0.3	0.444	0.110	24.646%
Skilled	1.5	1.359	0.512	37.652%
Unskilled	2.2	1.321	0.597	45.200%

d. One sample t-test

Null Hypothesis (H_0): $\bar{x} = \mu$

(There is no significant difference between observed mean and DUDBC norm)

Alternate Hypothesis (H_1): $\bar{x} \neq \mu$

(There is a significant difference between observed mean and DUDBC norm)

Test statistic:

$$t = (\bar{x} - \mu) / (s / \sqrt{n})$$

where;

t = calculated t-value

\bar{x} = mean value of observed data

μ = population mean (DUDBC standard value)

s = standard deviation of observed data

n = number of observations (n = 89)

Test conditions:

Significance level (α) = 0.05

Two-tailed test

Degrees of freedom (df) = n-1 = 88

t-critical ~ ±1.99

p-value < 0.05

One-sample t-test results / No. of observations (n)=89						
Resource	DUDBC Norm/ Population Mean (μ)	Mean (\bar{x})	Std Dev (s)	$\bar{x}-\mu$	Standard Error (s/sqrt(n))	t-value
Bricks	560	499.103	21.565	-60.897	2.286	-26.641
Sand	0.3	0.444	0.110	0.144	0.012	12.441
Skilled	1.5	1.359	0.512	-0.141	0.054	-2.600

Based on the tabulated results,

- $|t\text{-calculated}| > t\text{-critical}$
- Null hypothesis is rejected for all variables
- Deviations in brick, sand, and skilled manpower consumption are statistically significant.

e. One-sample Wilcoxon signed rank test

Null Hypothesis (H_0): Median = μ

(There is no significant difference between the observed median and DUDBC norm.)

Alternative Hypothesis (H_1): Median $\neq \mu$

(There is a significant difference between the observed median and DUDBC norm.)

For large sample sizes ($n > 30$), the test statistic is approximated using:

$$Z = \frac{W - \mu_W}{\sigma_W}$$

where:

W = Wilcoxon test statistic

μ_W = mean of rank sums

σ_W = standard deviation of rank sums

Z = standardized test statistic

Test conditions:

Significance level (α) = 0.05

Two-tailed test

One-sample Wilcoxon signed-rank test results / No. of observations (n)=89						
Resource	DUDBC Norm (μ)	Sample Median	Median Difference	W	Z-value	p-value
Cement	0.07	0.098	0.028	3873	7.969	<0.001
Unskilled	2.2	1.256	-0.944	107	-7.755	<0.001

Based on the results:

- p-value < 0.05 for all variables
- Null hypothesis is rejected
- Deviations in cement and unskilled manpower consumption are statistically significant.

All statistical computations were performed using SPSS (Version 27).

f. Calculations for X-bar and R charts

For Brick Usage												
	R Chart limits											
	UCL	81.716										
	LCL	0.000										
	CI	38.655										
Groups	B1	B2	B3	B4	B5	Range(R)	UCL	CI	LCL			
1.000	510.251	513.199	501.820	522.594	524.534	22.714	81.716	38.655	0.000			
2.000	486.934	504.053	523.394	544.477	529.537	57.543	81.716	38.655	0.000			
3.000	443.839	509.219	512.239	510.424	503.466	68.400	81.716	38.655	0.000			
4.000	496.711	516.498	546.259	489.865	503.707	56.394	81.716	38.655	0.000			
5.000	510.866	548.025	542.342	517.421	505.945	42.080	81.716	38.655	0.000			
6.000	490.062	489.439	496.940	482.704	493.165	14.236	81.716	38.655	0.000			
7.000	510.520	513.199	501.820	522.594	524.534	22.714	81.716	38.655	0.000			
8.000	474.931	496.170	476.596	463.610	510.138	46.528	81.716	38.655	0.000			
9.000	482.664	486.730	508.946	505.546	523.519	40.855	81.716	38.655	0.000			
10.000	475.843	530.818	486.835	532.102	481.484	56.259	81.716	38.655	0.000			
11.000	496.629	498.882	490.182	527.947	503.729	37.765	81.716	38.655	0.000			
12.000	479.311	470.623	517.441	488.614	493.938	46.818	81.716	38.655	0.000			
13.000	499.843	470.966	450.404	471.655	484.234	49.439	81.716	38.655	0.000			
14.000	475.675	468.675	472.061	457.482	465.346	18.193	81.716	38.655	0.000			
15.000	475.936	488.543	478.226	489.083	490.302	14.366	81.716	38.655	0.000			
16.000	488.187	496.997	491.591	488.296	523.250	35.063	81.716	38.655	0.000			
17.000	492.303	504.810	514.882	525.592	491.657	33.935	81.716	38.655	0.000			
18.000	526.382	507.186	506.600	493.896		32.486	81.716	38.655	0.000			
	X-bar chart limits									X-bar chart warning limits		
	UCL	521.686								UCL	514.226	
	LCL	477.078								LCL	484.539	
	CI	499.382								CI	499.382	
Groups	B1	B2	B3	B4	B5	Mean (X)	UCL	CI	LCL	Population Mean	UWCL	LWCL
1.000	510.251	513.199	501.820	522.594	524.534	514.480	521.686	499.382	477.078	560.000	514.226	484.539
2.000	486.934	504.053	523.394	544.477	529.537	517.679	521.686	499.382	477.078	560.000	514.226	484.539
3.000	443.839	509.219	512.239	510.424	503.466	495.837	521.686	499.382	477.078	560.000	514.226	484.539
4.000	496.711	516.498	546.259	489.865	503.707	510.608	521.686	499.382	477.078	560.000	514.226	484.539
5.000	510.866	548.025	542.342	517.421	505.945	524.920	521.686	499.382	477.078	560.000	514.226	484.539
6.000	490.062	489.439	496.940	482.704	493.165	490.462	521.686	499.382	477.078	560.000	514.226	484.539
7.000	510.520	513.199	501.820	522.594	524.534	514.533	521.686	499.382	477.078	560.000	514.226	484.539
8.000	474.931	496.170	476.596	463.610	510.138	484.289	521.686	499.382	477.078	560.000	514.226	484.539
9.000	482.664	486.730	508.946	505.546	523.519	501.481	521.686	499.382	477.078	560.000	514.226	484.539
10.000	475.843	530.818	486.835	532.102	481.484	501.416	521.686	499.382	477.078	560.000	514.226	484.539
11.000	496.629	498.882	490.182	527.947	503.729	503.474	521.686	499.382	477.078	560.000	514.226	484.539
12.000	479.311	470.623	517.441	488.614	493.938	489.985	521.686	499.382	477.078	560.000	514.226	484.539
13.000	499.843	470.966	450.404	471.655	484.234	475.420	521.686	499.382	477.078	560.000	514.226	484.539
14.000	475.675	468.675	472.061	457.482	465.346	467.848	521.686	499.382	477.078	560.000	514.226	484.539
15.000	475.936	488.543	478.226	489.083	490.302	484.418	521.686	499.382	477.078	560.000	514.226	484.539
16.000	488.187	496.997	491.591	488.296	523.250	497.664	521.686	499.382	477.078	560.000	514.226	484.539
17.000	492.303	504.810	514.882	525.592	491.657	505.849	521.686	499.382	477.078	560.000	514.226	484.539
18.000	526.382	507.186	506.600	493.896		508.516	521.686	499.382	477.078	560.000	514.226	484.539

For Cement Usage

R Chart limits	
UCL	0.095
LCL	0.000
CI	0.045

Groups	B1	B2	B3	B4	B5	Range	UCL	CI	LCL
1.000	0.095	0.087	0.116	0.075	0.084	0.041	0.095	0.045	0.000
2.000	0.095	0.091	0.110	0.111	0.086	0.025	0.095	0.045	0.000
3.000	0.108	0.060	0.102	0.119	0.137	0.077	0.095	0.045	0.000
4.000	0.171	0.159	0.168	0.100	0.141	0.071	0.095	0.045	0.000
5.000	0.116	0.109	0.145	0.083	0.091	0.062	0.095	0.045	0.000
6.000	0.096	0.085	0.115	0.087	0.088	0.030	0.095	0.045	0.000
7.000	0.087	0.095	0.086	0.082	0.085	0.013	0.095	0.045	0.000
8.000	0.138	0.102	0.090	0.063	0.131	0.075	0.095	0.045	0.000
9.000	0.093	0.107	0.130	0.098	0.121	0.037	0.095	0.045	0.000
10.000	0.083	0.100	0.075	0.086	0.070	0.030	0.095	0.045	0.000
11.000	0.058	0.114	0.129	0.057	0.111	0.072	0.095	0.045	0.000
12.000	0.093	0.091	0.101	0.103	0.083	0.020	0.095	0.045	0.000
13.000	0.085	0.086	0.084	0.101	0.089	0.017	0.095	0.045	0.000
14.000	0.097	0.097	0.072	0.091	0.091	0.025	0.095	0.045	0.000
15.000	0.114	0.148	0.160	0.076	0.146	0.084	0.095	0.045	0.000
16.000	0.056	0.098	0.150	0.127	0.124	0.094	0.095	0.045	0.000
17.000	0.087	0.108	0.100	0.106	0.113	0.026	0.095	0.045	0.000
18.000	0.122	0.109	0.111	0.112		0.013	0.095	0.045	0.000

X-bar chart limits	
UCL	0.129
LCL	0.077
CI	0.103

X-bar chart warning limits	
UCL	0.120
LCL	0.086
CI	0.103

Groups	B1	B2	B3	B4	B5	Mean (X)	UCL	CI	LCL	Population mean	UWCL	LWCL
1.000	0.095	0.087	0.116	0.075	0.084	0.091	0.129	0.103	0.077	0.070	0.120	0.086
2.000	0.095	0.091	0.110	0.111	0.086	0.099	0.129	0.103	0.077	0.070	0.120	0.086
3.000	0.108	0.060	0.102	0.119	0.137	0.105	0.129	0.103	0.077	0.070	0.120	0.086
4.000	0.171	0.159	0.168	0.100	0.141	0.148	0.129	0.103	0.077	0.070	0.120	0.086
5.000	0.116	0.109	0.145	0.083	0.091	0.109	0.129	0.103	0.077	0.070	0.120	0.086
6.000	0.096	0.085	0.115	0.087	0.088	0.094	0.129	0.103	0.077	0.070	0.120	0.086
7.000	0.087	0.095	0.086	0.082	0.085	0.087	0.129	0.103	0.077	0.070	0.120	0.086
8.000	0.138	0.102	0.090	0.063	0.131	0.105	0.129	0.103	0.077	0.070	0.120	0.086
9.000	0.093	0.107	0.130	0.098	0.121	0.110	0.129	0.103	0.077	0.070	0.120	0.086
10.000	0.083	0.100	0.075	0.086	0.070	0.083	0.129	0.103	0.077	0.070	0.120	0.086
11.000	0.058	0.114	0.129	0.057	0.111	0.094	0.129	0.103	0.077	0.070	0.120	0.086
12.000	0.093	0.091	0.101	0.103	0.083	0.094	0.129	0.103	0.077	0.070	0.120	0.086
13.000	0.085	0.086	0.084	0.101	0.089	0.089	0.129	0.103	0.077	0.070	0.120	0.086
14.000	0.097	0.097	0.072	0.091	0.091	0.090	0.129	0.103	0.077	0.070	0.120	0.086
15.000	0.114	0.148	0.160	0.076	0.146	0.129	0.129	0.103	0.077	0.070	0.120	0.086
16.000	0.056	0.098	0.150	0.127	0.124	0.111	0.129	0.103	0.077	0.070	0.120	0.086
17.000	0.087	0.108	0.100	0.106	0.113	0.103	0.129	0.103	0.077	0.070	0.120	0.086
18.000	0.122	0.109	0.111	0.112		0.114	0.129	0.103	0.077	0.070	0.120	0.086

For Sand Usage

R Chart limits	
UCL	0.420
LCL	0.000
CI	0.199

Groups	B1	B2	B3	B4	B5	Range	UCL	CI	LCL
1.000	0.453	0.417	0.544	0.352	0.393	0.192	0.420	0.199	0.000
2.000	0.447	0.426	0.517	0.348	0.269	0.248	0.420	0.199	0.000
3.000	0.339	0.286	0.481	0.563	0.355	0.277	0.420	0.199	0.000
4.000	0.442	0.411	0.434	0.260	0.366	0.182	0.420	0.199	0.000
5.000	0.300	0.281	0.376	0.214	0.235	0.162	0.420	0.199	0.000
6.000	0.451	0.399	0.543	0.410	0.412	0.144	0.420	0.199	0.000
7.000	0.408	0.447	0.403	0.387	0.399	0.060	0.420	0.199	0.000
8.000	0.649	0.477	0.422	0.297	0.615	0.352	0.420	0.199	0.000
9.000	0.438	0.504	0.613	0.462	0.571	0.175	0.420	0.199	0.000
10.000	0.391	0.470	0.353	0.404	0.330	0.140	0.420	0.199	0.000
11.000	0.272	0.533	0.608	0.269	0.521	0.339	0.420	0.199	0.000
12.000	0.438	0.429	0.475	0.486	0.391	0.095	0.420	0.199	0.000
13.000	0.399	0.406	0.395	0.472	0.417	0.077	0.420	0.199	0.000
14.000	0.453	0.455	0.340	0.428	0.429	0.115	0.420	0.199	0.000
15.000	0.534	0.693	0.750	0.358	0.687	0.392	0.420	0.199	0.000
16.000	0.265	0.459	0.703	0.596	0.581	0.438	0.420	0.199	0.000
17.000	0.409	0.506	0.472	0.496	0.533	0.124	0.420	0.199	0.000
18.000	0.572	0.511	0.524	0.527		0.061	0.420	0.199	0.000

X-bar chart limits	
UCL	0.560
LCL	0.331
CI	0.445

X-bar chart warning limits	
UCL	0.522
LCL	0.369
CI	0.445

Groups	B1	B2	B3	B4	B5	Mean (X)	UCL	CI	LCL	Population Mean	UWCL	LWCL
1.000	0.453	0.417	0.544	0.352	0.393	0.432	0.560	0.445	0.331	560.000	514.226	484.539
2.000	0.447	0.426	0.517	0.348	0.269	0.401	0.560	0.445	0.331	560.000	514.226	484.539
3.000	0.339	0.286	0.481	0.563	0.355	0.405	0.560	0.445	0.331	560.000	514.226	484.539
4.000	0.442	0.411	0.434	0.260	0.366	0.383	0.560	0.445	0.331	560.000	514.226	484.539
5.000	0.300	0.281	0.376	0.214	0.235	0.281	0.560	0.445	0.331	560.000	514.226	484.539
6.000	0.451	0.399	0.543	0.410	0.412	0.443	0.560	0.445	0.331	560.000	514.226	484.539
7.000	0.408	0.447	0.403	0.387	0.399	0.409	0.560	0.445	0.331	560.000	514.226	484.539
8.000	0.649	0.477	0.422	0.297	0.615	0.492	0.560	0.445	0.331	560.000	514.226	484.539
9.000	0.438	0.504	0.613	0.462	0.571	0.518	0.560	0.445	0.331	560.000	514.226	484.539
10.000	0.391	0.470	0.353	0.404	0.330	0.390	0.560	0.445	0.331	560.000	514.226	484.539
11.000	0.272	0.533	0.608	0.269	0.521	0.441	0.560	0.445	0.331	560.000	514.226	484.539
12.000	0.438	0.429	0.475	0.486	0.391	0.444	0.560	0.445	0.331	560.000	514.226	484.539
13.000	0.399	0.406	0.395	0.472	0.417	0.418	0.560	0.445	0.331	560.000	514.226	484.539
14.000	0.453	0.455	0.340	0.428	0.429	0.421	0.560	0.445	0.331	560.000	514.226	484.539
15.000	0.534	0.693	0.750	0.358	0.687	0.604	0.560	0.445	0.331	560.000	514.226	484.539
16.000	0.265	0.459	0.703	0.596	0.581	0.521	0.560	0.445	0.331	560.000	514.226	484.539
17.000	0.409	0.506	0.472	0.496	0.533	0.483	0.560	0.445	0.331	560.000	514.226	484.539
18.000	0.572	0.511	0.524	0.527		0.534	0.560	0.445	0.331	560.000	514.226	484.539

For Skilled Manpower Usage

R Chart limits	
UCL	2.200
LCL	0.000
CI	1.041

Groups	B1	B2	B3	B4	B5	Range	UCL	CI	LCL
1.000	1.463	1.256	1.085	0.701	0.643	0.820	2.200	1.041	0.000
2.000	0.666	0.792	2.202	1.112	0.860	1.536	2.200	1.041	0.000
3.000	0.841	0.554	0.762	0.991	1.797	1.243	2.200	1.041	0.000
4.000	1.991	2.083	1.760	1.507	1.413	0.670	2.200	1.041	0.000
5.000	1.353	1.899	2.537	1.446	1.193	1.344	2.200	1.041	0.000
6.000	0.880	0.778	0.560	0.545	1.023	0.478	2.200	1.041	0.000
7.000	1.159	1.307	1.211	1.040	1.700	0.660	2.200	1.041	0.000
8.000	1.968	1.451	1.124	2.367	2.010	1.243	2.200	1.041	0.000
9.000	1.707	1.966	1.250	0.753	1.594	1.213	2.200	1.041	0.000
10.000	1.041	1.167	1.503	0.860	1.123	0.643	2.200	1.041	0.000
11.000	0.705	1.915	1.941	1.931	1.169	1.236	2.200	1.041	0.000
12.000	0.513	0.830	2.529	1.725	1.386	2.016	2.200	1.041	0.000
13.000	1.698	1.296	1.025	1.307	1.539	0.673	2.200	1.041	0.000
14.000	1.336	1.107	0.988	1.139	0.880	0.456	2.200	1.041	0.000
15.000	1.137	1.770	0.997	1.067	0.822	0.948	2.200	1.041	0.000
16.000	0.493	1.343	1.589	2.028	1.192	1.535	2.200	1.041	0.000
17.000	1.739	1.455	1.883	1.319	2.127	0.808	2.200	1.041	0.000
18.000	1.781	1.409	2.229	2.618		1.209	2.200	1.041	0.000

X-bar chart limits	
UCL	1.967
LCL	0.766
CI	1.366

X-bar chart warning limits	
UCL	1.767
LCL	0.966
CI	1.366

Groups	B1	B2	B3	B4	B5	Mean (X)	UCL	CI	LCL	Population mean	UWCL	LWCL
1.000	1.463	1.256	1.085	0.701	0.643	1.030	1.967	1.366	0.766	1.500	1.767	0.966
2.000	0.666	0.792	2.202	1.112	0.860	1.126	1.967	1.366	0.766	1.500	1.767	0.966
3.000	0.841	0.554	0.762	0.991	1.797	0.989	1.967	1.366	0.766	1.500	1.767	0.966
4.000	1.991	2.083	1.760	1.507	1.413	1.751	1.967	1.366	0.766	1.500	1.767	0.966
5.000	1.353	1.899	2.537	1.446	1.193	1.686	1.967	1.366	0.766	1.500	1.767	0.966
6.000	0.880	0.778	0.560	0.545	1.023	0.757	1.967	1.366	0.766	1.500	1.767	0.966
7.000	1.159	1.307	1.211	1.040	1.700	1.283	1.967	1.366	0.766	1.500	1.767	0.966
8.000	1.968	1.451	1.124	2.367	2.010	1.784	1.967	1.366	0.766	1.500	1.767	0.966
9.000	1.707	1.966	1.250	0.753	1.594	1.454	1.967	1.366	0.766	1.500	1.767	0.966
10.000	1.041	1.167	1.503	0.860	1.123	1.139	1.967	1.366	0.766	1.500	1.767	0.966
11.000	0.705	1.915	1.941	1.931	1.169	1.532	1.967	1.366	0.766	1.500	1.767	0.966
12.000	0.513	0.830	2.529	1.725	1.386	1.397	1.967	1.366	0.766	1.500	1.767	0.966
13.000	1.698	1.296	1.025	1.307	1.539	1.373	1.967	1.366	0.766	1.500	1.767	0.966
14.000	1.336	1.107	0.988	1.139	0.880	1.090	1.967	1.366	0.766	1.500	1.767	0.966
15.000	1.137	1.770	0.997	1.067	0.822	1.159	1.967	1.366	0.766	1.500	1.767	0.966
16.000	0.493	1.343	1.589	2.028	1.192	1.329	1.967	1.366	0.766	1.500	1.767	0.966
17.000	1.739	1.455	1.883	1.319	2.127	1.705	1.967	1.366	0.766	1.500	1.767	0.966
18.000	1.781	1.409	2.229	2.618		2.009	1.967	1.366	0.766	1.500	1.767	0.966

For Unskilled Manpower Usage

Groups	B1	B2	B3	B4	B5	Range	UCL	CI	LCL
1.000	1.463	1.256	0.723	0.351	0.322	1.141	2.494	1.180	0.000
2.000	0.666	0.792	2.202	1.112	0.860	1.536	2.494	1.180	0.000
3.000	0.841	1.108	1.524	1.983	2.396	1.555	2.494	1.180	0.000
4.000	2.654	2.083	1.760	1.507	0.942	1.712	2.494	1.180	0.000
5.000	1.353	2.532	2.537	0.964	1.193	1.573	2.494	1.180	0.000
6.000	0.880	1.038	0.747	0.273	0.512	0.765	2.494	1.180	0.000
7.000	0.869	0.980	0.908	0.780	1.275	0.495	2.494	1.180	0.000
8.000	2.624	1.451	1.686	2.367	2.010	1.173	2.494	1.180	0.000
9.000	0.854	1.966	0.625	0.753	1.594	1.341	2.494	1.180	0.000
10.000	1.041	1.750	1.503	0.860	0.842	0.908	2.494	1.180	0.000
11.000	0.705	1.915	1.941	1.287	1.169	1.236	2.494	1.180	0.000
12.000	0.513	0.830	2.529	1.725	1.386	2.016	2.494	1.180	0.000
13.000	1.698	1.296	1.025	1.307	1.154	0.673	2.494	1.180	0.000
14.000	1.002	0.830	0.593	0.456	0.587	0.546	2.494	1.180	0.000
15.000	1.516	2.361	0.997	0.800	1.644	1.561	2.494	1.180	0.000
16.000	0.985	0.672	1.589	2.028	1.589	1.356	2.494	1.180	0.000
17.000	1.739	1.940	1.883	1.319	2.127	0.808	2.494	1.180	0.000
18.000	1.781	0.939	1.114	1.309		0.842	2.494	1.180	0.000

R Chart limits	
UCL	2.494
LCL	0.000
CI	1.180

X-bar chart limits		X-bar chart warning limits	
UCL	2.002	UCL	1.775
LCL	0.640	LCL	0.867
CI	1.321	CI	1.321

Groups	B1	B2	B3	B4	B5	Mean (X)	UCL	CI	LCL	Population mean	UWCL	LWCL
1.000	1.463	1.256	0.723	0.351	0.322	0.823	2.002	1.321	0.640	2.200	1.775	0.867
2.000	0.666	0.792	2.202	1.112	0.860	1.126	2.002	1.321	0.640	2.200	1.775	0.867
3.000	0.841	1.108	1.524	1.983	2.396	1.570	2.002	1.321	0.640	2.200	1.775	0.867
4.000	2.654	2.083	1.760	1.507	0.942	1.789	2.002	1.321	0.640	2.200	1.775	0.867
5.000	1.353	2.532	2.537	0.964	1.193	1.716	2.002	1.321	0.640	2.200	1.775	0.867
6.000	0.880	1.038	0.747	0.273	0.512	0.690	2.002	1.321	0.640	2.200	1.775	0.867
7.000	0.869	0.980	0.908	0.780	1.275	0.962	2.002	1.321	0.640	2.200	1.775	0.867
8.000	2.624	1.451	1.686	2.367	2.010	2.028	2.002	1.321	0.640	2.200	1.775	0.867
9.000	0.854	1.966	0.625	0.753	1.594	1.158	2.002	1.321	0.640	2.200	1.775	0.867
10.000	1.041	1.750	1.503	0.860	0.842	1.199	2.002	1.321	0.640	2.200	1.775	0.867
11.000	0.705	1.915	1.941	1.287	1.169	1.403	2.002	1.321	0.640	2.200	1.775	0.867
12.000	0.513	0.830	2.529	1.725	1.386	1.397	2.002	1.321	0.640	2.200	1.775	0.867
13.000	1.698	1.296	1.025	1.307	1.154	1.296	2.002	1.321	0.640	2.200	1.775	0.867
14.000	1.002	0.830	0.593	0.456	0.587	0.694	2.002	1.321	0.640	2.200	1.775	0.867
15.000	1.516	2.361	0.997	0.800	1.644	1.464	2.002	1.321	0.640	2.200	1.775	0.867
16.000	0.985	0.672	1.589	2.028	1.589	1.373	2.002	1.321	0.640	2.200	1.775	0.867
17.000	1.739	1.940	1.883	1.319	2.127	1.802	2.002	1.321	0.640	2.200	1.775	0.867
18.000	1.781	0.939	1.114	1.309		1.286	2.002	1.321	0.640	2.200	1.775	0.867

APPENDIX 4: DELPHI FORM ROUND 1 AND 2

Delphi form Round 1

Respected Sir/ Madam,

I am Vivek Shrestha, an MSc in Construction Management student, and this form is part of my Master's thesis titled **“Evaluating the applicability of DUDBC Norms for estimation of Brick Masonry Works: A Case Study of construction practices in Kathmandu Valley”**

This form represents the expert consultation stage as a part of “AHP method”, conducted to

- a. Identify and validate the factors responsible for deviations in masonry resource consumption from standard DUDBC norms.
- b. Identify potential interventions for enhancing accuracy and practical applicability DUDBC norms.

The factors included in this form have been identified through:

- Literature review
- Field data analysis
- Preliminary observations from construction sites

The literature sources reviewed are listed in the references below. Based on a synthesis of these studies, the identified financial risk factors have been systematically categorized by the researcher into six major groups:

1. Material related factors
2. Execution related factors
3. Worker related factors
4. Site related factors
5. Management-related factors
6. Norms-related factors (DUDBC-related)

You are kindly requested to

SECTION A

- **Tick the factors that you consider relevant.**
- **Cross out the factors you consider not irrelevant.**
- **Add any additional factors that are missing in this form.**

SECTION B

- **Suggest practical interventions improve applicability of DUDBC norms for 9” brick masonry work.**

SECTION A: Identification and Validation of factors causing deviation in resource utilization (brick, cement, sand and manpower) in 9” brick masonry work compared to DUDBC prescribed norms

Category	Factors	Source	Relevancy (✓ ×)
Material related Factors	Brick size variation	Site Observation	
	Variable sand grading (variable water for same workability)	[1],Site Observation	
	Bulking of sand	[2]	
Additional Factors	1.		
	2.		
	3.		
Execution related Factors	Mixing Method	Site Observation	
	Mortar Thickness	Site Observation	
	Wastage during handling (Cement, Sand, Mortar loss)	Site Observation	
Additional Factors	1.		
	2.		
	3.		
Worker related Factors	Mason Skill	[3][4]	
	Crew Composition	[3]	
	Experience	[3][5]	
Additional Factors	1.		
	2.		
	3.		
Site related Factors	Wall type variation (Partition walls, Exterior walls, Toe walls etc.)	[6]	
	Working height (Scaffolding vs floor)	[6]	
	Environmental conditions (weather)	[3][6]	
Additional Factors	1.		

	2.		
	3.		
Management related Factors	Quality control	[3]	
	Supervision	[3][4]	
	Improper Scheduling	[3][4]	
	Lack of training for manpower	[7][3]	
Additional Factors	1.		
	2.		
	3.		
Norms related Factors	Improved mason efficiency	[8], [9]	
	Reduced helper requirements	[8], [9]	
	Generalized assumptions (brick size, joint thickness)	[8], [9]	
Additional Factors	1.		
	2.		
	3.		

SECTION B: What can be done to improve applicability of DUDBC norms for 9” brick masonry work on actual site conditions?

References of factors listed for expert validation

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Thank you for your valuable time and contribution.

Your responses will be used solely for academic research and will remain confidential.

Name of the Expert:

Designation:

Date:

Signature:

Delphi form Round 2

Respected Sir/ Madam,

I am Vivek Shrestha, an MSc in Construction Management student, and this form is part of my Master's thesis titled **“Evaluating the applicability of DUDBC Norms for estimation of Brick Masonry Works: A Case Study of construction practices in Kathmandu Valley”**

This form represents the second round of expert consultation as a part of “Delphi”, conducted to

- c. Identify and validate the factors responsible for deviations in masonry resource consumption from standard DUDBC norms.
- d. Identify potential interventions for enhancing accuracy and practical applicability DUDBC norms.

You are kindly requested to

SECTION A

For each identified factor assign an influence score (1-5) based on your professional judgement.

- 1: Very low influence
- 2: Low influence
- 3: Moderate influence
- 4: High influence
- 5: Very high influence

SECTION B

For each identified potential intervention measures assign an effectiveness score (1-5) based on your professional judgement.

- 1: Very low effectiveness
- 2: Low effectiveness
- 3: Moderate effectiveness
- 4: High effective effectiveness
- 5: Very high effective effectiveness

Note: Some repetitive and similar natured factors have been grouped and integrated to respective categories for simplification and clarity.

- Factor “Storage area vs working area” has been integrated to “**Haulage distance of material from work place within site**” and placed in Site related Factors
- Wastage related factors have been integrated to a single factor “**Wastage during loading, unloading and handling (Brick, Cement, Sand, Mortar loss)**”
- Manpower availability and human resource vs work volume has been integrated to a single factor “**Crew composition**” as composition is depended on availability.
- Mood, Health and motivation have been integrated into “**Social and psychophysiological factors.**”
- Improper Scheduling and improper manpower deployment has been integrated to a single factor “**Improper Scheduling (Work plan and manpower)**”
- Wages and contract type related factors have been integrated to a single factor “**Mode of contract (measurement basis vs daily wages)** and placed in Management related factors.
- Work method (manual/ machine mixed) has been integrated to “**Mixing method (manual/ machine)**” and placed in Execution related factors.
- Co-ordination with other groups and other parallel activities have been integrated into a single factor “**Co-ordination with other site activities**” and placed in site related factors.
- Le Chatelier test for cement has been integrated to “**Quality Control**” and placed in management related factors.
- **Design factor (Simple or curve, large frequent opening, straight or slanting design elements)** has been placed in site related factors.
- Supervision has been integrated in “**site management plan**”
- Tool box training has been integrated into “**Lack of training**”
- Use of machinery, use of equipment, tools and equipment have been integrated into “**use of machinery**” and placed in Execution related factors.
- Improved mason efficiency, reduced helper requirements, generalized assumptions, monitoring enhancement, use of machinery for carrying materials (from norms related factors) have been consolidated into a single factor “**Difference between DUDBC norm assumptions and actual site practices and conditions.**”

SECTION A: Likert Scale Rating for identification of factors causing deviation in resource utilization (brick, cement, sand and manpower) in 9” brick masonry work compared to DUDBC prescribed norms

Please rate the influence of the following factors using a scale of 1 to 5, where 1 indicates very low effect and 5 indicates very high effect.

Category	Factors	Rating (1-5)
Material related Factors	1. Brick size variation	
	2. Variable sand grading (variable water requirement for same workability)	
	3. Bulking of sand	
	4. Variation in material quality due to source differences (sand origin, brick kiln)	
Execution related Factors	1. Mixing Method (machine/manual)	
	2. Variation in mortar Thickness	
	3. Wastage during loading, unloading and handling (Brick, Cement, Sand, Mortar loss)	
	4. Use of dry bricks without soaking	
	5. Use of machinery (transporting materials, mixing)	
Worker related Factors	1. Mason Skill	
	2. Crew Composition	
	3. Experience	
	4. Social harmony and physio-psychological condition of workers	
Site related Factors	1. Wall type variation (Partition, exterior, toe walls etc.)	
	2. Working height (Scaffolding vs floor)	
	3. Environmental conditions (weather)	
	4. Haulage distance of material from work place within site	
	5. Co-ordination with other site activities	
	6. Design Complexity (e.g. curved walls, large frequent openings, slanted walls, and other architectural features)	
Management related Factors	1. Quality control	
	2. Site management plan	
	3. Improper Scheduling (Work plan and manpower allocation)	
	4. Lack of training (Work procedure training, toolbox talks)	
	5. Mode of contract (measurement basis vs daily wages)	
	6. Motivation and expectation management	
Norms related Factors	1. Deviation between DUDBC norm assumptions and actual site practices and conditions.	
	2. Regional productivity variation	

SECTION B: Likert Scale Rating for potential interventions for enhancing applicability of DUDBC norms.

Please rate the effectiveness of the following factors using a scale of 1 to 5, where 1 indicates very low effect and 5 indicates very high effect.

Categories	Potential Interventions	Rating (1-5)
Quality Control Measures	1 Maintain required water volume for mortar preparation and ensure adequate soaking of bricks	
	2 Control mortar joint thickness within acceptable limits as per norms (10–12 mm)	
	3 Use trained manpower for batching and brick laying	
	4 Enforce strict quality control practices	
	5 Ensure materials procured on site meet standard grade before use on site	
	6 Use of appropriate tools and equipment for accuracy (mortar mixer, laser level for accuracy)	
Norms Update and Standardization	7 Periodic review and update of wastage factors in norms	
	8 Periodic review and update of manpower efficiency norms based on field data	
	9 Incorporate machinery usage (e.g., vertical transport equipment) into norms	
	10 Modify norms to account for complex designs and difficult site conditions	
	11 Define separate manpower requirements for substructure and superstructure works	
	12 Consider variability in worker productivity across regions	
	13 Conduct further region-specific studies across Nepal to refine norms	
Manufacturing and Procurement Control	14 Standardize nominal brick size in norms and regulate manufacturing practices through regulatory authorities (e.g., Nepal Bureau of Standards and Metrology)	
	15 Enforce quality control standards via regulatory bodies (DUDBC, DoR)	

Thank you for your valuable time and contribution.

Your responses will be used solely for academic research and will remain confidential.

Name of the Expert:

Designation:

Date:

Signature:

APPENDIX 5: DELPHI, RESPONSE FROM EXPERTS

Delphi Round 1 Response

Response factor validation and additional factors addition						
Category	Factors	Relevance (ü X)				
		E1	E2	E3	E4	E5
Material Related Factors	Brick Size Variation	✓	✓	✓	✓	✓
	Variable sand grading (variable water for same workability)	✓	✓	✓	✓	✓
	Bulking of sand	✓	✓	✓	✓	✓
	E1 Variation in material quality based on sand mne and kilns					
	E5 Quality of Bricks					
	Storage area vs working area					
Execution Related Factors	Mixing Method	✓	✓	✓	✓	✓
	Mortar Thickness	✓	✓	✓	✓	✓
	Wastage during handling (Cement, Sand, Mortar loss)	✓	✓	✓	✓	✓
	E1 Wastage of brick during loading, unloading and handling at site					
	E2 Use of dry bricks without soaking					
		Use of wastage/ half brick				
	E3 Use of machinery in transporting materials					
	E5 Unintended cutting and waste					
Worker Related Factors	Mason Skill	✓	✓	✓	✓	✓
	Crew Composition	✓	✓	✓	✓	✓
	Experience	✓	✓	✓	✓	✓
	E1 Social harmony and physico-psychological condition of workers					
	E2 Wage of skilled and unskilled manpower					
	E4 Mood (fresh/tension) and braining storming of workers					
	E5 Work contract type-daily wage vs contract					
		Manpower availability				

Site Related Factors	Wall type variation (Partition walls, Exterior walls, Toe walls etc.)	✓	✓	✓	✓	✓
	Working height (Scaffolding vs floor)	✓	✓	✓	✓	✓
	Environmental Conditionas	✓	✓	✓	✓	✓
E4	Haulage distance of material from work place within site					
E5	Other Parallel Activities					
Management Related Factors	Quality control	✓	✓	✓	✓	✓
	Supervision	✓	✓	✓	✓	✓
	Improper Scheduling	✓	✓	✓	✓	✓
	Lack of training for manpower	✓	✓	✓	✓	✓
E2	Work method (manual/ machine mixed)					
	Design factor (Simple or curve, large frequent opening, straight or slanting design elements)					
E4	1. Motivation and expectation management					
	2. Human resource VS work volume levelling					
	3. Mode of contract (measurement basis vs daily wages)					
E5	Improper Manpower Deployment					
Norms Related Factors	Improved mason efficiency	✓	✓	✓	✓	✓
	Reduced helper requirements	✓	✓	✓	✓	✓
	Generalized assumptions (brick size, joint thickness)	✓	✓	✓	✓	✓
E2	Working condition (provision of scaffolding)					
	Supervision/ monitoring- enhance the proper use of materials reduce wastage and unnecessary delay					
E3	Use of machinery in carrying materials					
	Variation in different regions					

Response for Open Ended Question for possible interventions	
E1	Enhanced level of mechanization as compared to its level when the norms were formulated.
	Required volume of water for preparation of mortar, soaking of bricks and curing.
	Mention of assumed nominal size of chimney brick, so as to adjust required numbers accordingly, as instructed.
	Provision for wastage of chimney bricks, considering its brittleness, since the volume could be significant.
	Requirement of scaffolds and other aiding devices to work at height, on exterior faces and under extreme weather conditions.
	Variable productivity of workers in different geographical/ecological locations of site
E2	Revision/ update of existing norms. (Update the manpower efficiency, reduce necessary manpower used for per unit product)-focus on the use tools and equipments.
	Strict regulation from authorized organization. (Nepal Bureau of standard and department of industry, DUDBC, DoR) for the quality check of construction material like brick, cement etc.
	Provision of modification/ adjustment in standard norms for complex design and difficult working conditions (easy/difficult access) should be made.
	Review on the wastage and update accordingly
E3	Note use of machinery for material transportation to upper floors and update in norms
	Control mortar joint thickness on site to acceptable limits (10-12mm)
	Use trained manpower for batching and brick laying.
	Strict quality control measures.
	Separate manpower requirements for sub structure and super structure.
	Further research needed in all parts of Nepal to compare with norms.
E4	Can be improve to its norms value by maintaining the size of brick prescribed in the norms and thickness of mortar.
E5	To improve applicability of DUDBC norms for 9” brick masonry work, different norms can be prepared based on general different type site conditions.
	Changes can be made based on given case studies and research to match the norms for given items.
	Materials have to be of proper grade as per norms

Delphi Round 2 Response (Likert scale rating)

Likert scale rating for identified factors

		Experts	E1	E2	E3	E4	E5
Factors							
Material Related Factors	1. Brick size variation	5	5	4	5	5	
	2. Variable sand grading (variable water requirement for same workability)	3	3	4	3	4	
	3. Bulking of sand	3	3	4	4	4	
	4. Variation in material quality due to source differences (sand origin, brick kiln)	4	4	3	3	4	
Execution Related Factors	1. Mixing Method (machine/manual)	4	3	4	5	2	
	2. Variation in mortar Thickness	3	5	5	5	5	
	3. Wastage during loading, unloading and handling (Brick, Cement, Sand, Mortar loss)	4	4	4	4	4	
	4. Use of dry bricks without soaking	5	4	4	3	3	
	5. Use of machinery (transporting materials, mixing)	3	5	4	4	4	
Worker Related Factors	1. Mason Skill	5	4	4	4	5	
	2. Crew Composition	4	4	4	5	5	
	3. Experience	4	4	4	5	4	
	4. Social harmony and physio-psychological condition of workers	4	4	4	5	3	
Site Related Factors	1. Wall type variation (Partition, exterior, toe walls etc.)	3	4	4	4	4	
	2. Working height (Scaffolding vs floor)	3	4	4	4	4	
	3. Environmental conditions (weather)	4	4	4	4	3	
	4. Haulage distance of material from work place within site	3	4	3	5	3	
	5. Co-ordination with other site activities	3	3	3	4	4	
	6. Design Complexity (e.g. curved walls, large frequent openings, slanted walls, and other architectural features)	3	4	3	4	5	
Management Related Factors	1. Quality control	5	4	4	3	4	
	2. Site management plan	3	4	4	5	4	
	3. Improper Scheduling (Work plan and manpower allocation)	3	4	4	4	4	
	4. Lack of training (Work procedure training, toolbox talks)	4	5	4	4	3	
	5. Mode of contract (measurement basis vs daily wages)	3	5	5	5	4	
	6. Motivation and expectation management	4	4	4	4	2	

Norms Related Factors	1. Deviation between DUDBC norm assumptions and actual site practices and conditions.	4	4	4	4	4
	2. Regional productivity variation	4	2	4	3	4

Likert scale rating for potential interventions

		Experts	E1	E2	E3	E4	E5
Potential Interventions							
Quality Control Measures	1. Maintain required water volume for mortar preparation and ensure adequate soaking of bricks	5	4	4	3	4	
	2. Control mortar joint thickness within acceptable limits as per norms (10–12 mm)	4	4	5	5	4	
	3. Use trained manpower for batching and brick laying	4	4	4	5	4	
	4. Enforce strict quality control practices	5	4	4	4	3	
	5. Ensure materials procured on site meet standard grade before use on site	5	4	4	4	4	
	6. Use of appropriate tools and equipment for accuracy (mortar mixer, laser level for accuracy)	4	4	4	4	4	
Norms Update and Standardization	7. Periodic review and update of wastage factors in norms	3	4	4	5	4	
	8. Periodic review and update of manpower efficiency norms based on field data	4	4	4	5	4	
	9. Incorporate machinery usage (e.g., vertical transport equipment) into norms	4	4	5	4	4	
	10. Modify norms to account for complex designs and difficult site conditions	4	4	4	5	3	
	11. Define separate manpower requirements for substructure and superstructure works	3	3	3	4	5	
	12. Consider variability in worker productivity across regions	4	5	4	3	4	
	13. Conduct further region-specific studies across Nepal to refine norms	4	3	4	3	4	
Manufacturing and Procurement Control	14. Standardize nominal brick size in norms and regulate manufacturing practices through regulatory authorities (e.g., Nepal Bureau of Standards and Metrology)	4	5	3	4	4	
	15. Enforce quality control standards via regulatory bodies (DUDBC, DoR)	4	5	3	3	2	

APPENDIX 6: EXPERTS SELECTED FOR DELPHI AND SITE IN CHARGE FROM OBSERVED CONSTRUCTION SITES

Experts Selected for Delphi Rounds

SN	Experts	Experience	Designation
1	Er. Om Dharananda Rajopadhyaya	30+ years	Freelancer (Ex-Joint Secretary of GoN)
2	Er. Prakirna Tuladhar	20+ years	Deputy Department Commissioner (KVDA)
3	Er. Himlal KC	20+ years	Senior Division Engineer (DUDBC)
4	Er. Krishna Gopal Shrestha	15+ years	Senior Project Manager (Religare Construction Pvt. Ltd.)
5	Er. Rajat Manandhar	10+ years	Project Manager (CE Construction Pvt. Ltd.)

Site in charge from observed construction sites

SN	Site ID	Site In charge	Remarks
1	S1	Er. Roshan Maharjan	
2	S2	Er	Consent not given
3	S3	Er. Pujan Rimal	
4	S4	Er. Ashok Sah	
5	S5	Er	Consent not given
6	S6	Er. Aryan Upadhayay	
7	S7	Er. Rajesh Twayana	
8	S8	Er. Bishnu Shrestha	
9	S9	Er. Suman Suwal	
10	S10	Ar. Rukesh Suwal	
11	S11	Ar. Mahesh Maharjan	
12	S12	Er. Sujana Maharjan	
13	S13	Er. Ashish Shrestha	
14	S14	Er. Hari Shyam Chawal	
15	S15	Er. Lalita Shakya	

APPENDIX 7: PHOTOGRAPHS



Photograph A7. 0.1: Photograph at site S1



Photograph A7. 0.2: Photograph at site S2



Photograph A7. 0.3 : Photograph at site S3



Photograph A7. 0.4: Photograph at site S4



Photograph A7. 0.5: Photograph at site S5



Photograph A7. 0.6: Photograph at site S6



Photograph A7. 0.7 : Photograph at site S7



Photograph A7. 0.8: Photograph at site S8



Photograph A7. 0.9 : Photograph at site S9



Photograph A7. 0.10 : Photograph at site S10



Photograph A7. 0.11 : Photograph at site S11



Photograph A7. 0.12 : Photograph at site S12



Photograph A7. 0.13 : Photograph at site S13



Photograph A7. 0.14 : Photograph at site S14



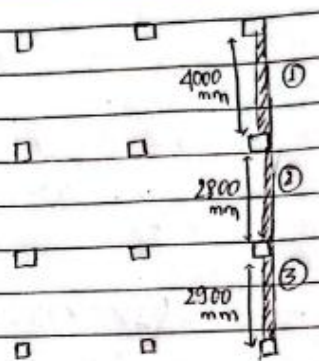
Photograph A7. 0.15 : Photograph at site S15

(1) Start vol = 0 m^3
 End vol = $(4000 \times 230 \times 1200) = 1.12 \text{ m}^3$
 No. of Bricks
 $\rightarrow \left[\frac{100}{230} \times 2 + 15 \times 2 + \frac{150}{230} \times 2 \right] \times 8$
 $+ [33] \times 8$
 $\rightarrow 521.39$

(2) Start vol = 0 m^3
 End vol = $(2800 \times 230 \times 1220) \Rightarrow 0.785 \text{ m}^3$
 No. of Bricks
 $\rightarrow \left[\frac{150}{230} \times 2 + 6 \times 2 + \frac{130}{230} \times 2 + 4 \times 2 + \frac{160}{230} \times 2 \right] \times 8$
 $+ [22] \times 8$
 $\rightarrow 366.60$

(3) Start vol = 0 m^3
 End vol = $(2900 \times 230 \times 1220) = 0.813 \text{ m}^3$
 No. of Bricks
 $\rightarrow \left[\frac{160}{230} \times 2 + 10 \times 2 + \frac{170}{230} \times 2 \right] \times 8 + [23] \times 8 \Rightarrow 365.56$

Total work vol = 2.718 m^3 No. of cement bags = 6.
 Total no. of Bricks = 1253.55.
 Scaffolding = No.
 Mortar = 1:6 Start time: 7 AM
 Skilled Manpower = 3 End time: 3 P.M.
 Unskilled Manpower = 4



Photograph A7. 0.16 : Site raw data collection

APPENDIX 8: ACCEPTANCE E-MAIL FOR 18th IOE GRADUATE CONFERENCE

4/30/26, 7:04 AM

Pulchowk Campus, Institute of Engineering, Tribhuvan University Mail - [IOEGC18] Editor Decision



VIVEK SHRESTHA <080mscom024.vivek@pcampus.edu.np>

[IOEGC18] Editor Decision

1 message

Dr. Pradeep Shrestha <ioegc17@gmail.com>

Mon, Apr 27, 2026 at 9:49 PM

To: Vivek Shrestha <080mscom024.vivek@pcampus.edu.np>, Mahendra Raj Dhital <mrhdhital@ioe.edu.np>

Vivek Shrestha, Mahendra Raj Dhital:

We have reached a decision regarding your submission to 18th IOE Graduate Conference, "Evaluating the Applicability of DUDBC Norms for Quantity Estimation: A Case Study of 9 inch Thick Masonry Works in Kathmandu Valley".

Our decision is to: Accept Submission

With Warm Regards,
IOEGC-18 Editorial Team

APPENDIX 9: ORIGINALITY REPORT



Similarity Report ID: oid:3117:584579018

PAPER NAME

Evaluating the Applicability of DUDBC Norms for Quantity Estimation: A Case Study of 9-inch-thick Brick Masonry Works in Kathmandu Valley

AUTHOR

Vivek Shrestha

WORD COUNT

17571 Words

CHARACTER COUNT

100817 Characters

PAGE COUNT

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